DOD/DOE Shipboard Fuel Cell Workshop

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

PEMFC R&D at the DOE Fuel Cell Technologies Program

March 29, 2011 Arlington, VA

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

Key Challenges

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The Program has been addressing the key challenges facing the widespread commercialization of fuel cells.

Technology Barriers*

Fuel Cell Cost & Durability

Targets*:

***Stationary Systems:* $750 per kW, 40,000-hr durability**

***Vehicles:* $30 per kW, 5,000-hr durability**

Hydrogen Cost

Target*: $2 – 3 /gge, (dispensed and untaxed)

Hydrogen Storage Capacity

Target: > 300-mile range for vehicles—without compromising interior space or performance

Technology Validation:

Technologies must be demonstrated under real-world conditions.

Economic & Institutional Barriers

Safety, Codes & Standards Development

Domestic Manufacturing & Supplier Base

Public Awareness & Acceptance

Hydrogen Supply & Delivery Infrastructure

Market Transformation

Assisting the growth of early markets will help to overcome many barriers, including achieving significant cost reductions through economies of scale.

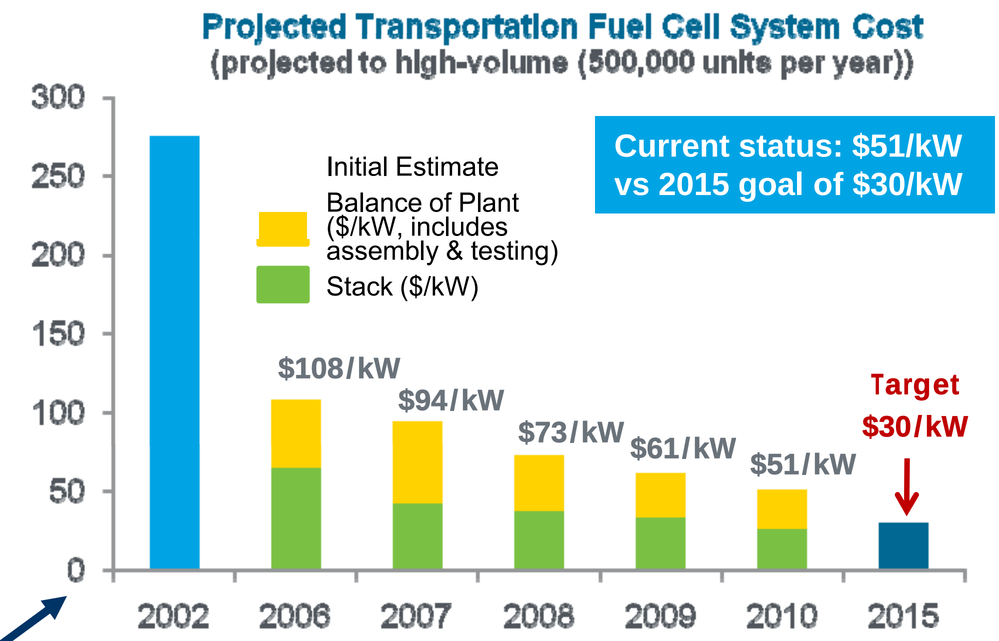
*** Targets and Metrics are being updated in 2010 .**

DOE Fuel Cell R&D — *Progress: Cost*

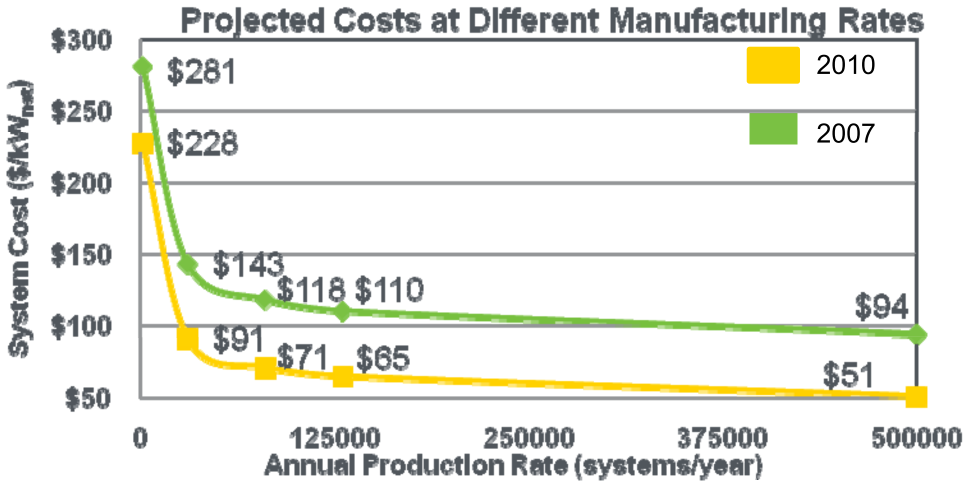
Projected high-volume cost of fuel cells has been reduced to $51/kW (2010)*

- ***More than 30% reduction since 2008***
- ***More than 80% reduction since 2002***
- ***2008 cost projection was validated by independent panel****

As stack costs are reduced, balance-of-plant components are responsible for a larger % of costs.



More than 80% cost 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***

Fuel Cell R&D — *Progress*

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The Program has reduced PGM content, increased power density, and simplified balance of plant, resulting in a decrease in system cost.

From 2008 to 2010, key cost reductions were made by:

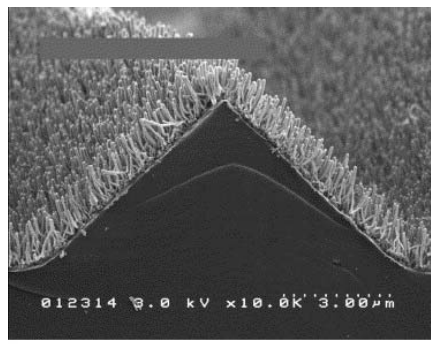
- **Reducing platinum group metal content from 0.35 to 0.18 g/kW**
- **Increasing power density from 715 to 833 mW/cm^2**
- **Simplifying balance of plant**

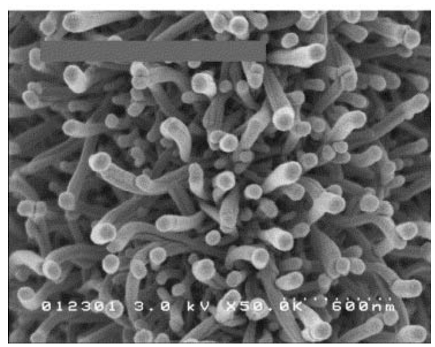
→ These advances contributed to a $22/kW cost reduction.

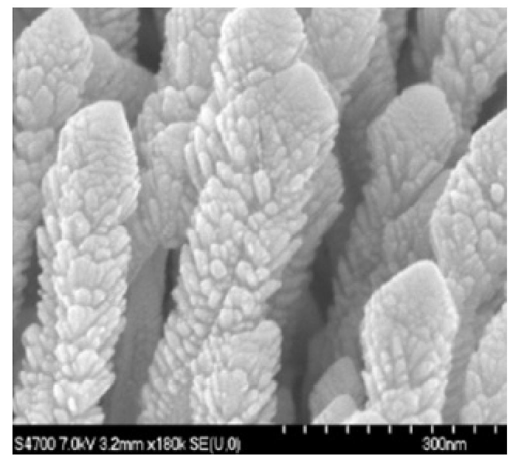
Key improvements enabled by using novel organic crystalline whisker catalyst supports and Pt-alloy whiskerettes.

There are ~ 5 billion $whiskers/cm^2$.

Whiskers are ~ 25 X 50 X 1000 nm.







