U.S. DEPARTMENT OF ENERGY

Fuel Cell Subprogram Overview

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2007 DOE Hydrogen Program Merit Review and Peer Evaluation Meeting

May 15, 2007

Outline

- Goal and Objectives
- Budget
- Challenges
- Progress
  - Accomplishments/Status
- Future Plans

Fuel Cell Subprogram

Goal

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

Objectives

For transportation applications:

- By 2010, develop a 60% peak-efficient, direct hydrogen fuel cell power system at a cost of $45/kW with 5000 hours of durability (80°C); by 2015, a cost of $30/kW.

For stationary power and other early market fuel cell applications:

- By 2011, develop a distributed generation PEM fuel cell system operating on natural gas or LPG that achieves 40% electrical efficiency and 40,000 hours durability at $750/kW.
- By 2010, develop a fuel cell system for consumer electronics (<50 W) with an energy density of 1,000 Wh/L.
- By 2010, develop a fuel cell system for auxiliary power units (3-30 kW) with a specific power of 100 W/kg and a power density of 100 W/L.

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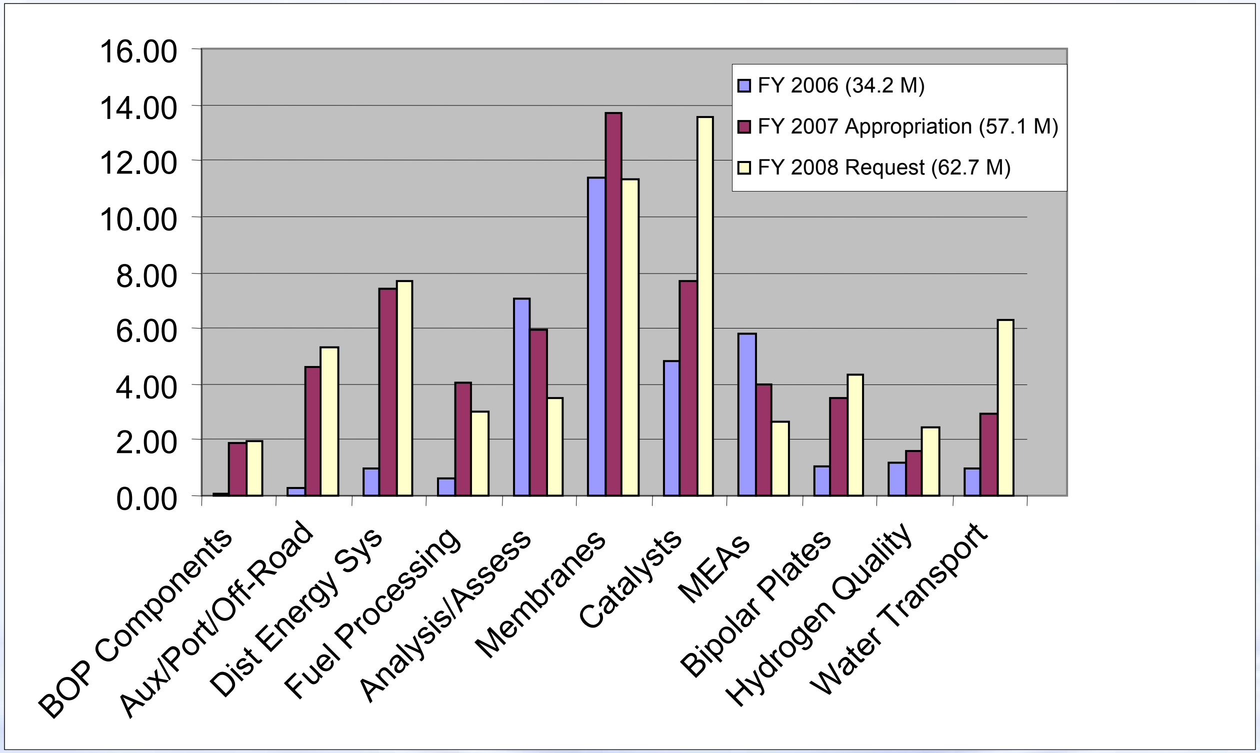
Fuel Cell Budget

