Fuel Cell Cost Reduction and R&D Progress through the U.S. Department of Energy's Hydrogen Program

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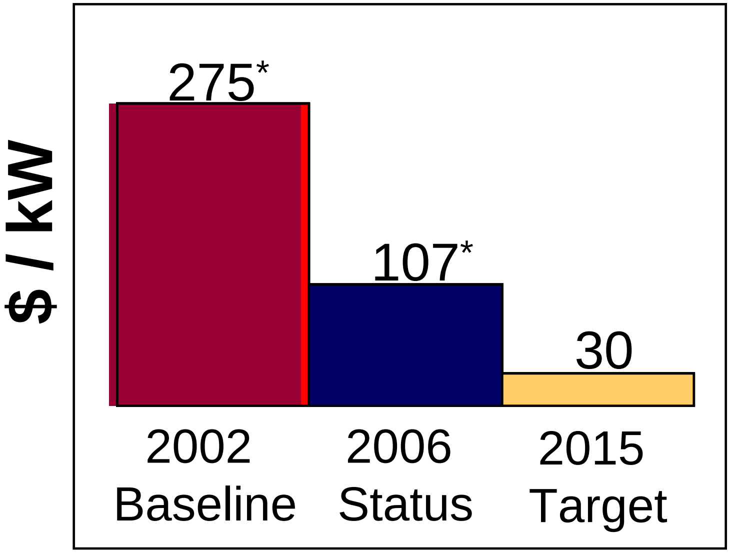
Fuel Cell Progress

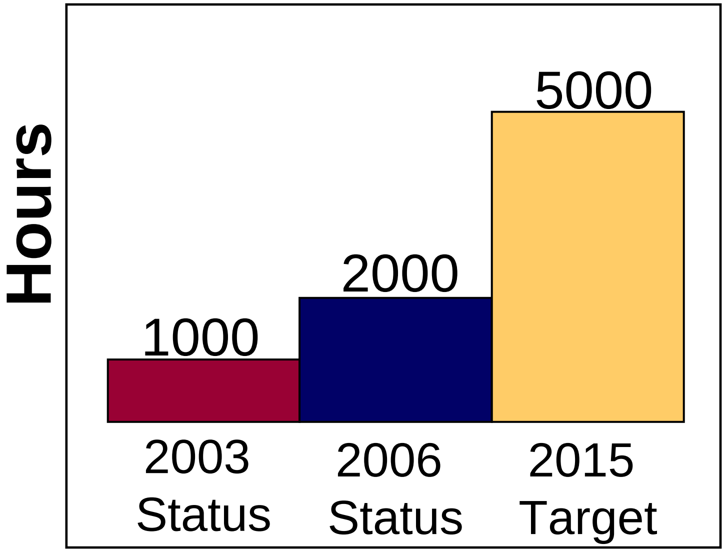
R&D accomplishments have led to reduced cost and improved durability.

Fuel Cell System Cost Status vs. Targets



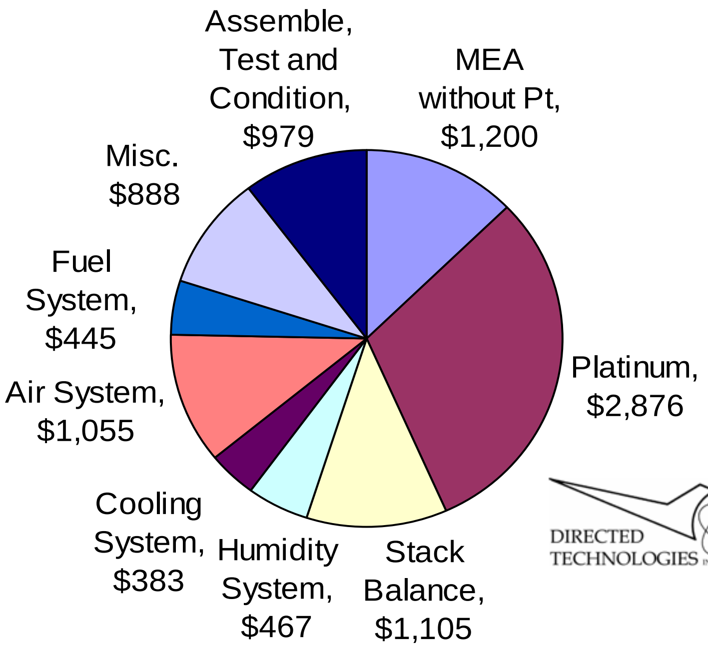
*projected to high volume production of 500,000 units/year

Fuel Cell System Durability Status vs. Targets

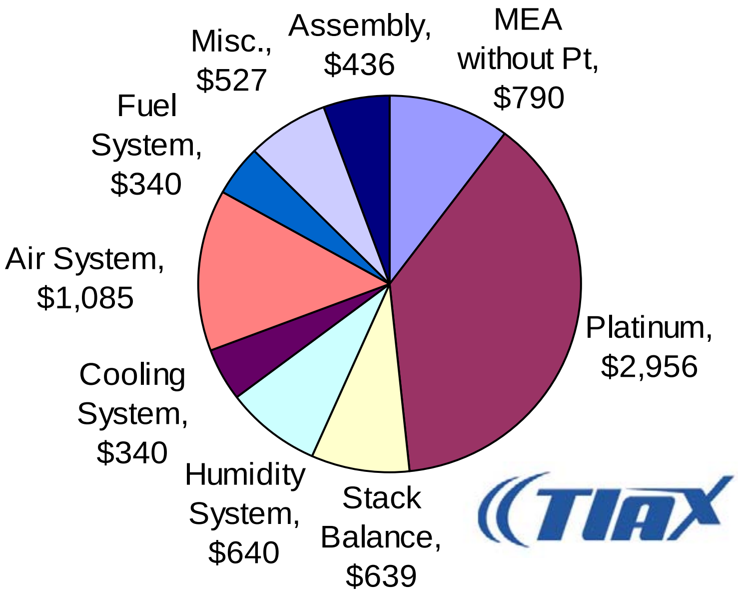


Two High-volume Cost Analyses in 2006 - DTI and TIAX

DTI Fuel Cell System 80 kW Direct H_2
Cost = $118/kW (net), $9412



TIAX Fuel Cell System 80 kW Direct H_2
Cost = $97/kW (net), $7760



- **The differences between the DTI and TIAX estimates are: the cost of the MEA and seals in stack balance and DTI included Test & Conditioning**
- **The 2015 cost target is $30/kW, $3200.**

Stack Cost 2007 Material Assumptions

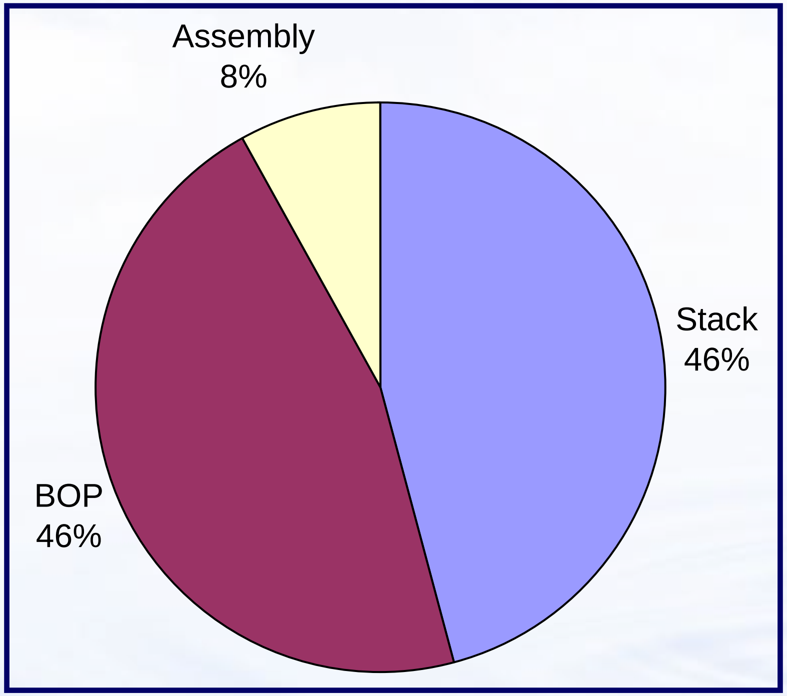
Component	Selection
Membrane	3M PFSA (EW=825)
Electrodes – Cathode and Anode	Ternary $PtCo_xMn_y$ alloy
	Nano-Structured Thin Film
	Organic whiskers
Gas Diffusion Layer	Woven Carbon fiber
Bipolar Plate	Expanded graphite foil