Whiskerettes:
6 nm x 20 nm

Source: 3M

Catalysts and Supports

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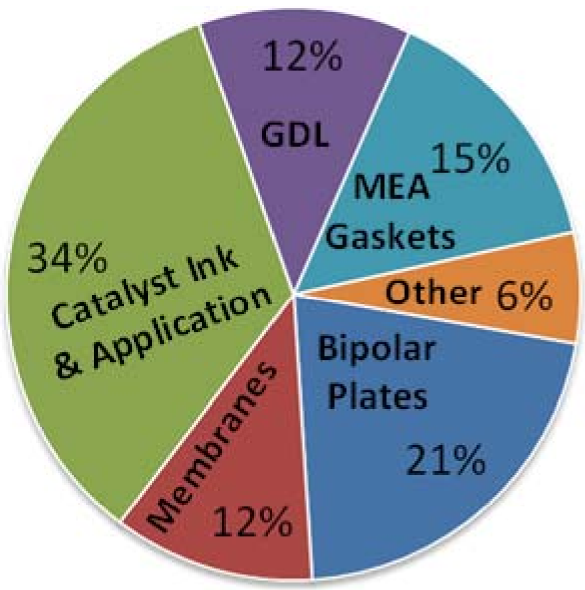
Challenges:

- ***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

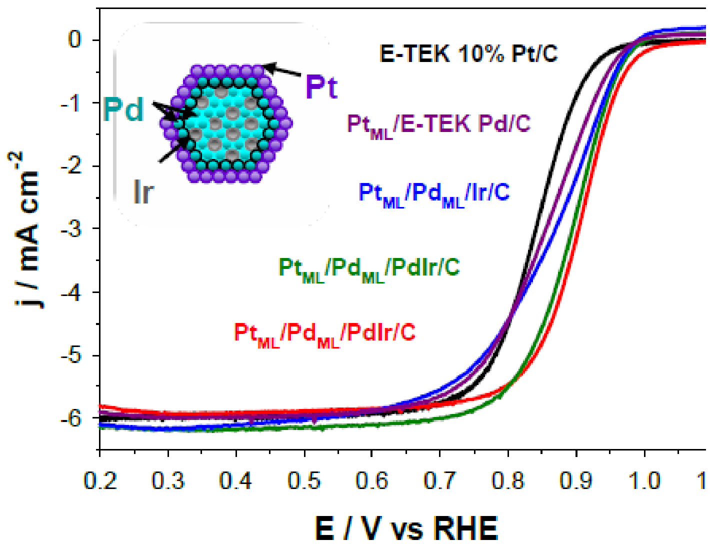
Used $1100/Troy Ounce for Pt Cost

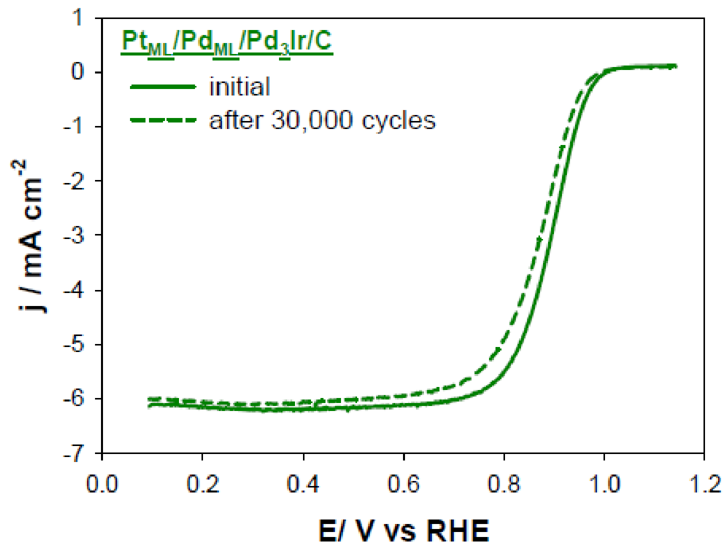
B. James, 2010 DOE Hydrogen Program Review

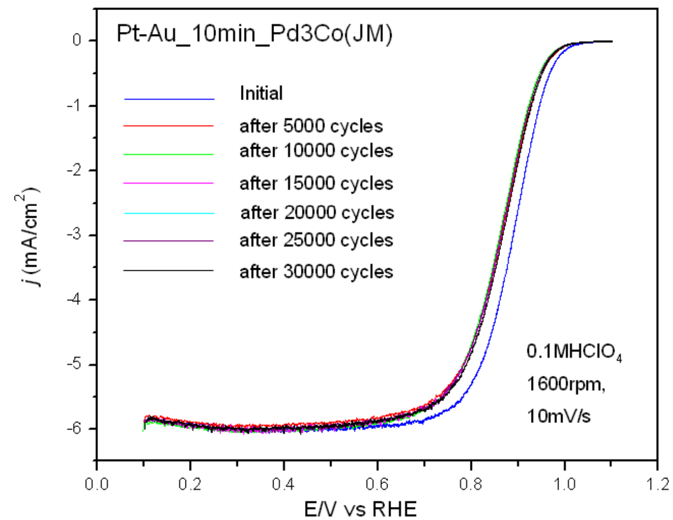
Ultra-low Pt Content Catalysts

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

Brookhaven National Laboratory: Development of core-shell catalyst structures enabled reduction in PGM content







- **Highlight:** **0.35 A/mg$_{PGM}$** **for Pd-interlayer and** **1.10 A/mg$_{PGM}$** **for Au-interlayer catalysts**

- ***0.44 A/mg$_{PGM}$ exceeded in RDE testing!***

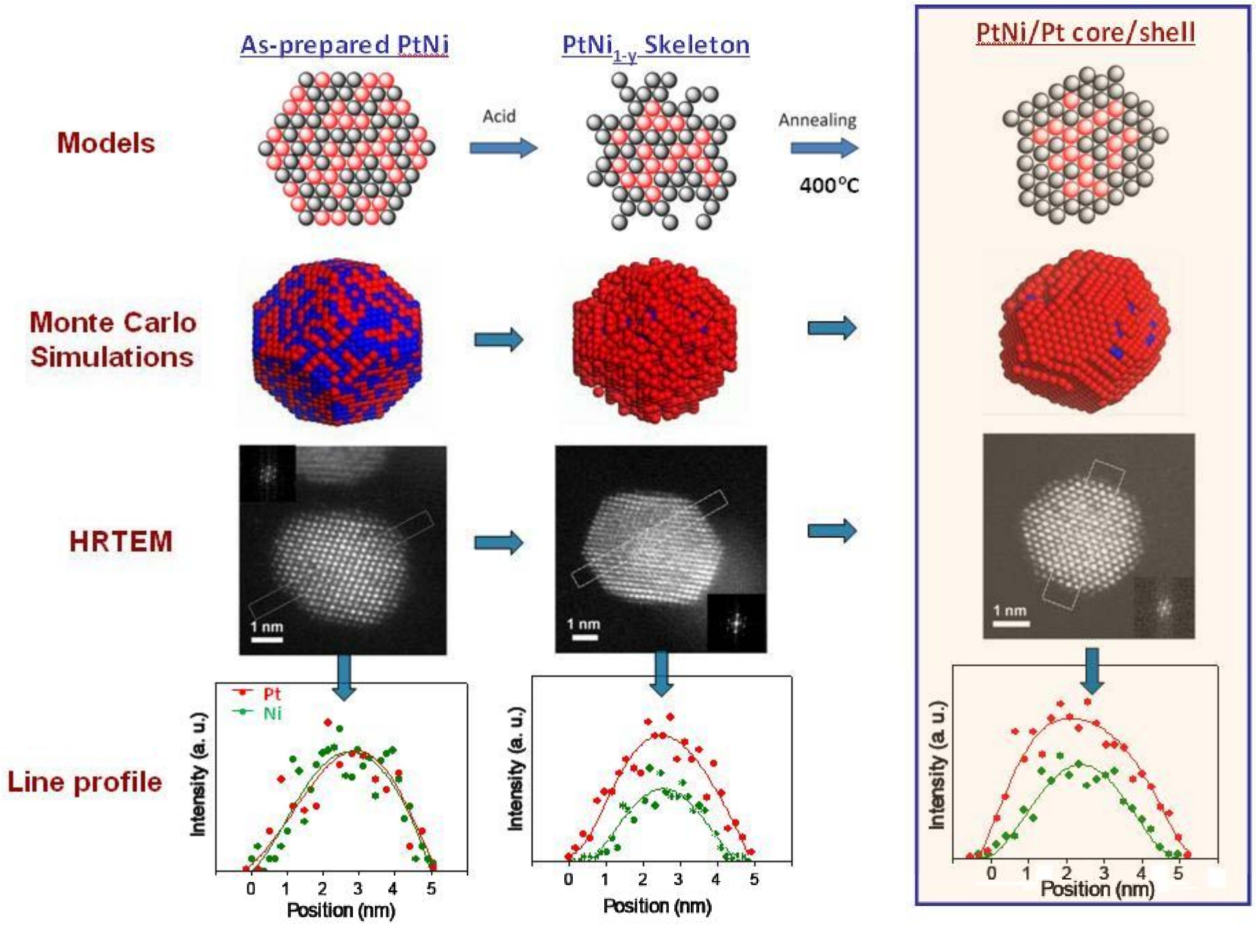
- **Highlight:** **$E_{1/2}$ loss after 30,000 cycles of only 19 mV (Pd-interlayer) and 22 mV (Au-interlayer) vs. 39 mV for Pt/C**

