

# Highlighting the U.S. Department of Energy's Efforts in Promoting Fuel Cell Technologies: Current Developments and Future Prospects

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*U.S. Department of Energy Fuel Cell Technologies Program*

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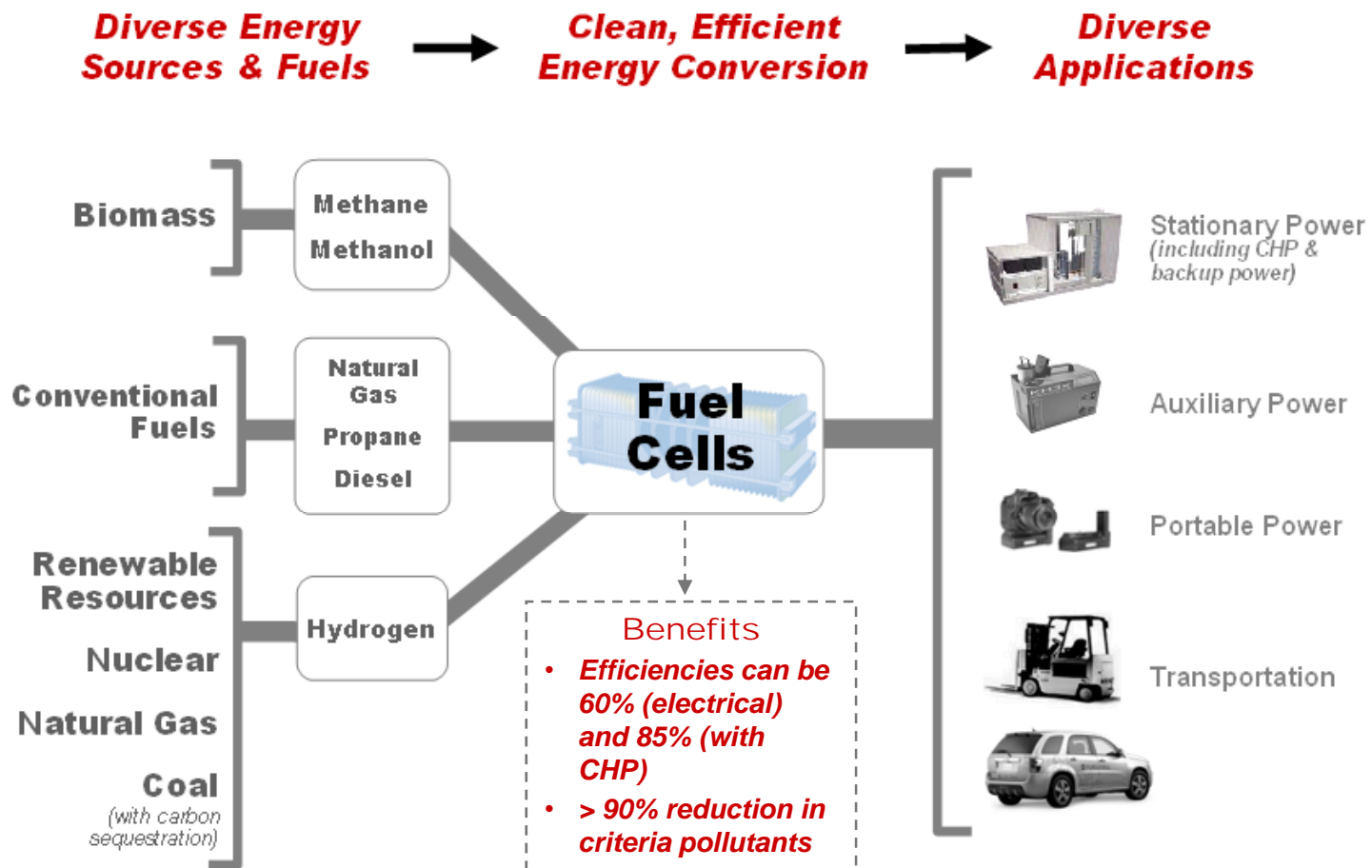
# Fuel Cells: Addressing Energy Challenges

Energy Efficiency and Resource Diversity

→ **Fuel cells offer a highly efficient way to use diverse fuels and energy sources.**

Greenhouse Gas Emissions and Air Pollution:

→ **Fuel cells can be powered by emissions-free fuels that are produced from clean, domestic resources.**



# Program Goals and Barriers

*The Program's overarching goal is to enable the widespread commercialization of hydrogen and fuel cell technologies.*