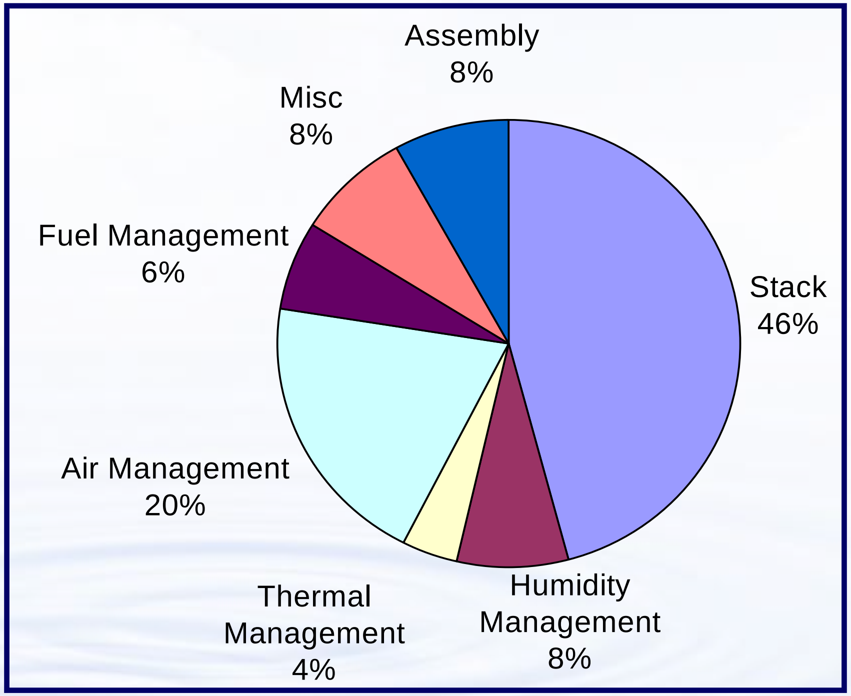
The major differences from the 2005 material assumptions lie in the catalyst composition and support structure.

TIAX System Cost Breakdown- Interim 2007 estimates- preliminary results

Estimated fuel cell system cost as low as $67/kW for 500,000 units/year, stack accounts for 46% of system cost.

Fuel Cell System Cost – 80 kW Direct Hydrogen



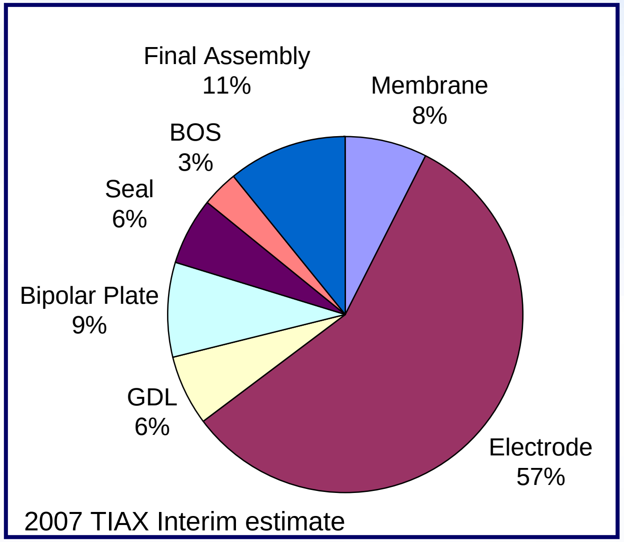


TIAX used 2005 estimates for the air and fuel management; these will be updated with bottom-up costing.

Example of Key R&D Focus Area- Catalysts and Supports

Importance to goals:

- ***Platinum cost is ~60% of total stack cost***
- ***Catalyst durability needs improvement***



2007 TIAX Interim estimate

Four Strategies for Catalysts and Supports Research:

- **Strategy 1 – Lower PGM**
  Improve Pt catalyst utilization along with durability.
- **Strategy 2 – Pt alloys**
  Pt based alloys that maintain performance and durability compared to Pt and reduce cost
- **Strategy 3 – Novel support structures**
  Explore non-carbon supports and alternative carbon structures
- **Strategy 4 – Non-Pt catalysts**
  Non precious metal catalysts that maintain performance and durability compared to Pt

Example of Key R&D Focus Area- Fuel Cell Membranes

Importance to goals:

- ***Fuel cell stack performance and durability depend on membrane characteristics***
- ***Membrane limitations add complexity to the fuel cell system***

Three Strategies for High-Temperature Membrane Research:

- **Strategy 1 – Phase segregation control**

  Polymer - Separate blocks of hydrophobic and hydrophilic functionality incorporated within the same polymer molecule

  Membrane – Two-polymer composites. One polymer provides mechanical properties, while the other polymer provides proton conduction

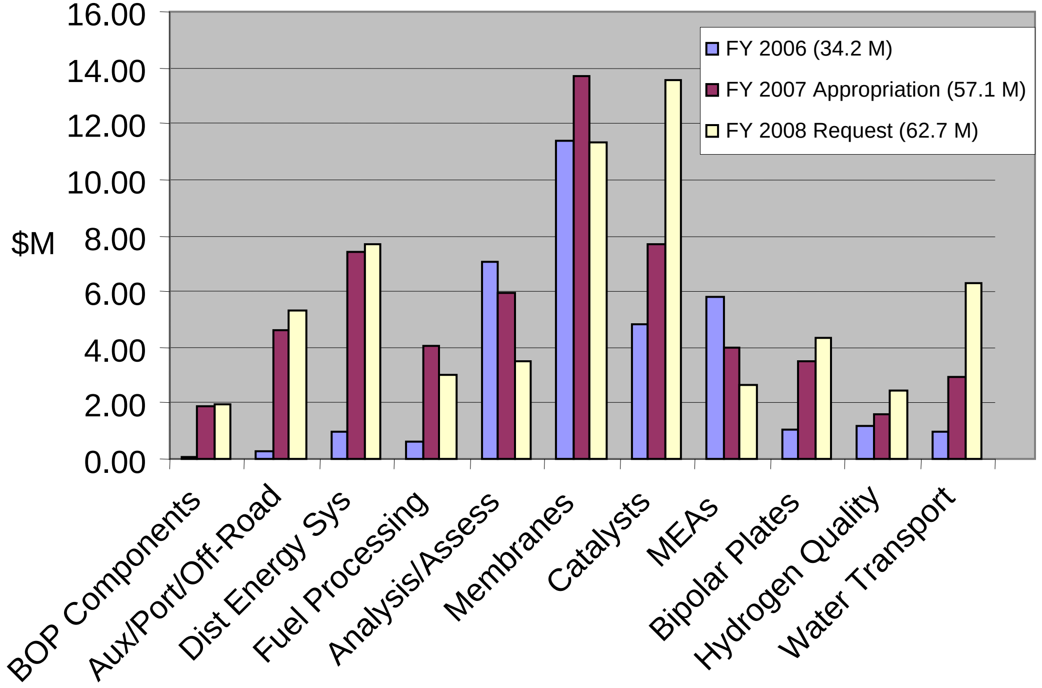
- **Strategy 2 – Non-aqueous proton conductors**