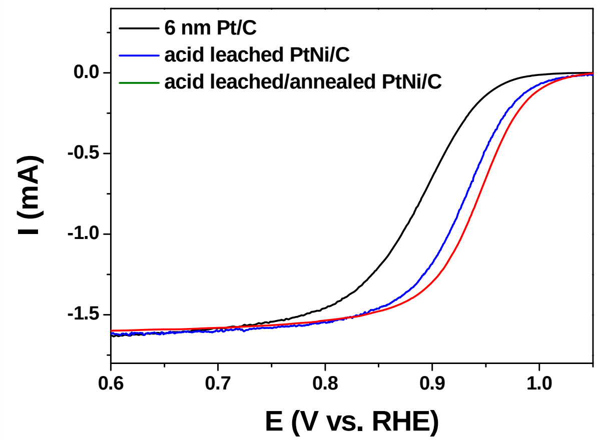
R. Adzic and P. Zelenay, 2009 and 2010 DOE Hydrogen Program Reviews

Nano-segregated Cathode Catalysts

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

Argonne National Laboratory: Nanosegregated multi-metallic nanoparticles and nanostructed thin metal films





PtNi/Pt core/shell catalyst has 7X activity over same size Pt/C

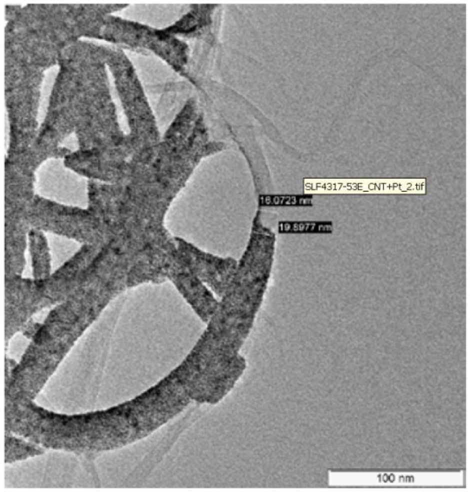
N. Markovic, 2010 DOE Hydrogen Program Review

Extended PGM Catalysts

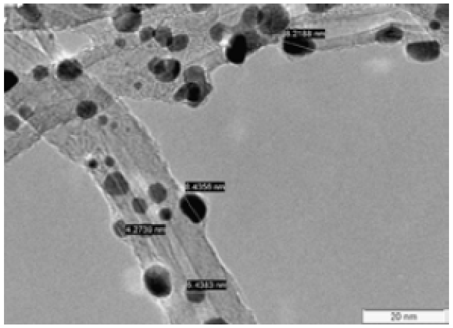
National Renewable Energy Laboratory: Extended, continuous Pt nanostructures in thick, dispersed electrodes

Combining advantages of continuous extended catalysts and dispersed nanoparticle catalysts

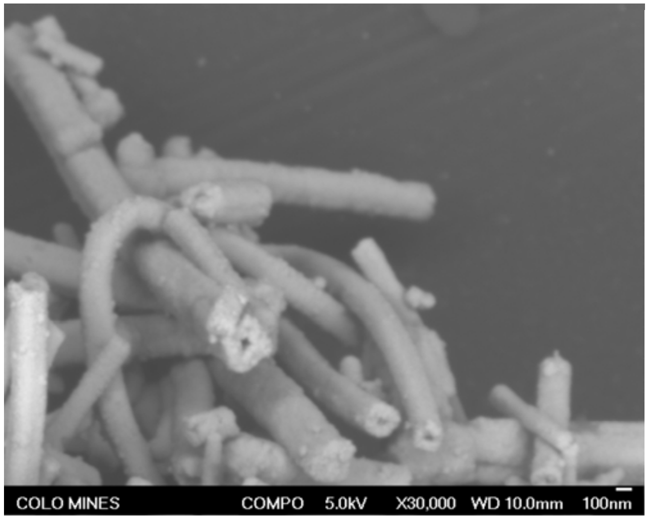
- Extended Pt surfaces have **high specific activity and good durability**
- Thick, dispersed electrodes are **tolerant to wide range of operating conditions**



Continuously Pt-coated CNTs



Typical Pt/CNTs



Pt-Cu nanotubes

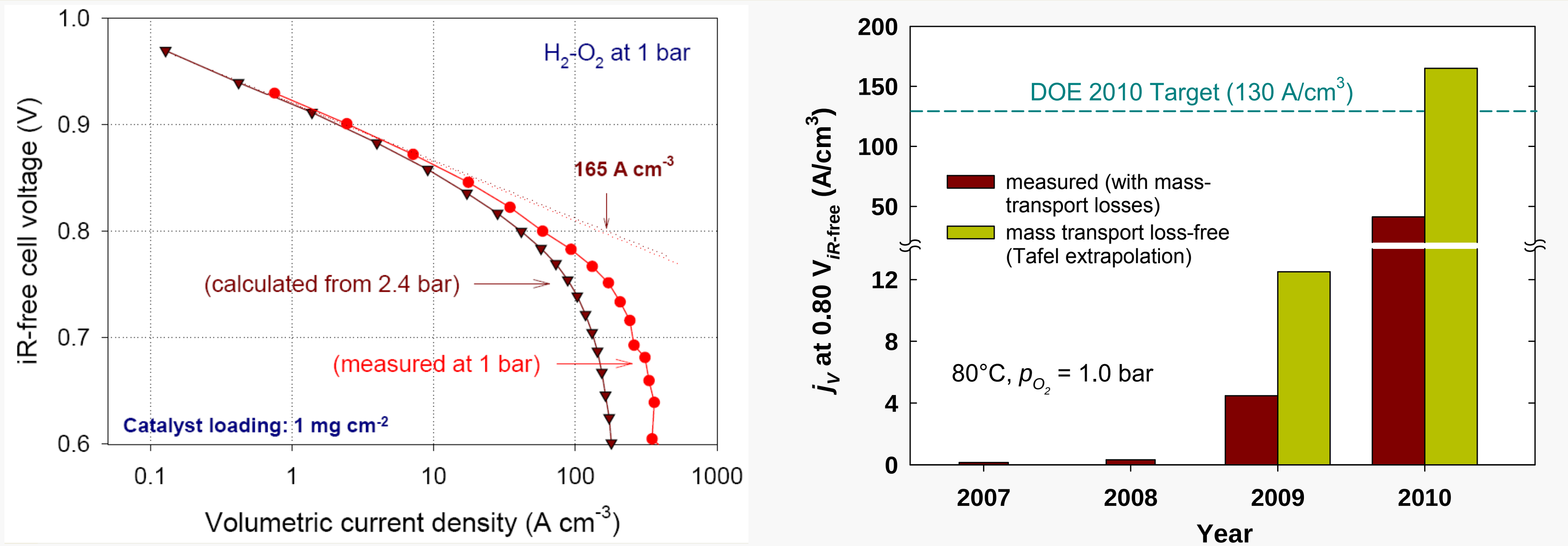
- First demonstration of extended Pt structures based on carbon nanotubes
- First demonstration of free-standing Pt-Cu nanotubes - *specific activity promising*

B. Pivovar, 2010 DOE Hydrogen Program Review

PGM-Free Catalysts

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

Los Alamos National Laboratory: Non-PGM catalyst activity increased



- **High ORR activity reached with several non-PGM catalysts by LANL, including cyanamide-Fe-C catalyst (shown).**
- **Intrinsic catalyst activity is projected to exceed 130 A/cm^3 at 0.80 V.**

P. Zelenay, 2010 DOE Hydrogen Program Review

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:

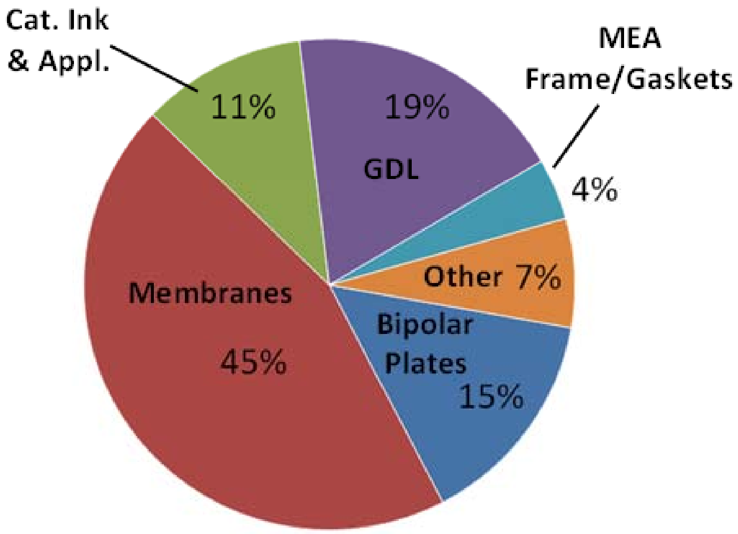
High-Temperature, Low Humidity Conductivity

- **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 (low volume) - $144/kW



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

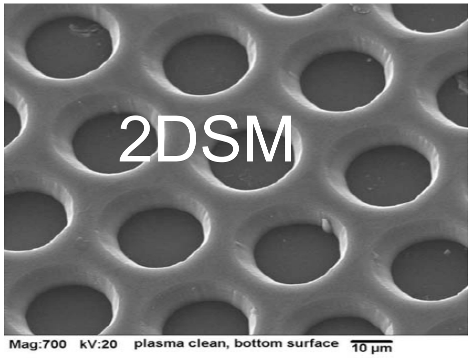
B. James, 2010 DOE Hydrogen Program Review

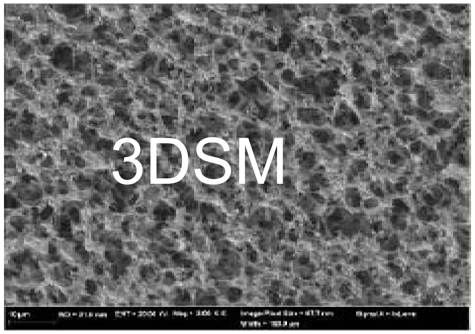
Dimensionally Stabilized Membranes

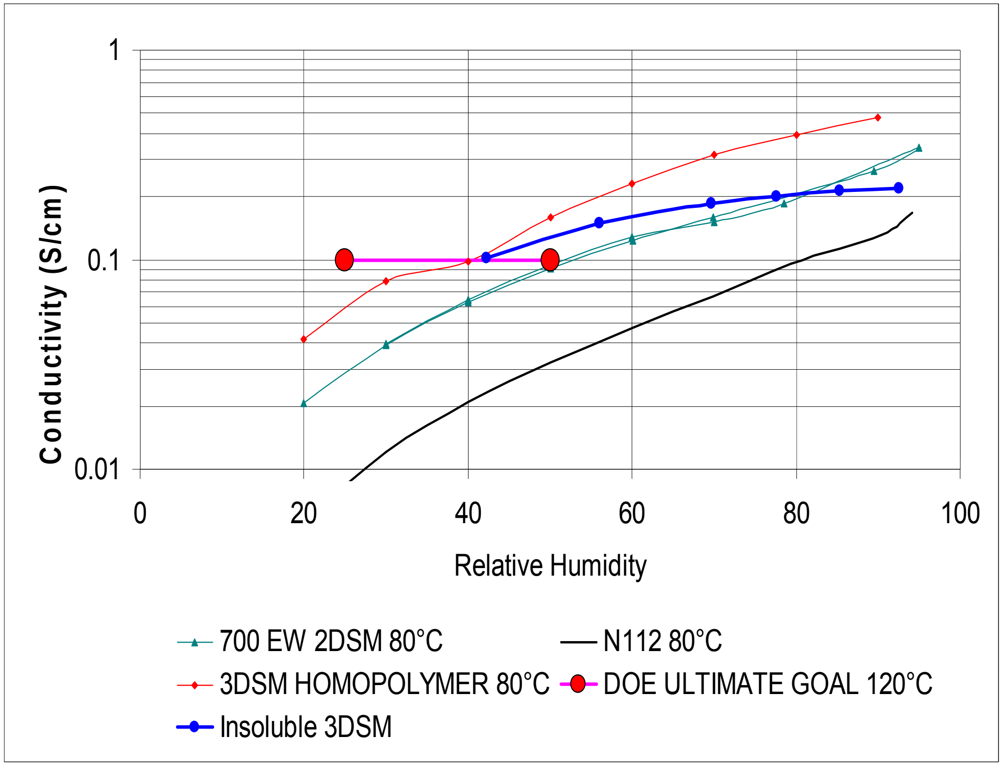
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Giner Electrochemical Systems: Low EW PFSA materials supported with high-strength non-acidic materials

- Engineering polymer matrix provides mechanical stability
- Low-EW ionomer allows for better conductivity under low RH
- Next Steps: Impregnation of thinner porous mats with low-EW ionomer planned along with the fabrication of large-area films







C. Mittelsteadt, 2010 DOE Hydrogen Program Review

Nanocapillary Network Membranes

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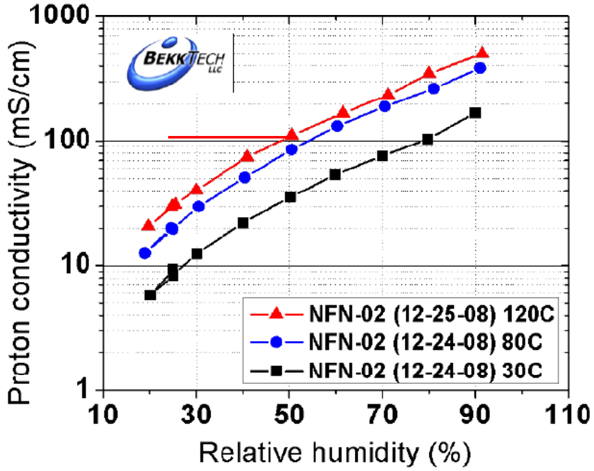
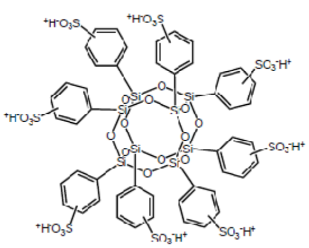
Vanderbilt University: Electrospun ionomer and support polymer

Generation 1: PFSA/SPOSS nanofiber mat that is impregnated with inert polymer

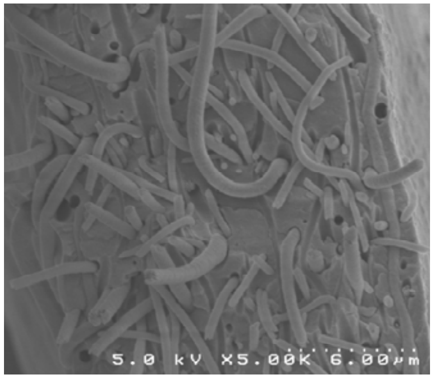


Membrane: 60 wt% 3M PFSA (825EW) + 35 wt% SPOSS + 5 wt% poly(acrylic acid) with NAO63 (inert matrix)



SPOSS = sulfonated polyhedral gomeric silsesquioxanes

Generation 2: Co-spin PFSA and polysulfone nanofibers then process into membrane



Nafion® matrix (~70 vol%), polyphenylsulfone nanofibers

- Simultaneous electro-spinning of PFSA and polyphenylsulfone (inert matrix) – eliminates need for impregnation step; also can create PFSA nanofibers with polysulfone matrix from the same dual fiber mat
- Next step: Establish water retention at low RH, improve performance