Budget Activity	Funding ($ in thousands)	
	FY 2007 Appropriation	FY 2008 Request
Fuel Cell Stack Component R&D	38,082	44,000
Transportation Fuel Cell Systems	7,518	8,000
Distributed Energy Fuel Cell Systems	7,419	7,700
Fuel Processor R&D	4,056	3,000

Fuel Cell Budget by topic



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Fuel Cell Challenges

A. Durability

B. Cost

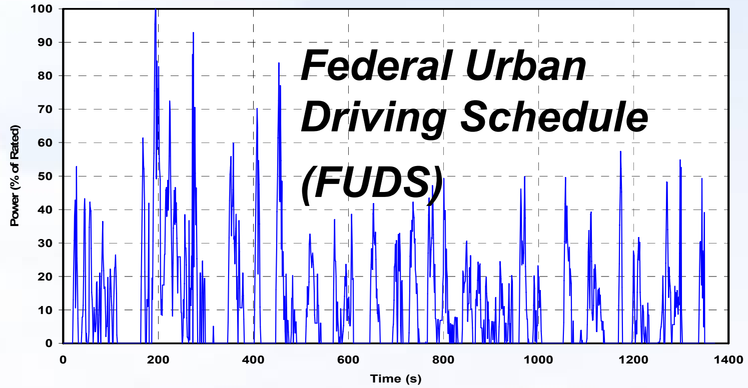
C. Performance

D. Air Management

E. System Thermal and Water Management

F. Water Transport within the Stack

G. Start-up and Shut-down Time-and-Energy/Transient Operation



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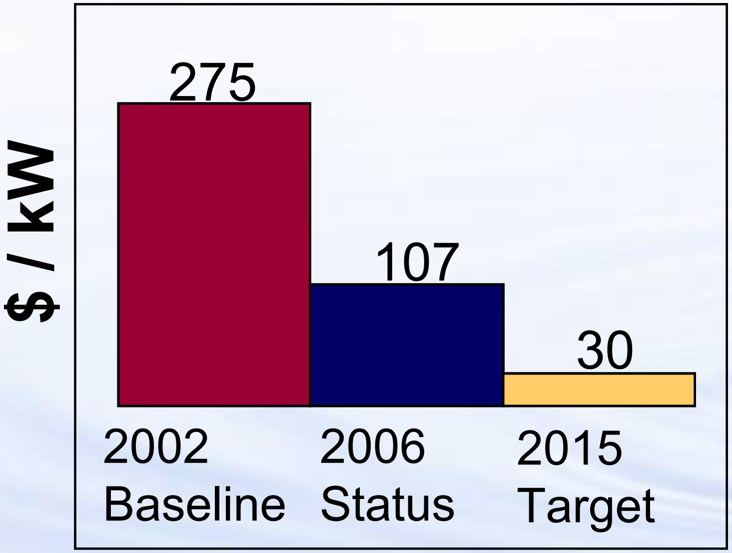
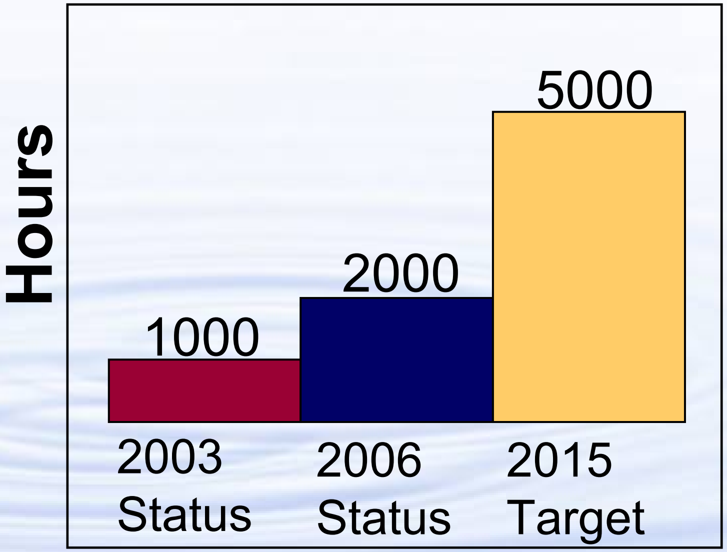
Fuel Cells Progress

Program has reduced cost and improved durability.