  Membranes that use inorganic oxides, heteropolyacids or ionic liquids, rather than water, to enhance conductivity

- **Strategy 3 – Hydrophilic additives**

  Membranes with additives that maintain water content and conductivity at higher temperature

Fuel Cell Budget



Thank you

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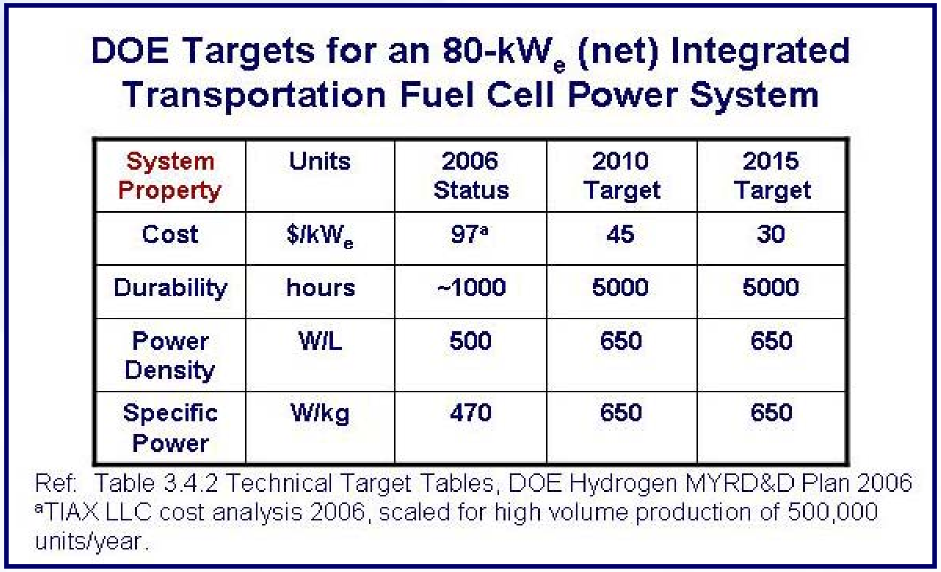
BACK-UP SLIDES

Fuel Cell Targets and Status

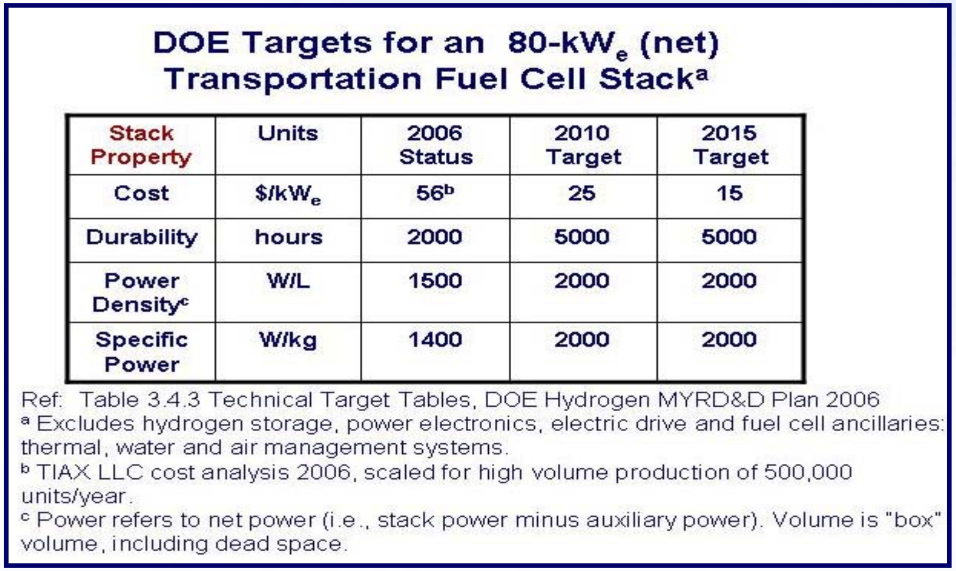


DOE Targets for an 80-kW$_e$ (net) Integrated Transportation Fuel Cell Power System

System Property	Units	2006 Status	2010 Target	2015 Target
Cost	$\$/\mathrm{kW}_e$	97[a]	45	30
Durability	hours	~1000	5000	5000
Power Density	W/L	500	650	650
Specific Power	W/kg	470	650	650

Ref: Table 3.4.2 Technical Target Tables, DOE Hydrogen MYRD&D Plan 2006

[a] TIAX LLC cost analysis 2006, scaled for high volume production of 500,000 units/year.



DOE Targets for an 80-kW$_e$ (net) Transportation Fuel Cell Stack[a]

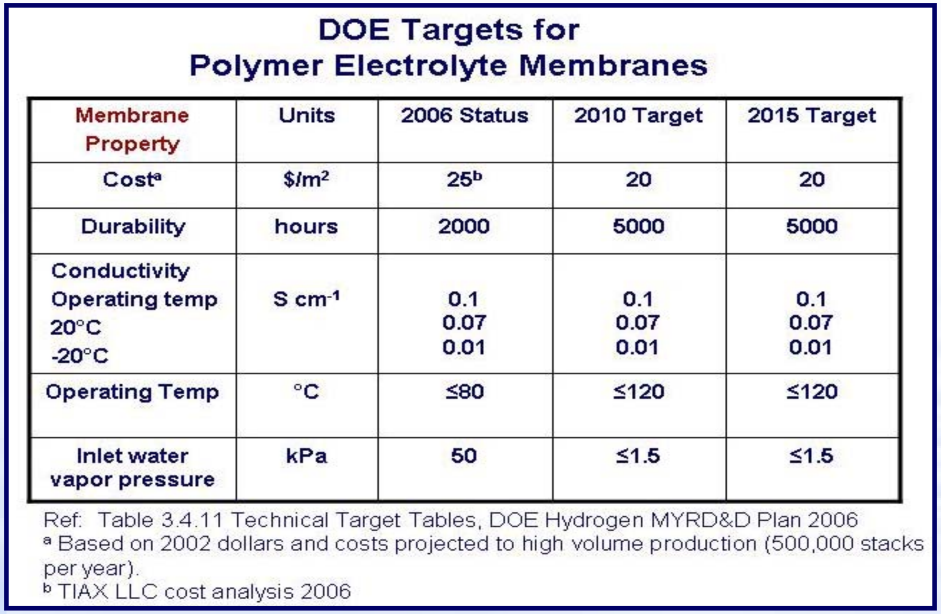
Stack Property	Units	2006 Status	2010 Target	2015 Target
Cost	$\$/\mathrm{kW}_e$	56[b]	25	15
Durability	hours	2000	5000	5000
Power Density[c]	W/L	1500	2000	2000
Specific Power	W/kg	1400	2000	2000

Ref: Table 3.4.3 Technical Target Tables, DOE Hydrogen MYRD&D Plan 2006

[a] Excludes hydrogen storage, power electronics, electric drive and fuel cell ancillaries: thermal, water and air management systems.

[b] TIAX LLC cost analysis 2006, scaled for high volume production of 500,000 units/year.

[c] Power refers to net power (i.e., stack power minus auxiliary power). Volume is "box" volume, including dead space.