P. Pintauro, 2009, 2010 DOE Hydrogen Program Review

Multi-acid Side Chain Polymers

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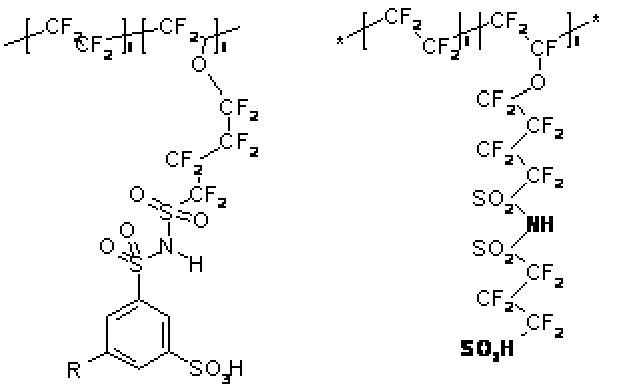
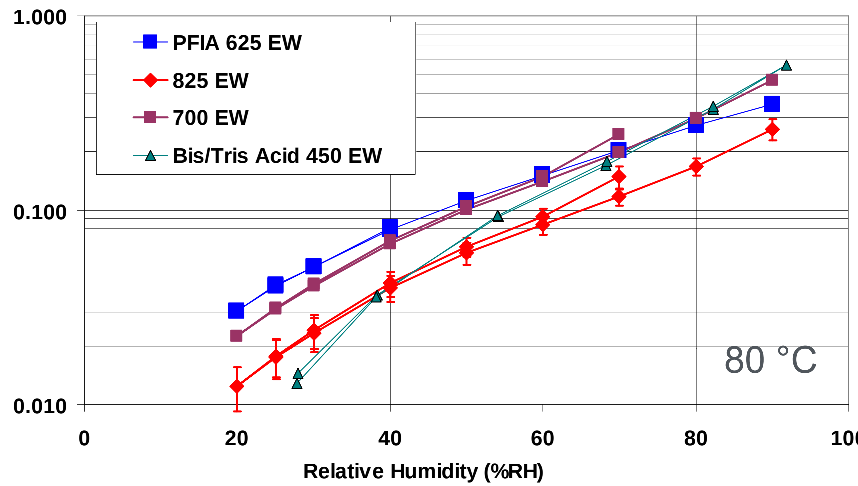
3M: Per Fluoro Imide Acid (PFIA) and Sulfonic Acid

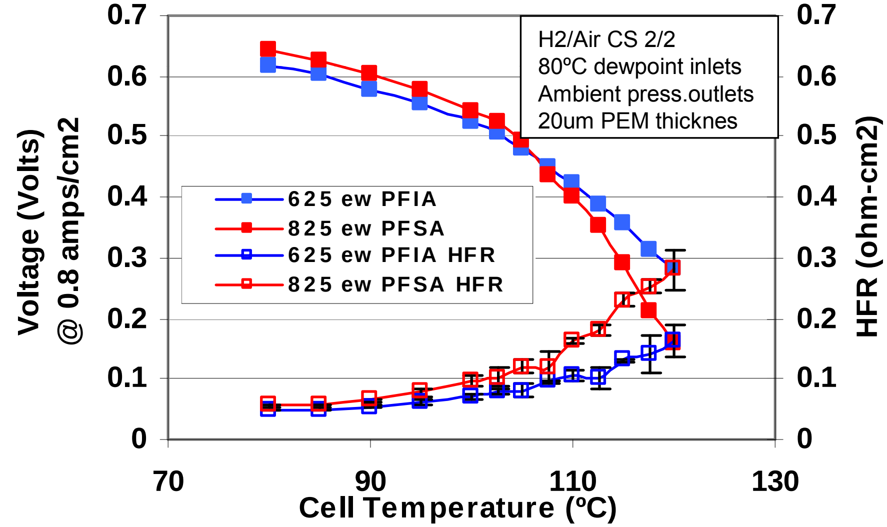
- Multi Acid Side-chains (MASC) allow Lower EW while maintaining higher crystallinity
- Starting with an 835 EW polymer, prepared a MASC PFIA ionomer with 625 EW
- Membrane has >100 mS/cm conductivity at 120ºC, 50% RH – similar to about 700 EW PFSA
- Durability of PFIA to be evaluated



Bis/Tris Acid
R = 1:1 SO3H/X

PFIA

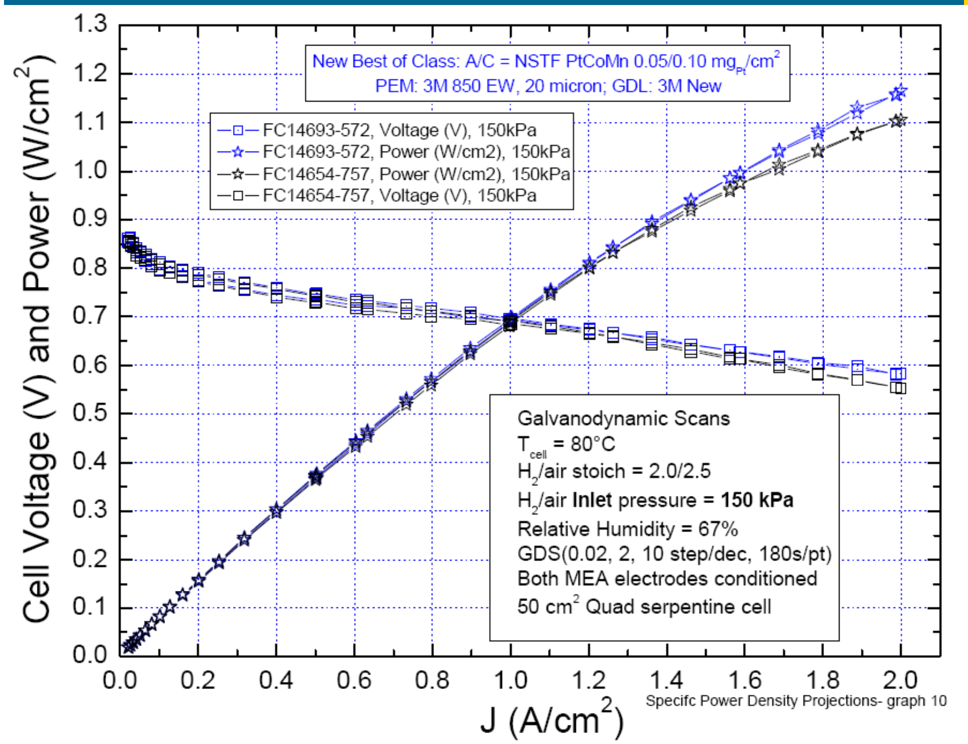




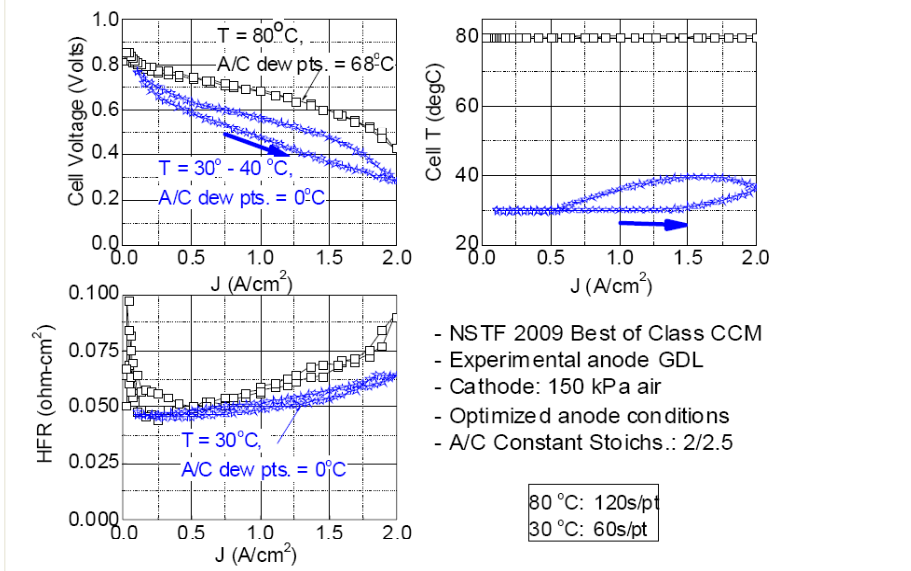
S. Hamrock, 2010 DOE Hydrogen Program Review

Low-PGM MEAs

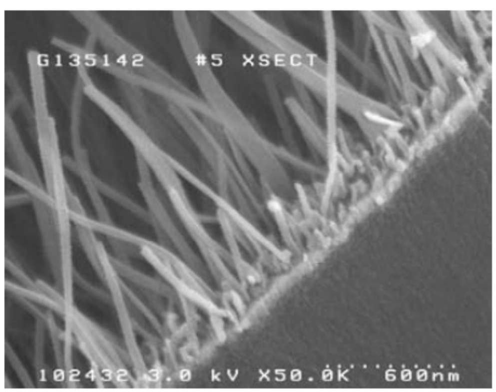
3M: Nanostructured Thin Film Catalysts



First time standard NSTF CCM has ever hit 1.5 to 2 A/cm² at 30 to 35°C



Changes to anode allow high performance operation under challenging conditions – temperature as low as 30 °C