Fuel Cell System Costs Status vs. Targets



Fuel Cell System Durability Status vs. Targets



Major Project - Fuel Cell Membranes

Importance to goals:

- Fuel cell stack performance and durability depend on membrane properties
- Membranes are a significant contributor to the fuel cell cost
- Membrane limitations add complexity to the fuel cell system

Three Strategies for High-Temperature Membrane Research:

- **Strategy 1 – Phase segregation control** (*polymer & membrane*)

  Polymer - Separate blocks of hydrophobic and hydrophilic functionality incorporated within the same polymer molecule (CWRU, Clemson, GE, Penn State, University of Tennessee, Virginia Tech, University of Central Florida).

- *Membrane* – Two-polymer composites. One polymer provides mechanical strength while the other polymer enables proton conduction (Arkema, CWRU, Fuel Cell Energy, Giner, 3M).

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

  Membranes that use inorganic oxides, heteropolyacids, or ionic liquids, rather than water, for proton conductivity (Arizona State, Colorado School of Mines, Penn State, LBNL).

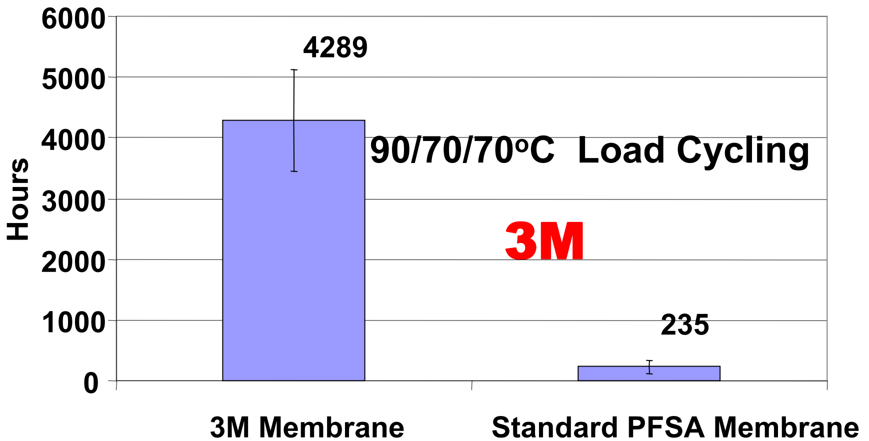
- **Strategy 3 – Hydrophilic additives**

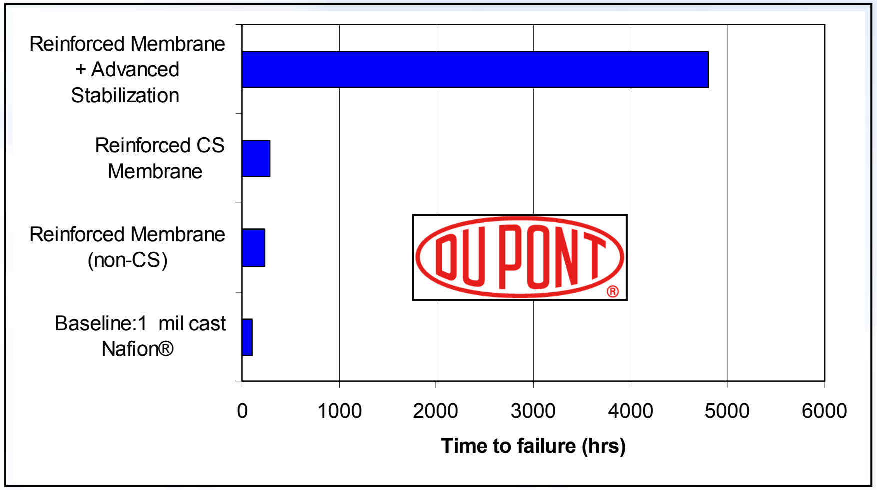
  Membranes with additives that maintain water content and conductivity at higher temperature (CWRU, Fuel Cell Energy, GE, University of Central Florida, 3M).