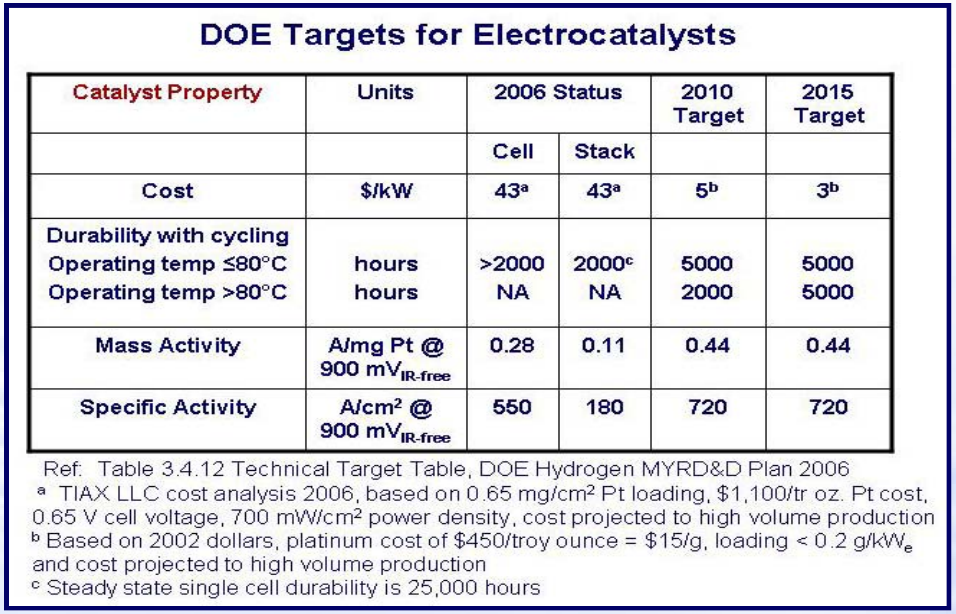
DOE Targets for Polymer Electrolyte Membranes

Membrane Property	Units	2006 Status	2010 Target	2015 Target
Cost[a]	$\$/\mathrm{m}^2$	25[b]	20	20
Durability	hours	2000	5000	5000
Conductivity Operating temp 20°C -20°C	 $S\ cm^{-1}$	 0.1 0.07 0.01	 0.1 0.07 0.01	 0.1 0.07 0.01
Operating Temp	°C	≤80	≤120	≤120
Inlet water vapor pressure	kPa	50	≤1.5	≤1.5

Ref: Table 3.4.11 Technical Target Tables, DOE Hydrogen MYRD&D Plan 2006

[a] Based on 2002 dollars and costs projected to high volume production (500,000 stacks per year).

[b] TIAX LLC cost analysis 2006



DOE Targets for Electrocatalysts

Catalyst Property	Units	2006 Status		2010 Target	2015 Target
		Cell	Stack		
Cost	$\$/\mathrm{kW}$	43[a]	43[a]	5[b]	3[b]
Durability with cycling Operating temp ≤80°C Operating temp >80°C	 hours hours	 >2000 NA	 2000[c] NA	 5000 2000	 5000 5000
Mass Activity	A/mg Pt @ 900 mV$_{IR\text{-}free}$	0.28	0.11	0.44	0.44
Specific Activity	A/cm^2 @ 900 mV$_{IR\text{-}free}$	550	180	720	720

Ref: Table 3.4.12 Technical Target Table, DOE Hydrogen MYRD&D Plan 2006

[a] TIAX LLC cost analysis 2006, based on 0.65 mg/cm^2 Pt loading, \$1,100/tr oz. Pt cost, 0.65 V cell voltage, 700 mW/cm^2 power density, cost projected to high volume production

[b] Based on 2002 dollars, platinum cost of \$450/troy ounce = \$15/g, loading < 0.2 g/kW$_e$ and cost projected to high volume production

[c] Steady state single cell durability is 25,000 hours

Key Technical Targets Define System

	units	2006	2010	2015
DOE Tech Targets that drive analysis:				
Stack Efficiency @ Rated Power	%	55%	55%	55%
MEA Areal Power Density @ Peak Power	mW/cm^2	700	1000	1000
Total Catalyst Loading	g/kW_{gross}	0.65	0.29	0.19
Key Derived Performance Parameters:				
System Gross Electric Power (Output)	g/kW_{gross}	90.6	87.6	87.1
Active Area	cm^2	348	235	234
Cell Voltage @ Peak Power	V/cell	0.68	0.68	0.68
Operating Pressure (Peak)	atm	2.3	2.0	1.5

- A few key DOE Tech. Target values are used to anchor system definition
- All other system parameters flow from DTI calculations & judgment

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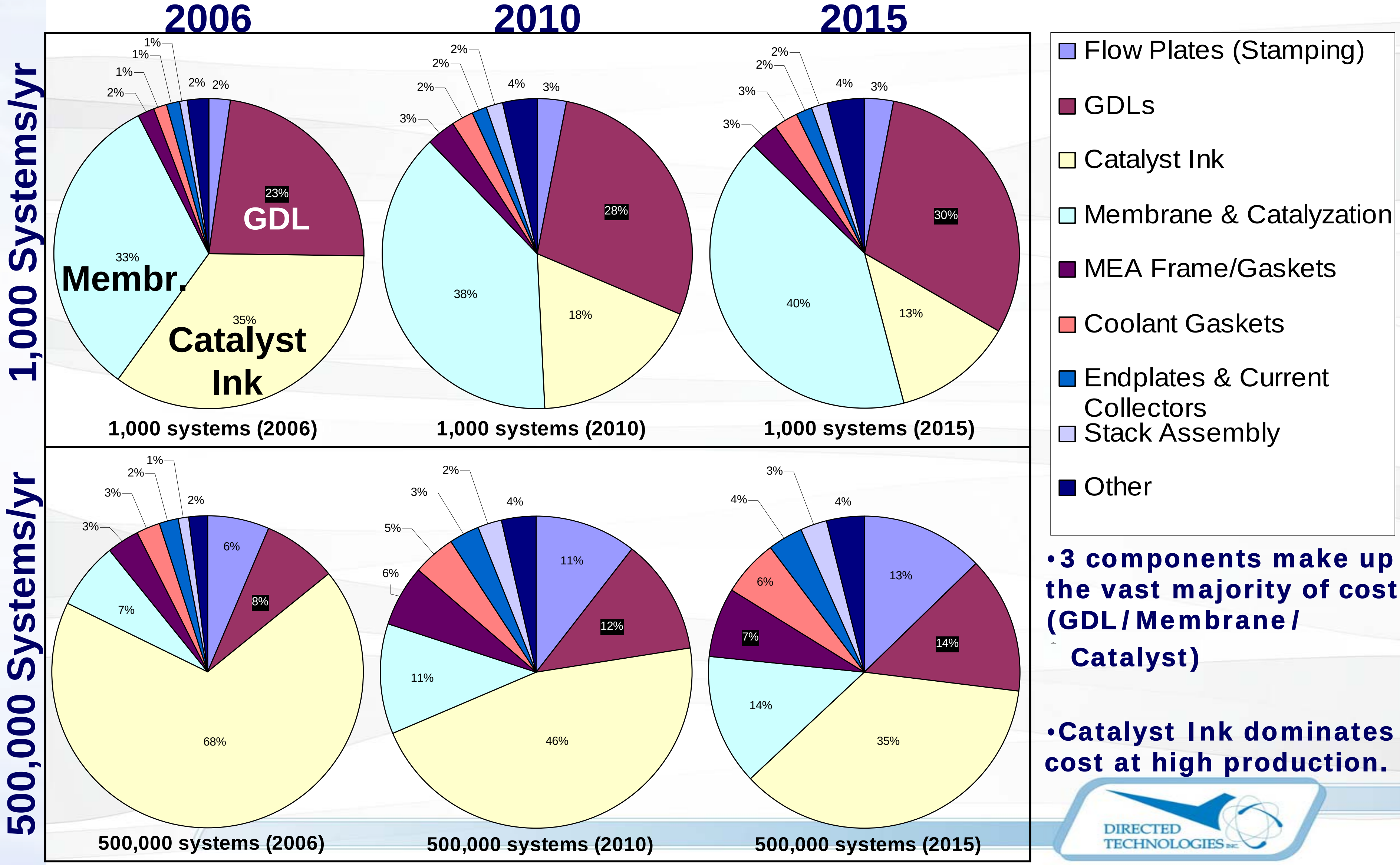
Example of Stack Component Cost Distribution