NSTF meets major performance and durability targets

- **High power at low PGM loading – 0.18 g_{PGM}/kW (single cell), 0.19 g_{PGM}/kW (stack) – *DOE 2010 target: 0.3 g_{PGM}/kW***
- **Membrane Durability Test – 5000 hours with cycling (single cell) – *DOE 2010/2015 target: 5000 hours***

M. Debe, 2010 DOE Hydrogen Program Review

MEA and Component Durability

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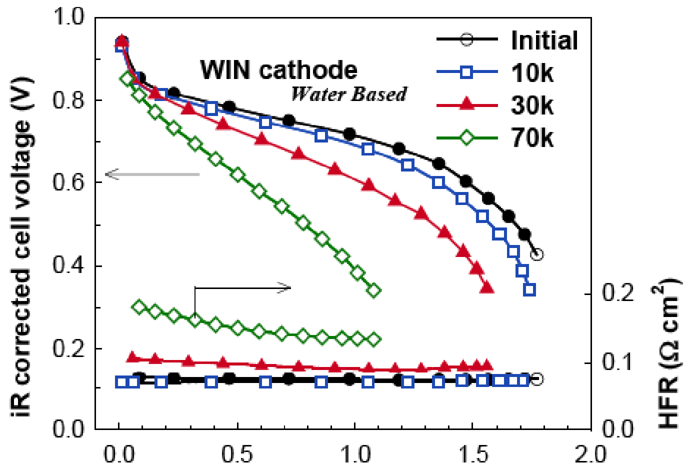
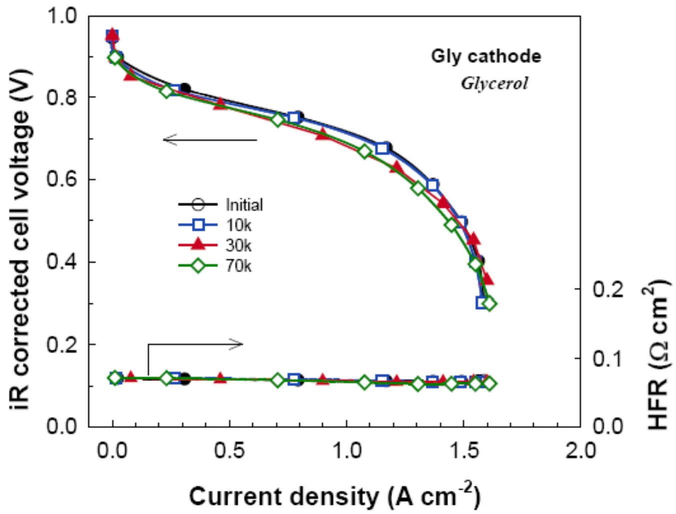
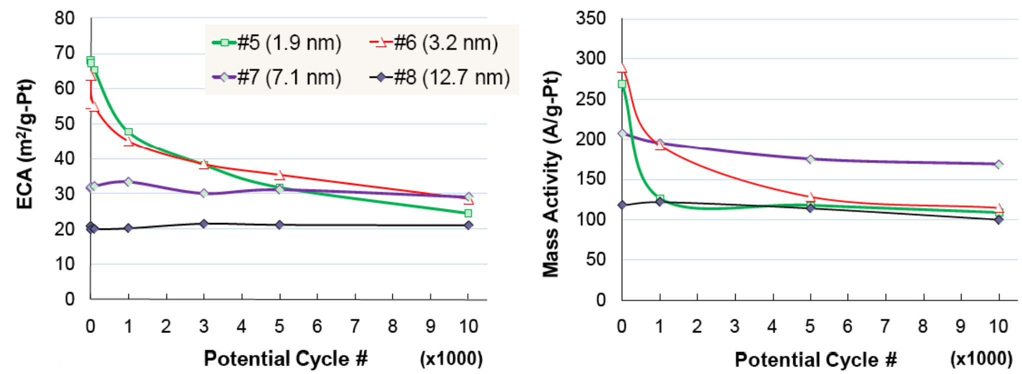
Los Alamos and Argonne National Laboratories: Improving Durability





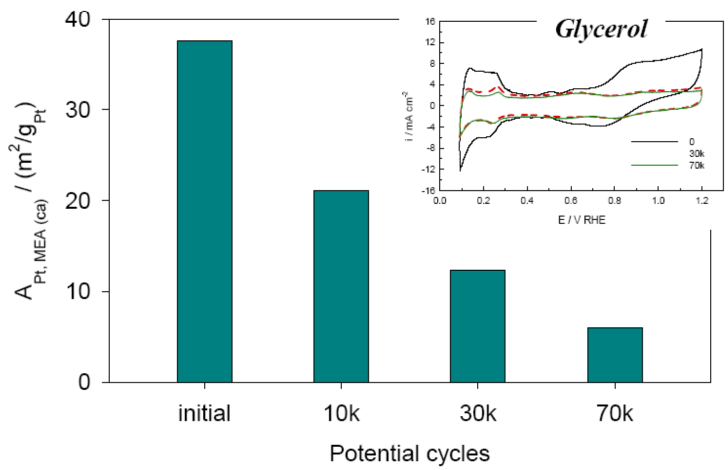
Electrode preparation affects durability

R. Borup, 2010 DOE Hydrogen Program Review



Cycling degrades performance of catalysts with small initial particle size toward that of larger particles

D. Meyers, 2010 DOE Hydrogen Program Review



Catalyst degradation is complex – major loss in ECSA with negligible loss in performance

Low-cost Bipolar Plates

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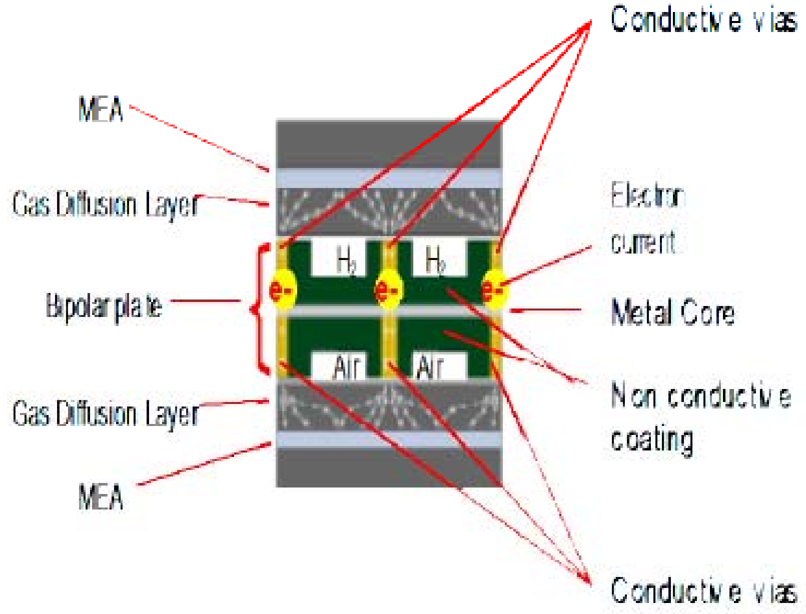
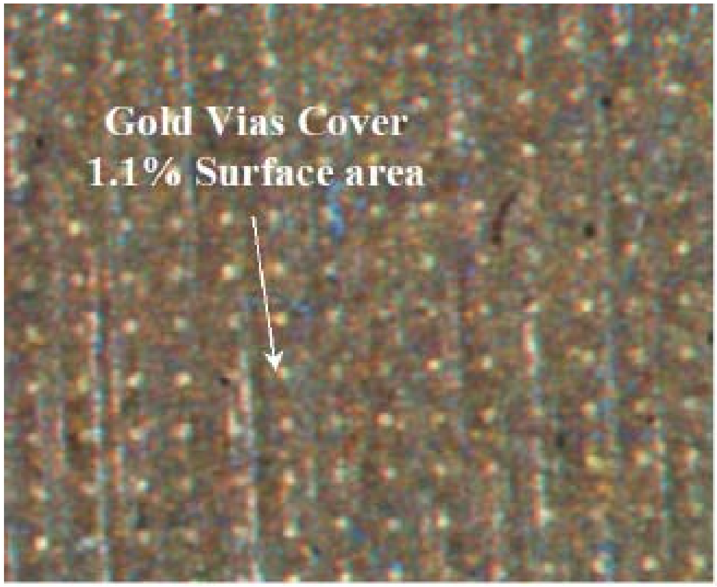
TreadStone: Surface patterning for materials cost reduction