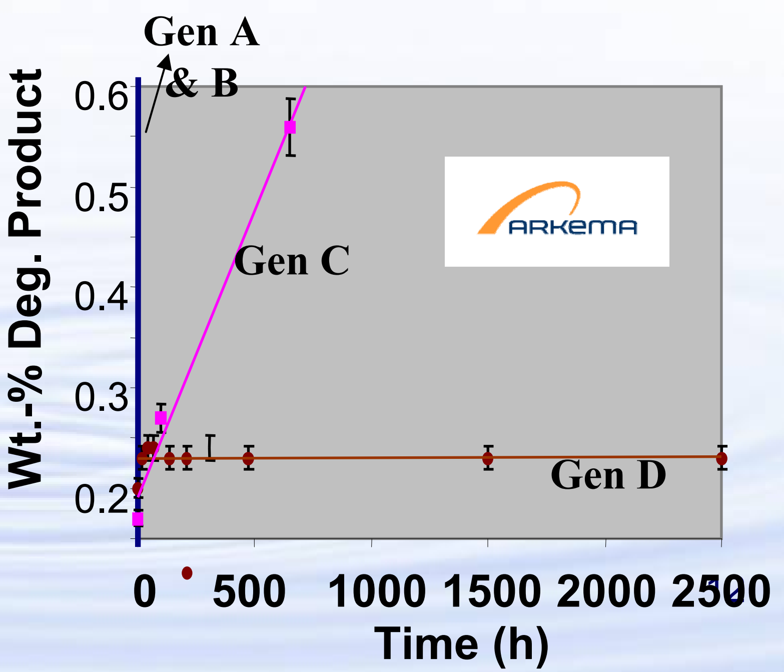
Results: R&D Highlights - Membranes

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



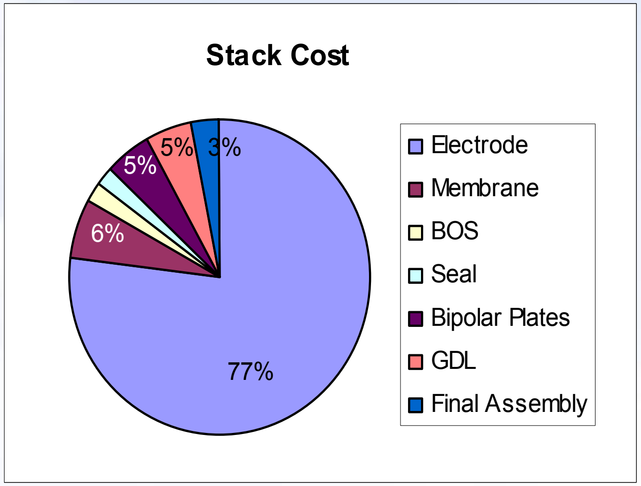




Major Project - Catalysts & Supports

Importance to objectives:

- Platinum cost is ~80% of total stack cost
- Platinum availability is an issue at high loading
- Catalyst durability needs improvement



Four Strategies for Catalysts & Supports R&D:

Strategy 1 – Lower PGM content

Improved Pt catalyst utilization along with durability (Brookhaven, ANL, LANL)

Strategy 2 – Pt alloys

Pt-based alloys that maintain performance compared to Pt and cost less (3M, Cabot, UTC, Brookhaven)

Strategy 3 – Novel support structures

Non-carbon supports and alternative carbon structures (3M, ANL)

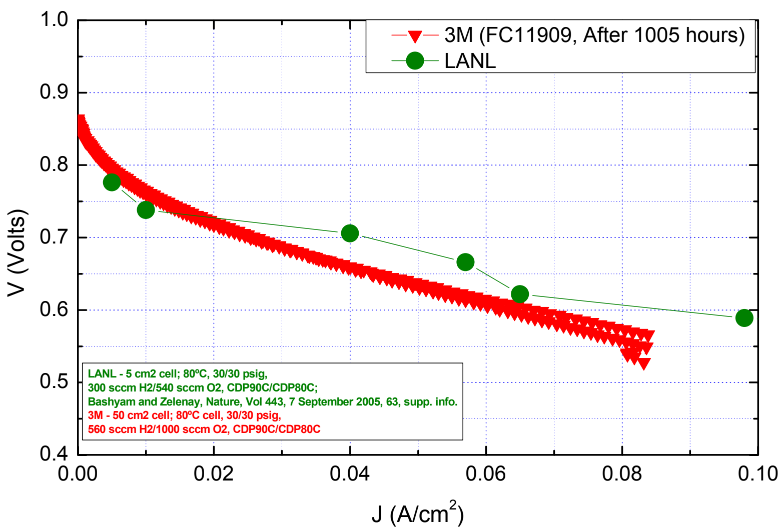
Strategy 4 – Non-Pt catalysts

Non-precious metal catalysts that maintain performance and durability compared to Pt (3M, Los Alamos NL, Ballard, U. of S. Carolina).