**Technology Barriers**

### Fuel Cell Cost & Durability

	Status:	Targets:
<b>Stationary Systems:</b>	~\$3,500/kW	\$750/kW
	20,000 hr	40,000-hr durability
<b>Vehicles:</b>	\$61/kW	\$30/kW
	2,000 hr	5,000-hr durability

### Cost of H<sub>2</sub> Production & Delivery (cost is untaxed and delivered)

	Status:	Targets:
<b>Production:</b>	\$3 - \$12/gge	\$2 - 3/gge
<b>Delivery:</b>	\$2.30 - 3.30/gge	<\$1/gge

gge = gallon gasoline equivalent

### Capacity & Cost of H<sub>2</sub> Storage

(>300 mile range)	Status:	Targets:
<b>Volumetric</b>	15 - 50 g/L	70 g/L
<b>Gravimetric</b>	3.0 - 6.5 wt%	7.5 wt%
<b>Cost</b>	\$15 - 23/kWh	\$2/kWh

### Technology Validation:

*Technologies must be demonstrated under real-world conditions.*

*e.g., 140 vehicles & 20 stations demonstrated with GM, Ford, Daimler/Chrysler, Hyundai*

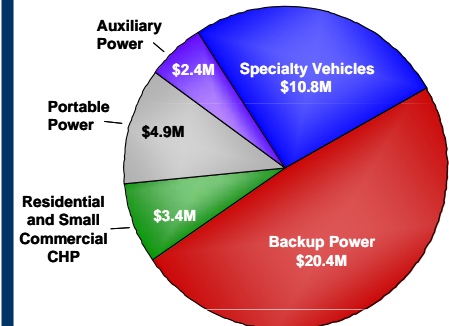
*>2.2 million miles, 90,000 kg dispensed; 53-58% efficiency; up to 254 mile range demonstrated.*

**Economic & Institutional Barriers**

- Safety, Codes & Standards Development
- Domestic Manufacturing & Supplier Base
- Public Awareness & Acceptance
- Investment in Delivery Infrastructure

COMPANY	AWARD
Anheuser-Busch	\$1.1 M
Delphi Automotive	\$2.4 M
FedEx	\$1.3 M
GENCO	\$6.1 M
Jadoo Power	\$1.8 M
MTI MicroFuel Cells	\$2.4 M
Nuvera Fuel Cells	\$1.1 M
Plug Power	\$3.4 M
Plug Power	\$2.7 M
PolyFuel	\$2.5 M
ReliOn (inc. AT&T)	\$8.6 M
Sprint Comm.	\$7.3 M
Sysco of Houston	\$1.2 M

## Market Transformation



**Recovery Act enables up to 1,000 fuel cell systems for early markets (\$42M)**

NOTE: All costs are projected to high-volume manufacturing and production.

# Fuel Cells — *Where are we today?*

## Fuel Cells for Stationary Power, Auxiliary Power, and Specialty Vehicles

The largest markets for fuel cells today are in stationary power, portable power, auxiliary power units, and forklifts.

~52,000 fuel cells have been shipped worldwide.

~18,000 fuel cells were shipped in 2008 (> 50% increase over 2007).

*Fuel cells can be a cost-competitive option for critical-load facilities, backup power, and forklifts.*



For more details, see Tuesday LRD24 PEMFC session, 4:30-5:00pm

Donna Ho, "The U.S. Department of Energy's Activities in Stationary, APU and Portable Power Fuel Cells"

## Fuel Cells for Transportation

In the U.S., there are currently:

> 200 fuel cell vehicles

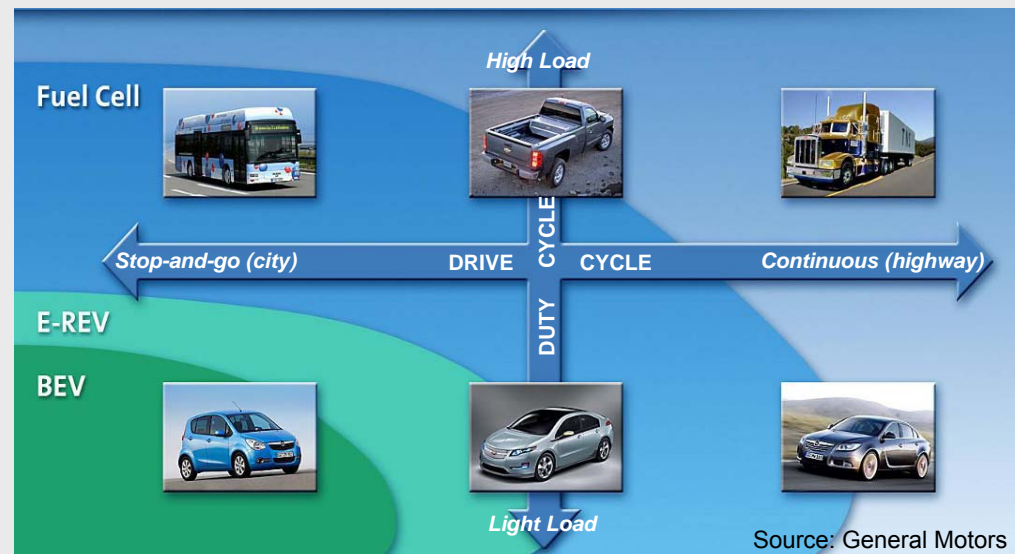
> 20 fuel cell buses

~ 60 fueling stations

A variety of technologies—including fuel cell vehicles, extended-range electric vehicles (or "plug-in hybrids"), and all-battery powered vehicles—will be needed to meet our diverse transportation needs.

The most appropriate technology depends on the drive cycle and duty cycle of the application.

Several manufacturers have announced commercialization plans.



Source: General Motors

# Fuel Cells — Worldwide Interest & Investment

Interest in fuel cells and hydrogen is global, with more than \$1 billion in public investment in RD&D annually, and 17 members of the International Partnership for the Hydrogen Economy (IPHE).



U.S.A.

**RD&D Funding:**

~\$500 M (FY09, total)  
~\$270 M (FY09, DOE)

**Deployments/Demonstrations:**

~ 2,000 stationary fuel cells  
~ 60 fueling stations  
> 200 fuel cell vehicles  
> 20 fuel cell buses



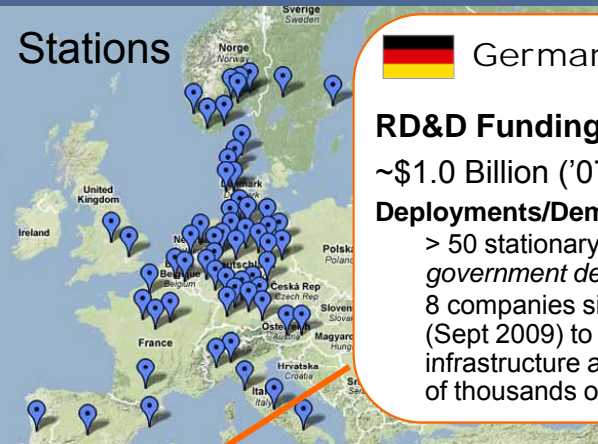
European Union

**RD&D Funding:**

>\$600 M ('08 – '13)

*Fuel Cell and Hydrogen Joint Technology Initiative: 50/50 cost-shared with industry.*

**Stations**



Germany

**RD&D Funding:**

~\$1.0 Billion ('07 – '16)

**Deployments/Demonstrations:**

> 50 stationary fuel cells in government demonstrations  
8 companies signed MOU (Sept 2009) to launch infrastructure and hundreds of thousands of vehicles