- **Small vias provide electronic conductivity, while most of the metal plate is covered by corrosion-resistant coating**
- **Plate technology successfully demonstrated with Au vias and SS substrate. Cost: ~$3.5/kW**
- **Currently developing plates with lower-cost vias (carbon nanotubes, conductive carbides) and substrates (carbon steel) to achieve $3/kW cost target**

C. Wang, 2010 DOE Hydrogen Program Review

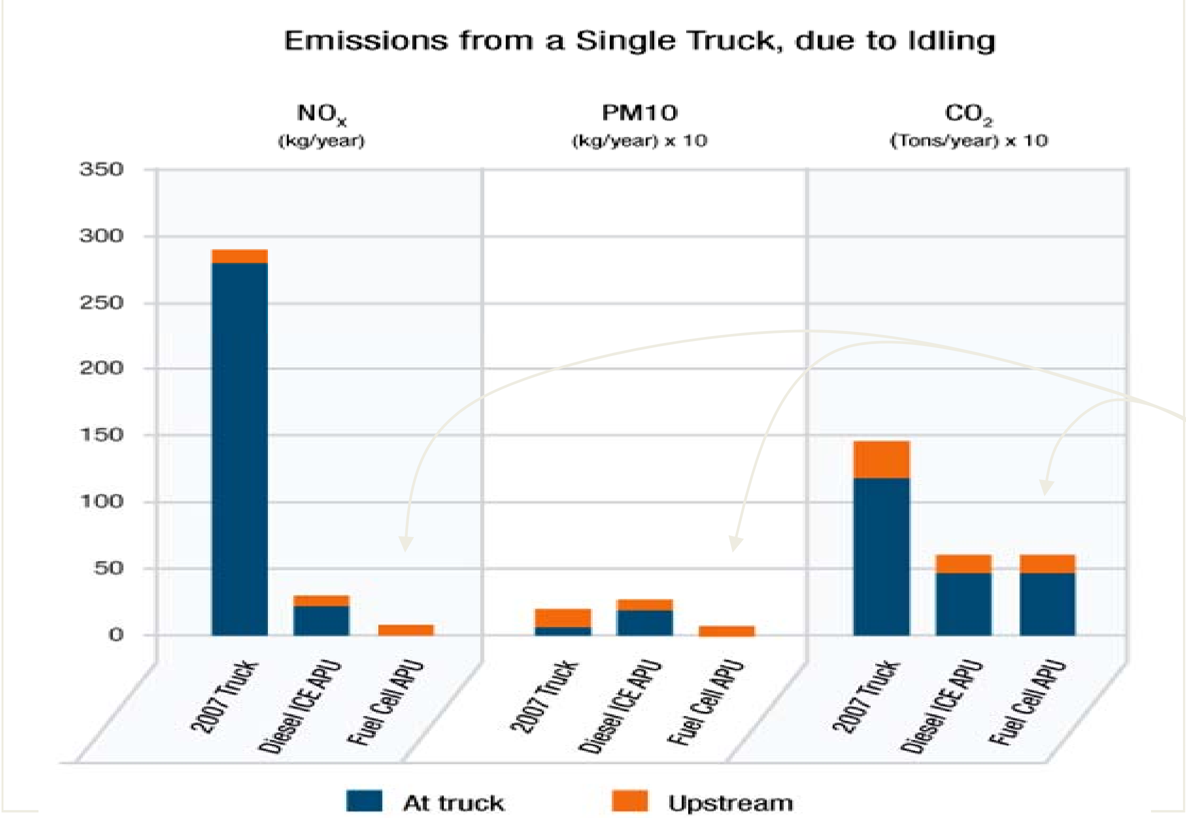
Auxiliary Power Units (APUs)

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

Potential Petroleum Savings and Emissions Reductions from fuel cell APUs in trucking industry*

> 700 million gallons of diesel fuel savings annually in 2030

> 8.9 million tons reduction in CO_2 emissions per year in 2030



Diesel-powered fuel cell APUs offer significant emissions reductions

*DOE Hydrogen Program Record http://hydrogen.energy.gov/pdfs/9010_fuel_cell_apu_trucks.pdf

Truck APU Targets

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

Characteristic	2010 Status	2013	2015	2020
Electrical efficiency at rated power[1]	25%	30%	35%	40%
Power density	17 W/L	30 W/L	35 W/L	40 W/L
Specific power	20 W/kg	35 W/kg	40 W/kg	45 W/kg
Factory cost, stack plus required BOP[2]	$750/kW[3]	$700/kW	$600/kW	$500/kW
Factory cost, system[4]	$2000/kW	$1400/kW	$1200/kW	$1000/kW
Transient response (10 to 90% rated power)	5 min	4 min	3 min	2 min
Start-up time from:				
20 °C	50 min	45 min	45 min	30 min
Standby conditions[5]	50 min	20 min	10 min	5 min
Degradation with cycling[6]	2.6%/1000 h	2%/1000 h	1.3%/1000 h	1%/1000 h
Operating lifetime[6,7]	3000 h	10,000 h	15,000 h	20,000 h
System availability	97%	97.5%	98%	99%

[1] Regulated DC net/LHV of fuel.

[2] Cost in 2010 dollars includes materials and labor costs to produce stack, plus any balance of plant necessary for stack operation. Cost defined at 50,000 unit/year production of a 5 kW system. Today's low-volume cost is expected to be higher than quoted status. Allowable cost is expected to be higher than the target for systems with rated power below 5 kW, and lower than the target for systems with rated power above 5 kW.

[3] Available cost status is that of a fuel cell stack only.

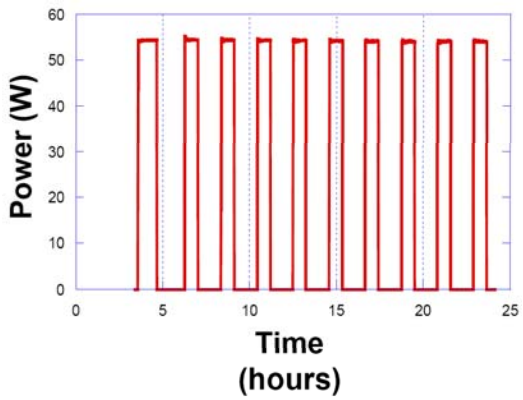
[4] Cost in 2010 dollars includes materials and labor costs to produce system. Cost defined at 50,000 unit/year production of a 5 kW system. Today's low-volume cost is expected to be higher than quoted status. Allowable cost is expected to be higher than the target for systems with rated power below 5 kW, and lower than the target for systems with rated power above 5 kW.

[5] Standby conditions may be at or above ambient temperature depending on operating protocol.

[6] Durability testing should include, at minimum, daily cycles to stand-by condition, and weekly cycles to full off condition (ambient temperature). The system should be able to meet durability criteria during and after exposure to vibration associated with transportation and highway operation, and during operation in a range of ambient temperature from -40 to 50 °C, a range of ambient relative humidity from 5% to 100%, and in dust levels up to 2 mg/m^3.

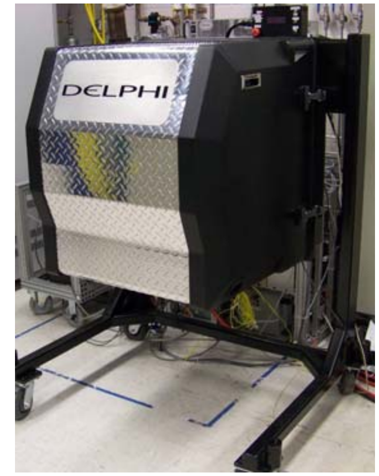
[7] Time until >20% net power degradation.