Results: R&D Highlights - Catalysts

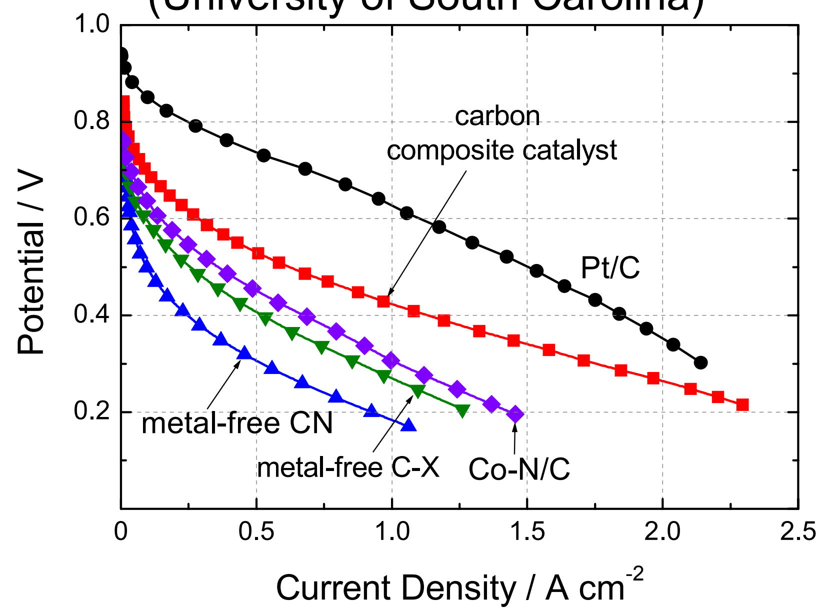
Non-PM Catalysts

- Increased durability of non-PM catalysts, achieved 1,000 h with practically no irreversible degradation losses (3M)



Non-PM Catalysts

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



- ***Anode:** 2 mg/cm² of ETEK 20% Pt/C*
- ***Cathode:** 6 mg/cm² of cathode catalyst*
- ***Membrane:** Nafion® 112*
- ***Operating temperature:** 77°C (H_2); 75 °C (O_2); 75°C (cell)*
- ***Back pressure:** 30 psi (H_2)/40 psi (O_2)*

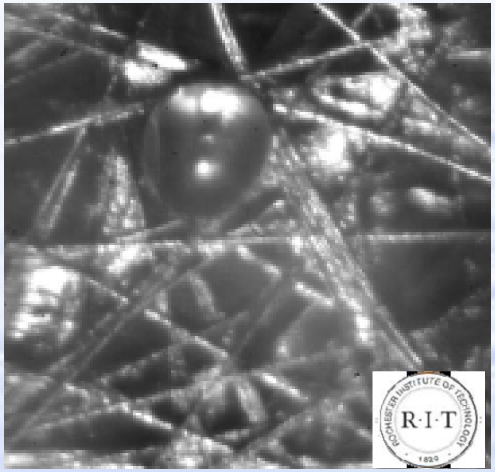
Major Project - Water Transport

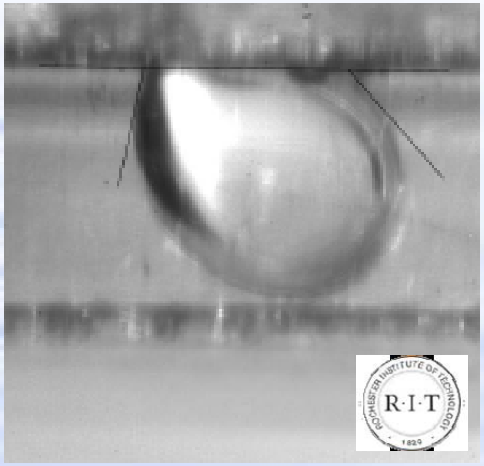
Importance to goals:

- 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:

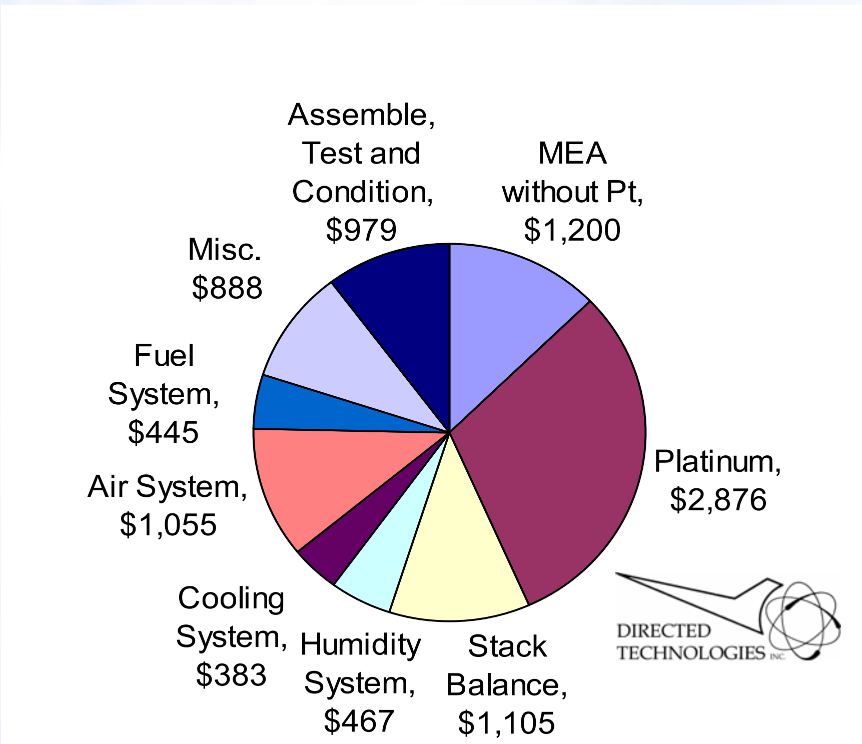
- Optical and neutron imaging of water movement in fuel cells and theoretical modeling (NIST, LANL, CFD Research, Nuvera, RIT, GM, ANL)
- New projects beginning