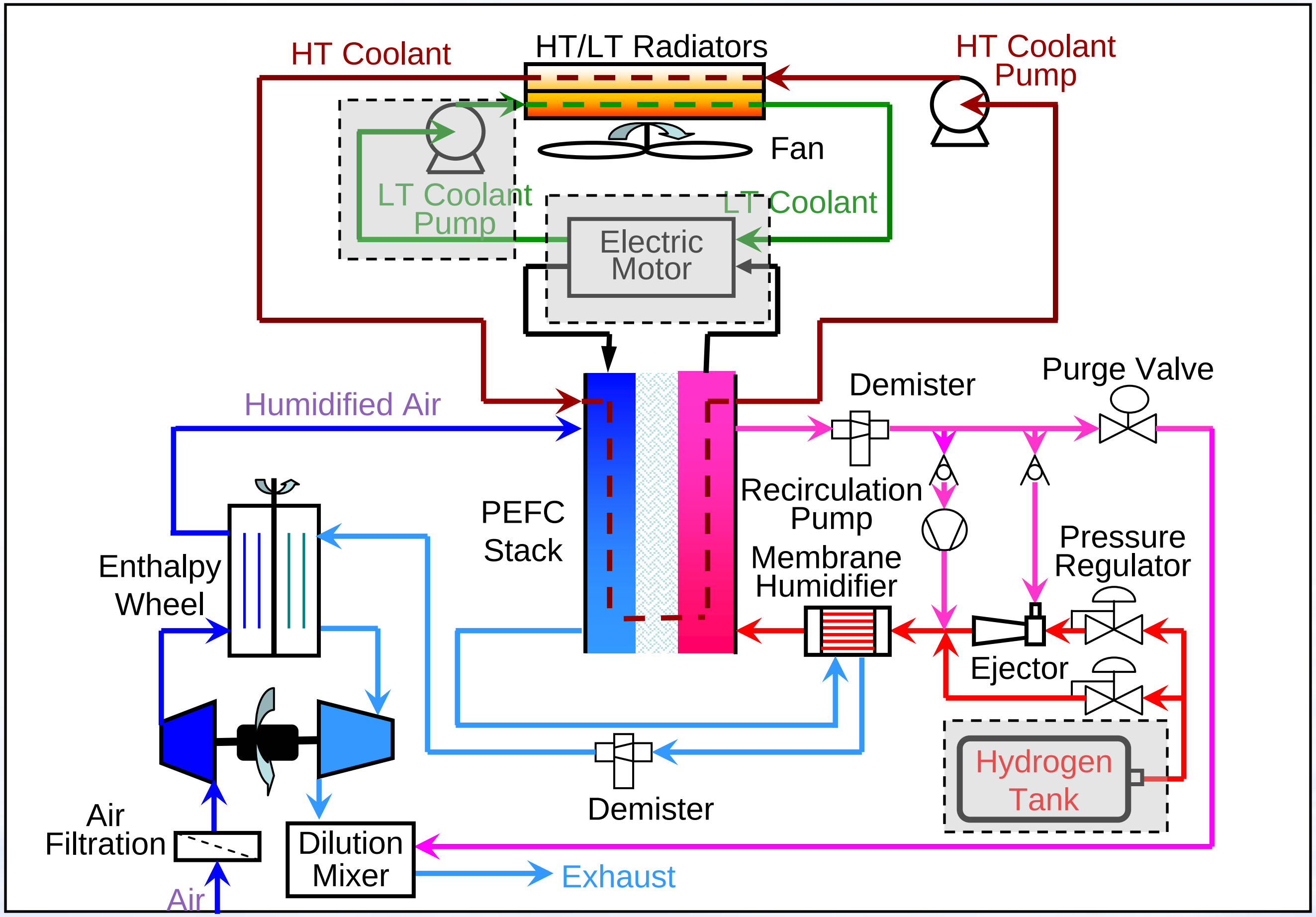


- **3 components make up the vast majority of cost (GDL / Membrane / Catalyst)**

- **Catalyst Ink dominates cost at high production.**

Approach - System Layout

2007 system configuration and component specifications



Not included in the fuel cell subsystem

Source: Dr. Rajesh Ahluwalia of ANL

Stack Cost - Specifications

Stack specifications and performance assumptions are key drivers of cost and power density.

Parameters	Units	2007 Direct H_2	S/C[1]	Comments
Production volume	per year	500,000	S	Same as in previous studies
Fuel cell net power	kW_e	80	S	DOE/Freedom Car Spec.
Fuel cell gross power	kW_e	86.4	C	ANL[2]
Cell voltage @ rated power	V	0.68	S	ANL[2]
Stack voltage @ rated power	V	300 V @ 266 A	S	ANL[2]
Stack efficiency @ rated power	%	54%	C	ANL[2]
Number of stacks		2	S	Same as in previous studies
Number of cells per stack		221	C	Calculated by TIAX
Cell pitch	Cells / inch Cells/cm	10.00/inch, 3.85/cm	C	Calculated by TIAX
Total Pt Loading (Cathode / Anode)	mg/cm^2	0.2/0.1	S	ANL[2] / Developer feedback
Power density @ 0.68V	mW/cm^2	753	S	ANL[2]
Active area per cell	cm^2	269	C	Calculated by TIAX
Active area to total area	%	85	S	ANL[2]

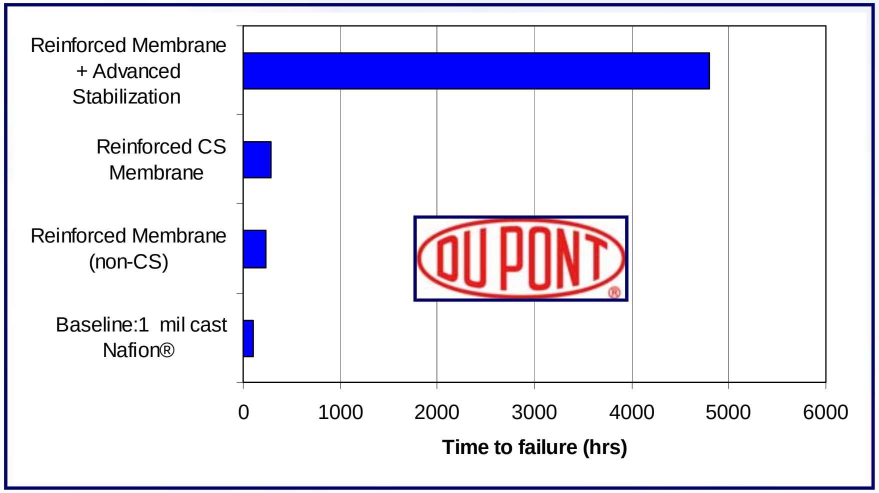
[1] S – Specified, C – Calculated

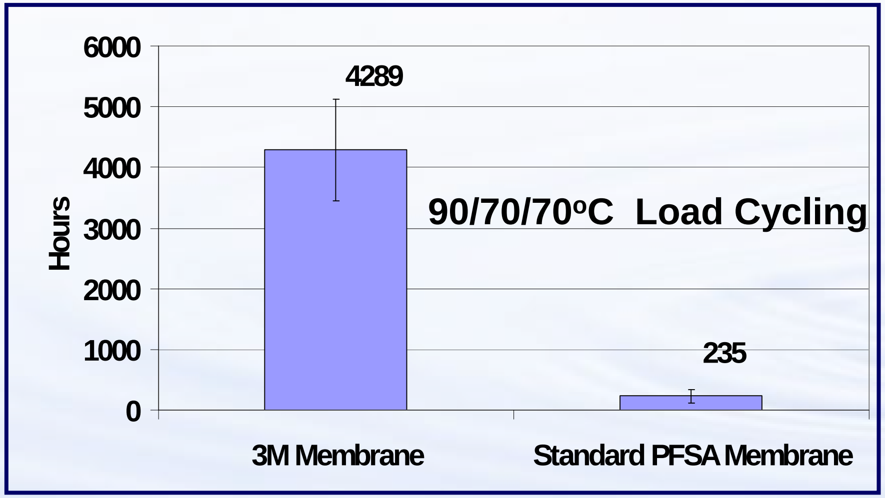
[2] R.K. Ahluwalia and X. Wang, Reference Fuel Cell System Configurations for 2007: Interim Results, ANL, Feb. 6, 2007