Cummins and Delphi: Demonstrating APU systems for heavy-duty trucks



< 1% degradation in 10 thermal cycles

Next Generation Endothermic Reformer



	Rated Power (Watts)	Weight Kg	Volume L	Fuel Consumption gph avg	Noise dB(A) @ 3m
Diesel APU	4000 Available	170	235	0.27 @ 1500 W	75dB(A)
SOFC System Total	3800 Peak AC 1100 Net DC 820 Net AC	197 Total	360 Total	0.24 @ 1100 W	55 dB(A) (est.)
SOFC Unit		120	304	N/A	N/A
Control Power Electronics		29	31	N/A	N/A
Batteries 2 x Group 24		48	25	N/A	N/A

D. Norrick, 2010 Hydrogen Program Review

Accomplishments

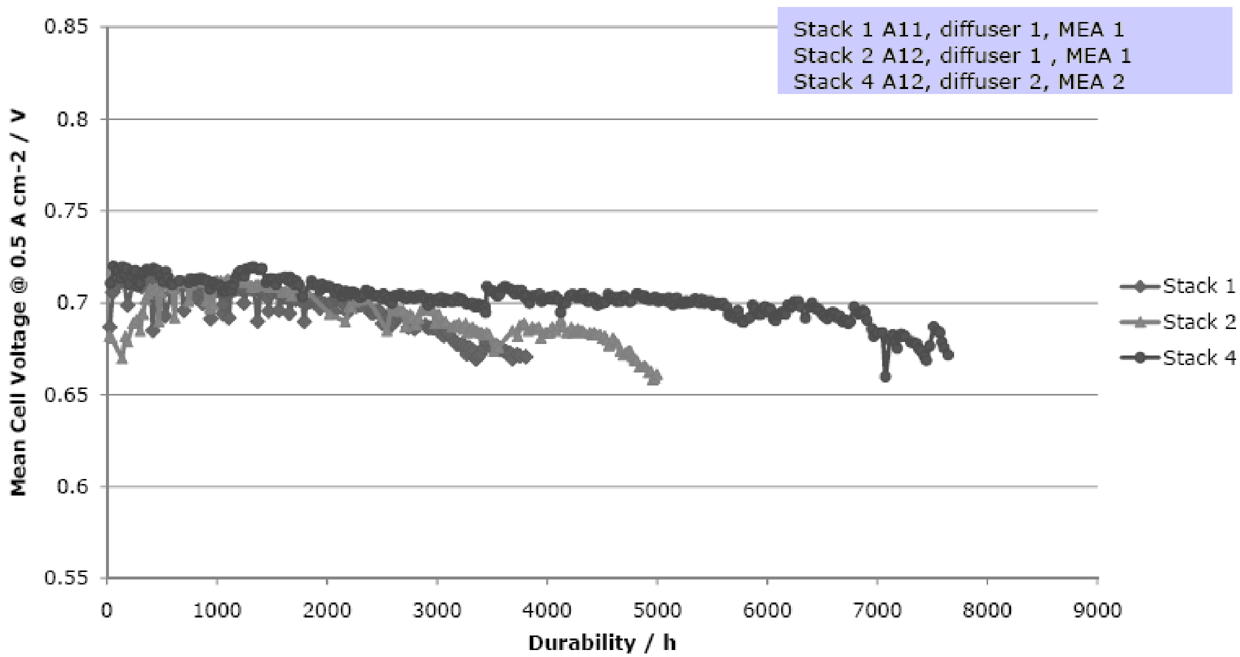
- 1.4kW Net Peak Load
- 18 ULSD Starts
- 7 Full Thermal Cycles on ULSD
- 18% System Efficiency Demonstrated
- System Noise Benchmark
- Unit tested on Natural Frequency Sine Sweep for Vibration Characterization
- Achieved Better Stack Performance Correlation to Stack Lab Data

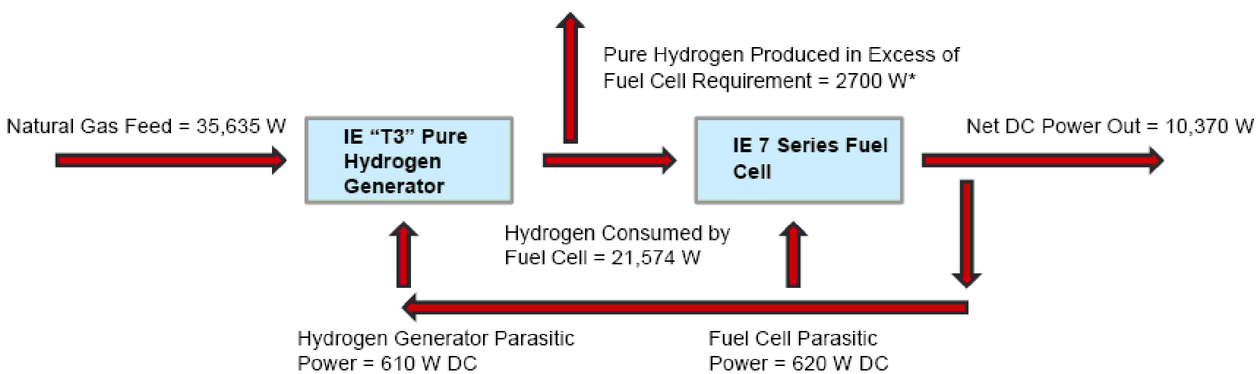
G. Blake, 2010 Hydrogen Program Review

Progress – Micro-CHP

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

Intelligent Energy: Improved stationary PEMFC durability and efficiency





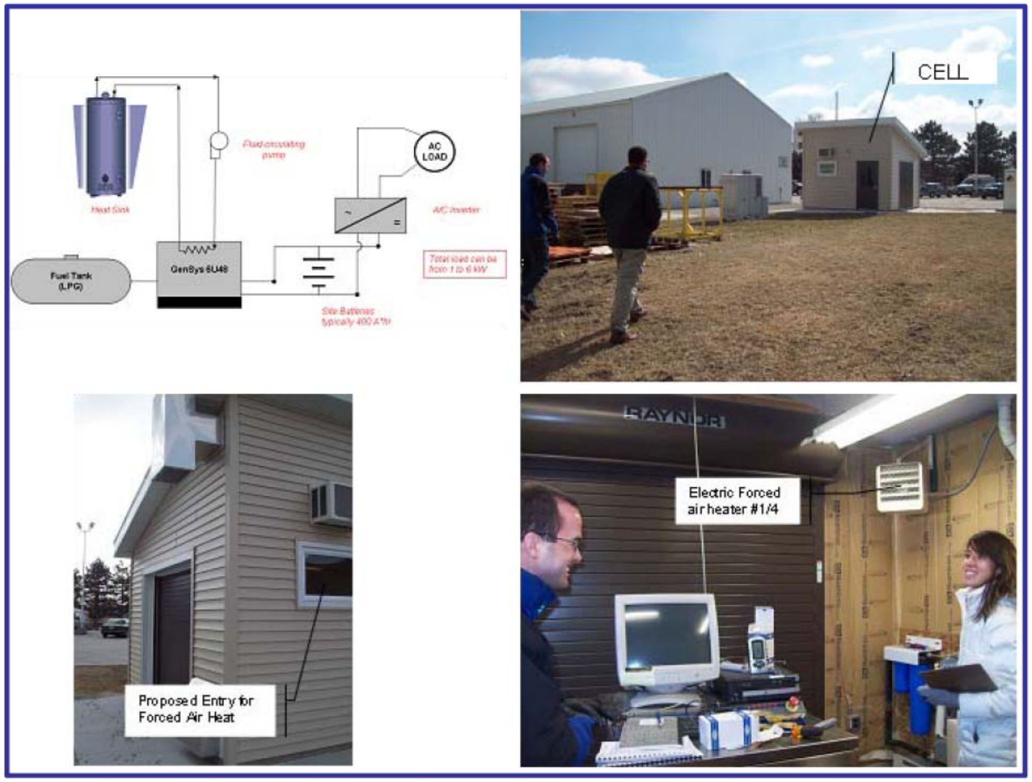
- **IE system uses reformer, pressure swing adsorption to supply pure H_2 to fuel cell stack**
- **33% electrical efficiency and 61%CHP efficiency demonstrated in unoptimized system**
- **Implementation of adsorption-enhanced reformer expected to increase efficiency**
- **Over 7000 hours durability with load cycling demonstrated in 20-cell stack**

D. Swamy, 2010 DOE Hydrogen Program Review

Progress – Micro-CHP

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

Plug Power: Demonstrating high temperature PEMFCs



- **PBI-based high-temperature PEM systems demonstrated for stationary and CHP applications in US and Europe through US-EU collaboration**
- **Current project examines durability of HT PEM systems**
- **6 units being tested in-house at Plug Power**
- **Additional units being demonstrated in California: residential (3 units) and light commercial (3 units)**

Thank you

For more information, please contact

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