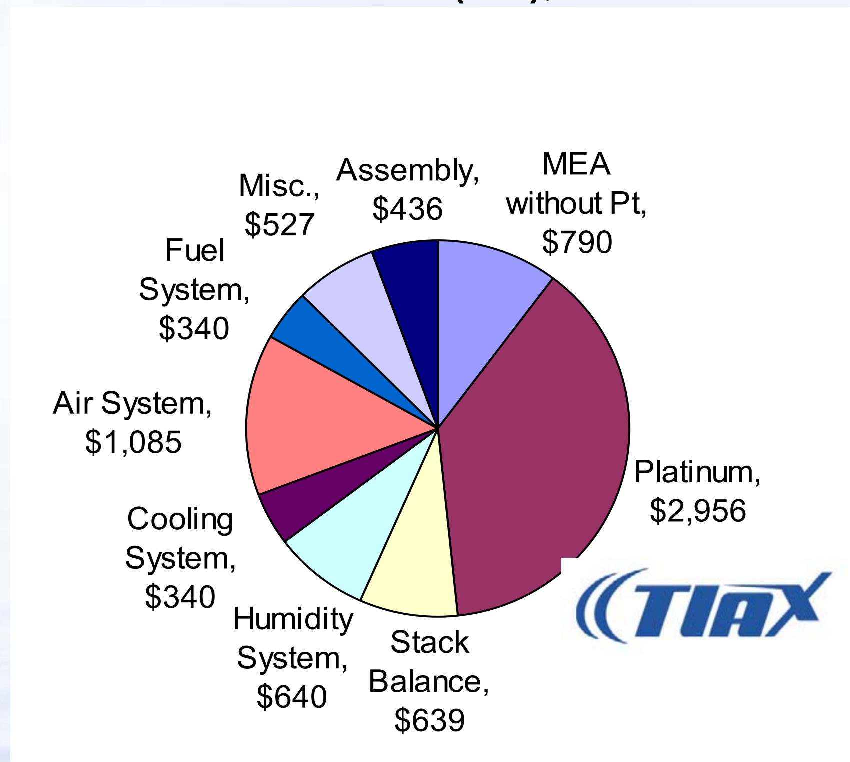


Two High-volume Cost Analyses in 2006 - Directed Technologies and TIAX

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.**

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New Fuel Cell projects from 2006 Solicitation/LabCall

Improved Fuel Cell Membranes

- Semi-interpenetrating networks of PVDF & sulfonated polyelectrolyte (Arkema $6.3M)
- Membranes/MEAs for dry, hot operating conditions (3M - $8.9M)
- New Polyelectrolyte Materials (LBNL- $6M)

Water Transport within the Stack

- Characterization under Freezing Conditions (RIT - $2.7M)
- Subfreezing Start/Stop Protocol (Nuvera - $5.0M)
- Water Transport Exploratory Studies (LANL - $5.5M)
- Modeling, Material Selection, Testing & Optimization (CFD Research - $4.7M)

Catalysts and Supports

- Advanced Cathode Catalysts and Supports (3M - $8.4M)
- Highly Dispersed Alloy Cathode Catalyst for Durability (UTC - $6.4M)
- Non-Platinum Bi-metallic Cathode Electrocatalysts (LANL - $6.8M)
- Alternative and Durable High Performance Cathode (ANL - $5.4M)
- Supports for PEM Fuel Cells (PNNL - $4.6M)

New Fuel Cell Projects (Continued)

Cell Hardware

- Next Gen. Bipolar Plates for Automotive PEMFCs (GrafTech - $2.3M)
- Nitrided Metallic Bipolar Plates (ORNL - $4.5M)
- Low Cost, Durable Seals (UTC - $2.0M)

Innovative Fuel Cell Concepts

- Adaptive Stack with Subdivided Cells (Plug Power - $1.0M)
- Light-weight, Low-cost PEM Fuel Cell Stacks (CWRU - $0.8M)
- Low-Cost, Microchannel Humidification Systems (PNNL - $1.0M)
- Stack Using Patterned, Aligned Carbon Nanotubes as Electrodes (ANL - $1.0M)

Effects of Impurities on Fuel Cell Performance and Durability

- University of Connecticut - $1.9M
- Clemson University - $2.0M
- Los Alamos National Laboratory (LANL - $3.6M)

Stationary Fuel Cell Demonstration

- International: Combined Heat & Power Unit (Intelligent Energy - $2.2M)
- IPHE: Development & Demo of High Efficiency (Plug Power - $3.6M)
- Intergovernmental: Stationary Fuel Cell System Demo (Plug Power - $4.0M)

2010-2015 Research Goals

Performance

- Develop membranes and catalysts that operate at high temperature (120ºC) with little or no humidification
- Develop water management strategies that prevent the membrane from either flooding or dehydrating
- Develop materials and strategies that enable start-up from -40ºC