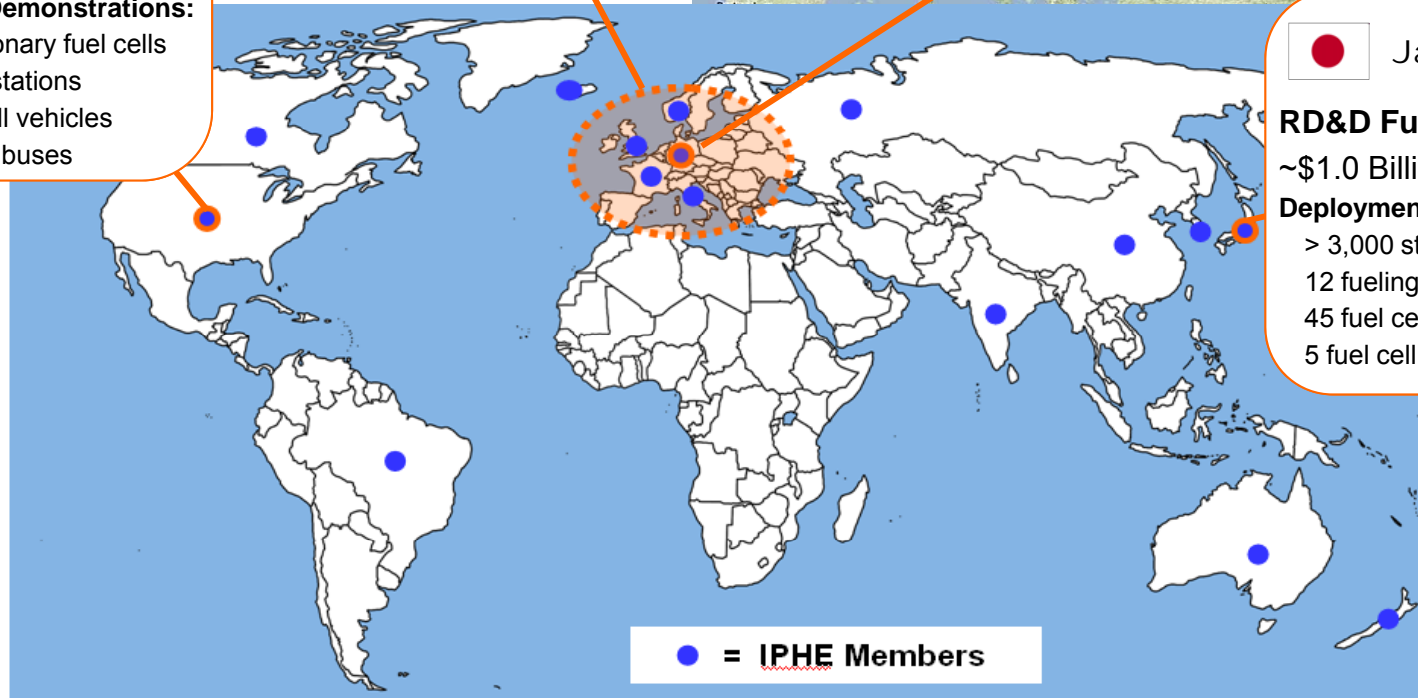
Japan

**RD&D Funding:**

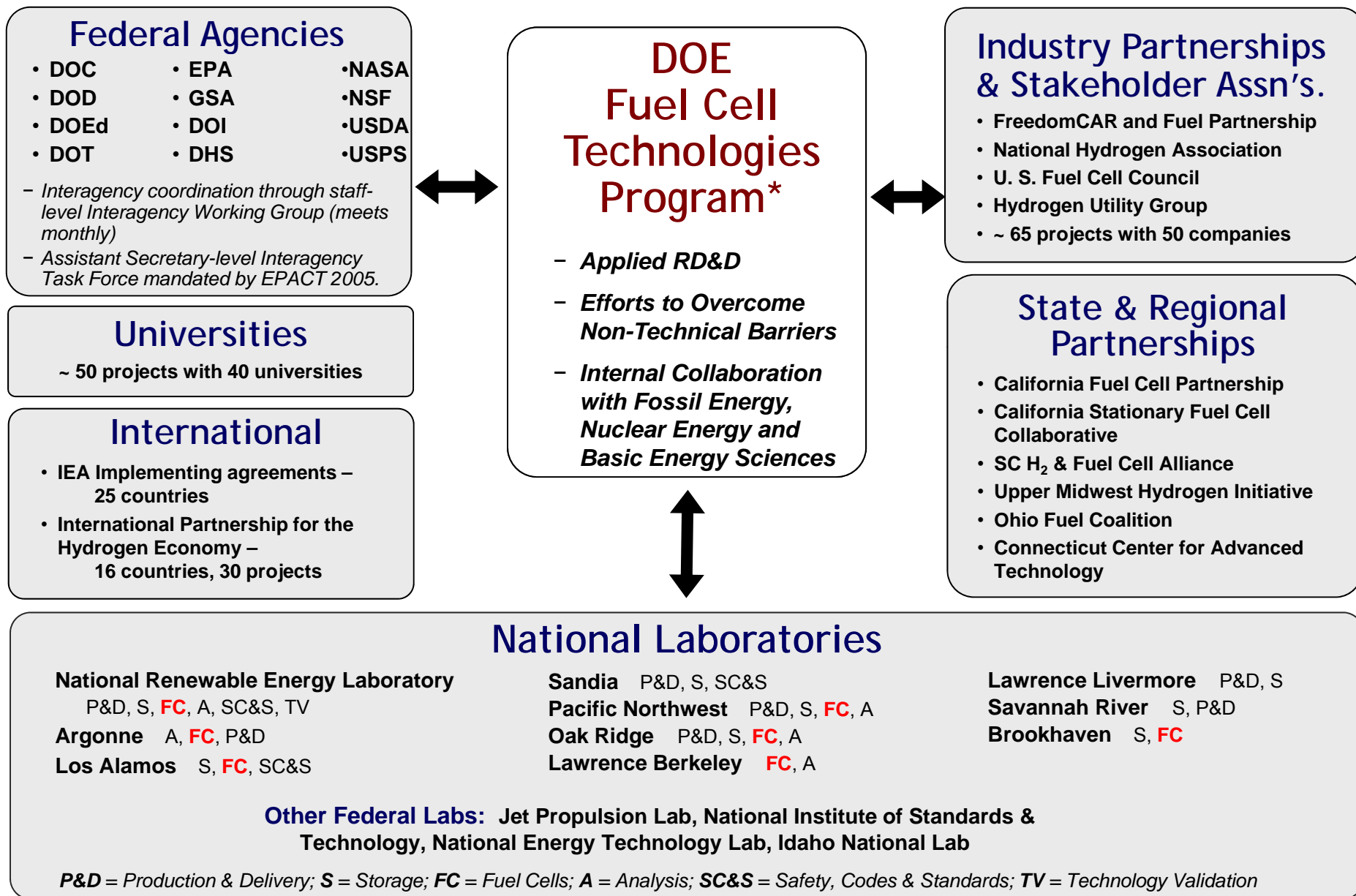
~\$1.0 Billion ('08 – '12)