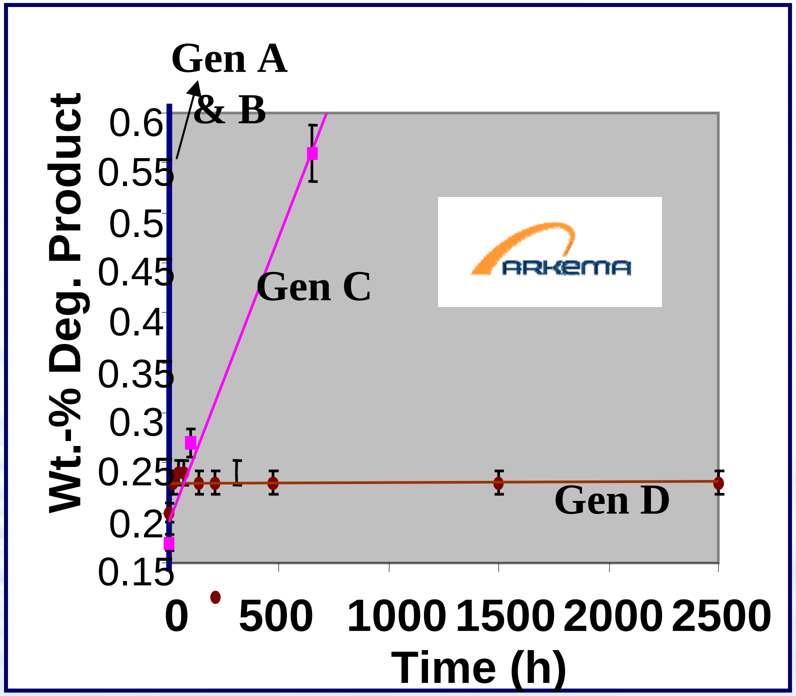
Results: R&D Highlights - Membranes

Membrane Durability

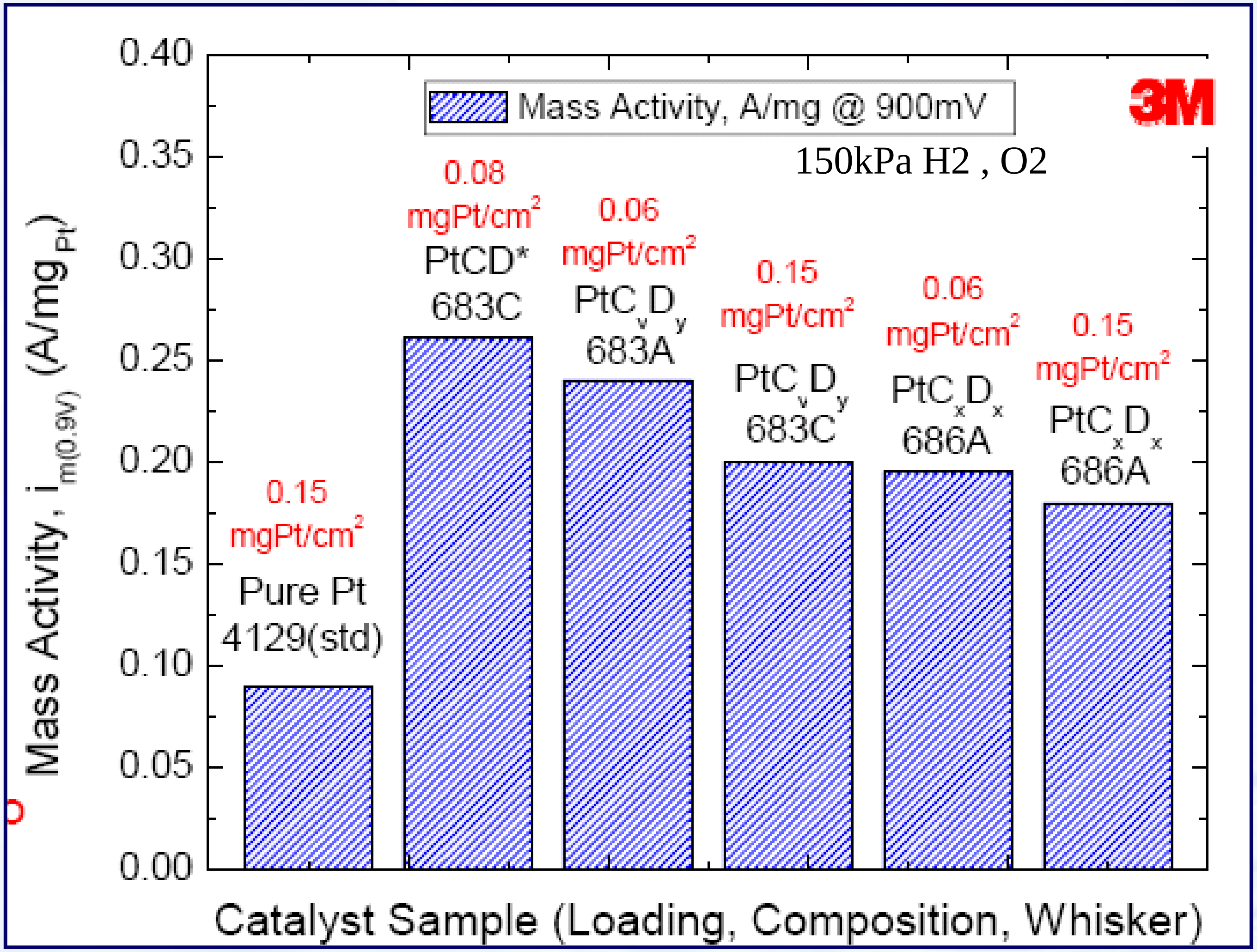
- **Developed membrane with nearly 5,000 hours (DOE target) durability with humidity and voltage cycling (Dupont)**
- **Sulfur loss issue resolved in PVDF composite membrane (Arkema)**
- **Initial fluoride release in voltage cycle testing correlated to accelerated lifetime (3M)**
- **DOE Accelerated Stress Test protocols developed for membranes/MEAs**







Catalysts with Higher Activity and Greater Stability



Membrane life improvements

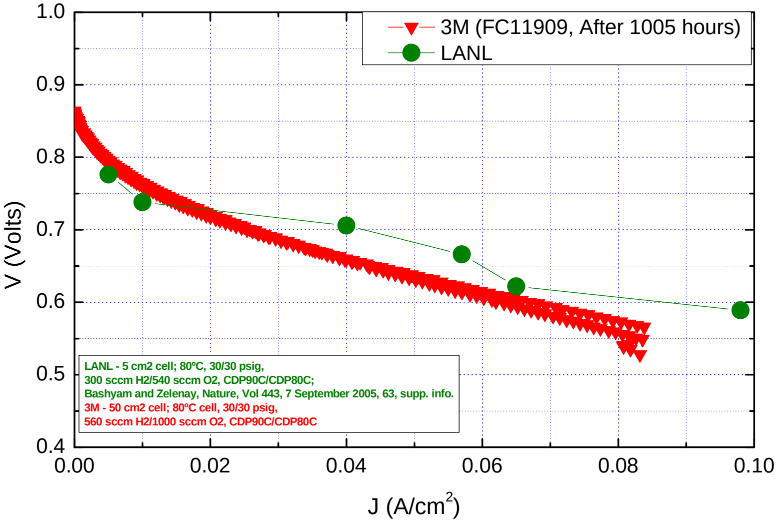
- Improved resistance to corrosion and Pt area loss over graphitic carbon
- Support structure and ternary composition are also factors