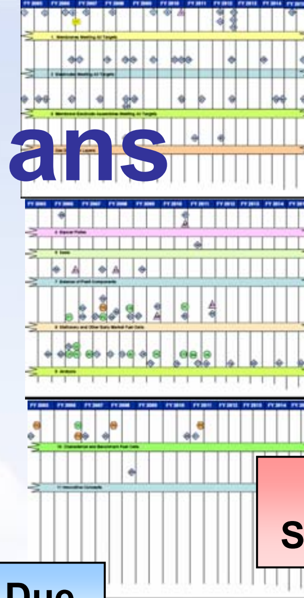
Durability

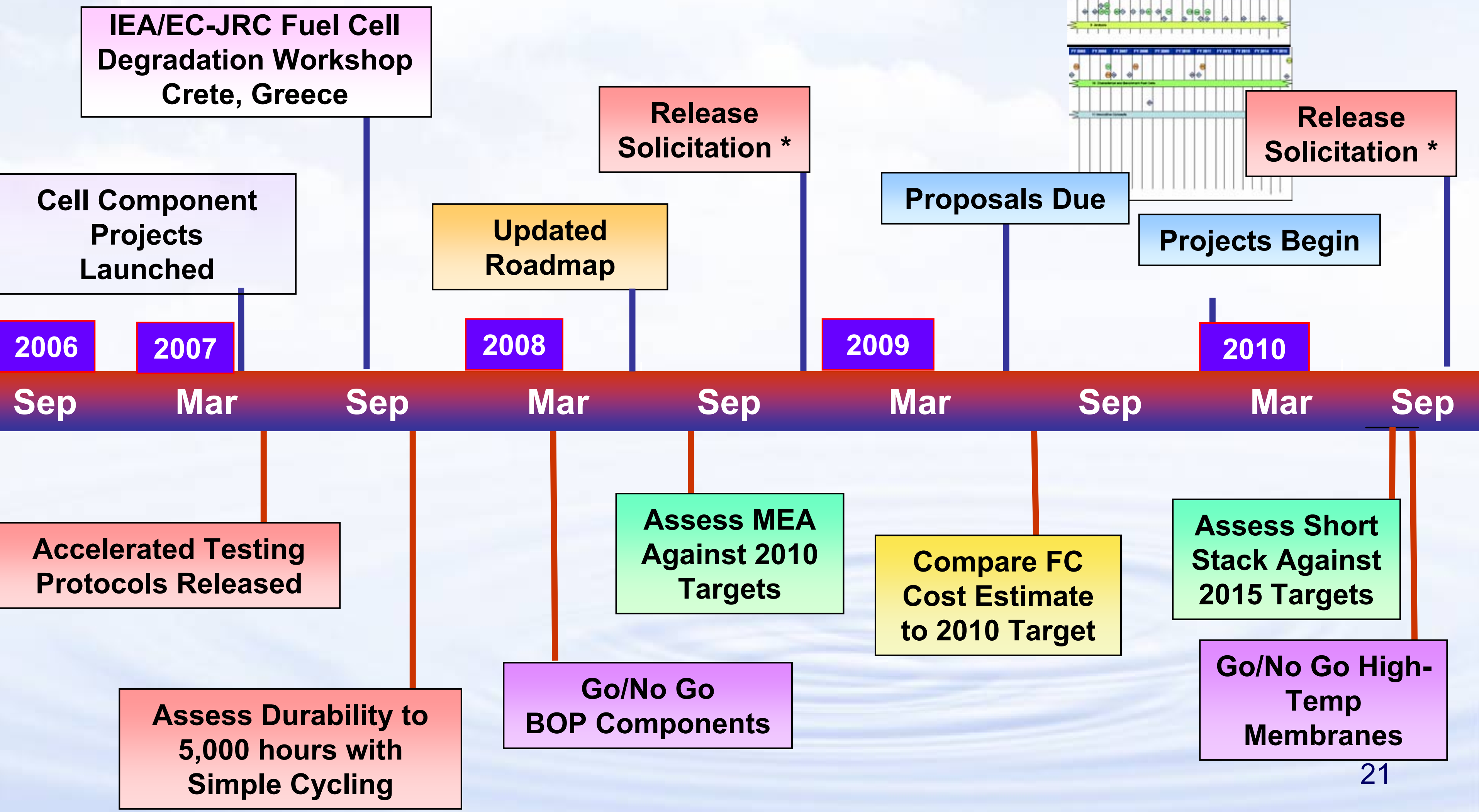
- Develop stable catalyst supports that do not corrode during fuel cell operation
- Develop membranes and catalysts that withstand the chemical and mechanical stresses of fuel cell operation
- Quantify effects of impurities on fuel cell performance, develop mitigation strategies, and establish H_2/air(?) purity requirements for fuel cells

Cost

- Develop high performance precious and non-precious metal catalysts that meet catalyst loading targets (0.3 mg Pt/cm^2: 2010; 0.2 mg Pt/cm^2:2015)
- Investigate non-traditional stack and system designs that enable the use of less expensive materials and components

Fuel Cells – Future Plans





*Subject to appropriations

For More Information

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