Pt-alloy catalysts show higher mass activity compared to pure Pt, with more stable structure

Results: R&D Highlights - Catalysts

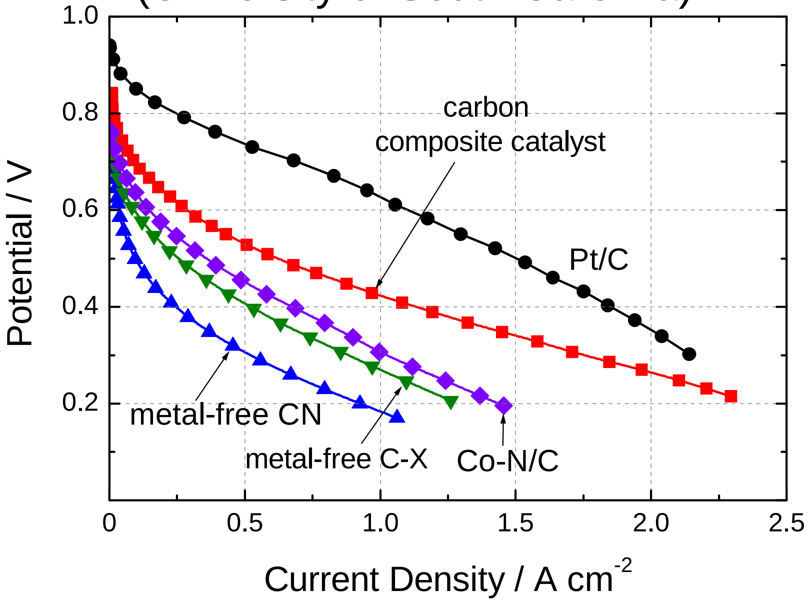
Non-PM Catalysts

- Increased durability of non-PM catalysts, achieving 1,000 h with practically no irreversible degradation losses



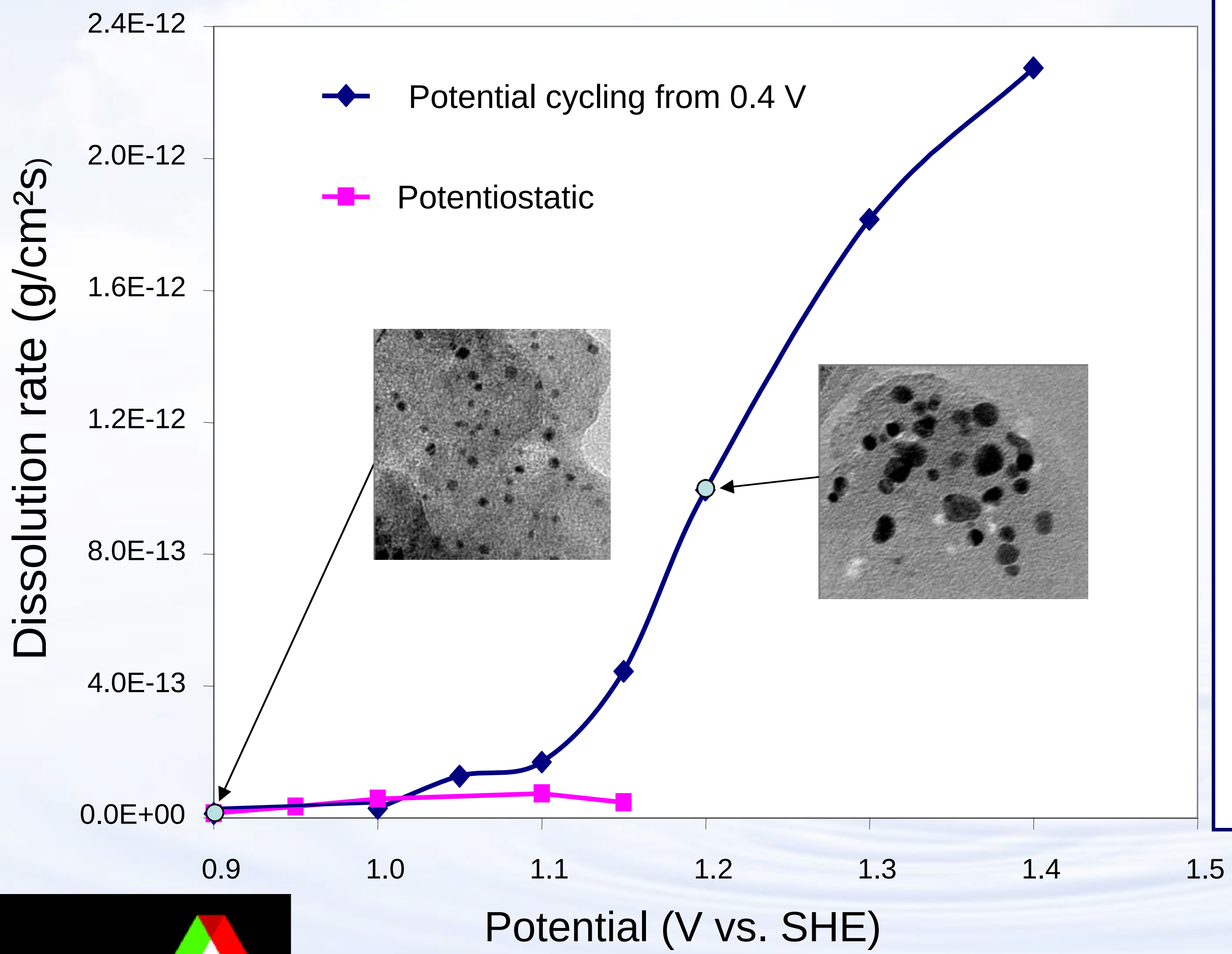
Catalysts (Non-PM)

- Increased activity of non-PM catalysts (University of South Carolina)



- ***Anode:* 2 mg cm-2 of ETEK 20% Pt/C**
- ***Cathode:* 6 mg cm-2 of cathode catalyst**
- ***Membrane:* Nafion 112**
- ***Operating temperature:* 77 ºC (H_2); 75 ºC (O_2); 75 ºC (cell)**
- ***Back pressure:* 30 psi (H_2)/40 psi (O_2)**

Identified Platinum Degradation Mechanism



- •Pt dissolution rate for Pt/C is accelerated by potential cycling
- •Increase in Pt particle size with cycling
- •Particle size increases with increasing potential
- •Increased particle size leads to decreased surface area and decreased activity

Major Project - Water Transport

Importance to goals:

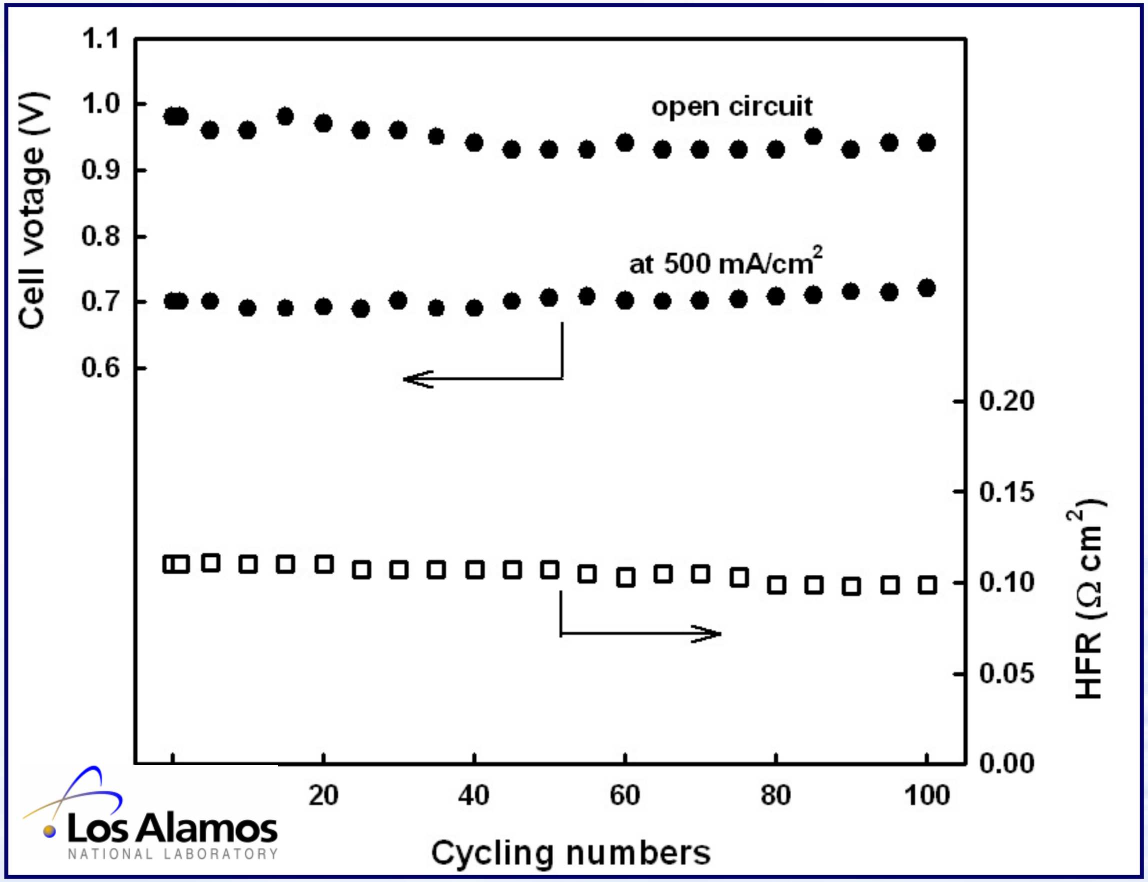
- ***Understanding water transport key to operation in cold climates***
- ***Water management at high power to prevent flooding***
- ***Water management to prevent membrane drying out***

Strategy for Water transport Research:

- Optical and neutron imaging of water movement in fuel cells and theoretical modeling (NIST, LANL, CFD Research, Nuvera, RIT, GM, ANL)
- New projects beginning

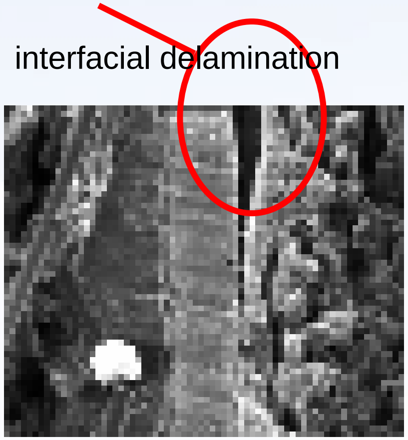
LANL Analysis Shows Freeze Tolerance of Nafion

Demonstrated Durable MEA during Freeze/Thaw cycling from -40 to 80˚C showed no loss in performance through 100 cycles



*Fuel cells cycled under wet conditions (no attempt to dry)

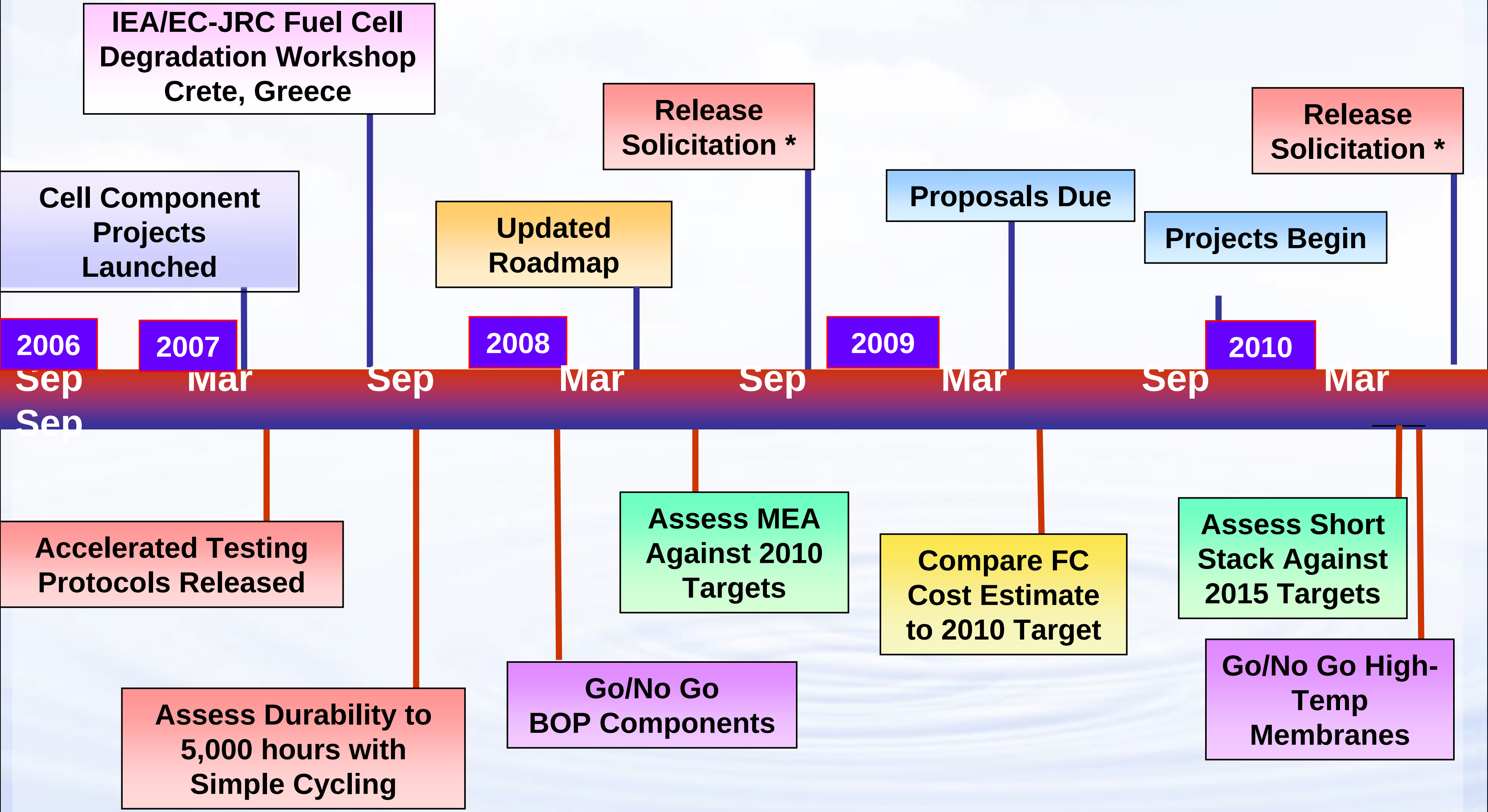
interfacial delamination



SEM micrograph of MEA after 10 cycles from –80 to 80°C

The Fast Freeze/Thaw cycling from -80 to 80˚C quickly degraded performance (8 cycles). HFR increase and the above SEM study indicate interfacial delamination

Fuel Cells – Future Plans



Cell Component Projects Launched

IEA/EC-JRC Fuel Cell Degradation Workshop Crete, Greece

Updated Roadmap

Release Solicitation *

Proposals Due

Projects Begin

Release Solicitation *

Accelerated Testing Protocols Released

Assess Durability to 5,000 hours with Simple Cycling

Go/No Go BOP Components

Assess MEA Against 2010 Targets

Compare FC Cost Estimate to 2010 Target

Assess Short Stack Against 2015 Targets

Go/No Go High-Temp Membranes

*Subject to appropriations