**Deployments/Demonstrations:**

> 3,000 stationary fuel cells  
12 fueling stations  
45 fuel cell vehicles  
5 fuel cell buses



# Collaborations



\* Office of Energy Efficiency and Renewable Energy

## U.S. PARTNERSHIPS

- **FreedomCAR & Fuel Partnership:** *Ford, GM, Chrysler, BP, Chevron, ConocoPhillips, ExxonMobil, Shell, Southern California Edison, DTE Energy*
- **Hydrogen Utility Group:** *Xcel Energy, Sempra, DTE, Entergy, New York Power Authority, Sacramento Municipal Utility District, Nebraska Public Power Authority, Southern Cal Edison, Arizona Public Service Company, Southern Company, Connexus Energy, etc.*
- **State/Local Governments:** *California Fuel Cell Partnership, California Stationary Fuel Cell Collaborative*
- **Industry Associations:** *US Fuel Cell Council, National Hydrogen Association*

## INTERNATIONAL PARTNERSHIPS



**International Partnership for the Hydrogen Economy—  
*partnership among 16 countries and the European Commission***



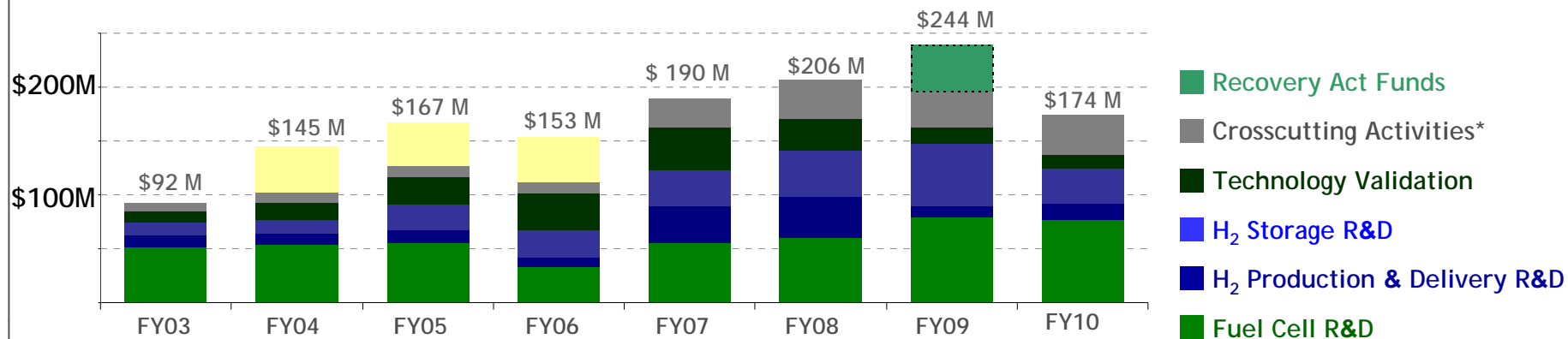
**International Energy Agency — Implementing Agreements**

- *Hydrogen Implementing Agreement — 21 countries and the European Commission*
- *Advanced Fuel Cells Implementing Agreement — 19 countries*

# Funding History for Fuel Cells

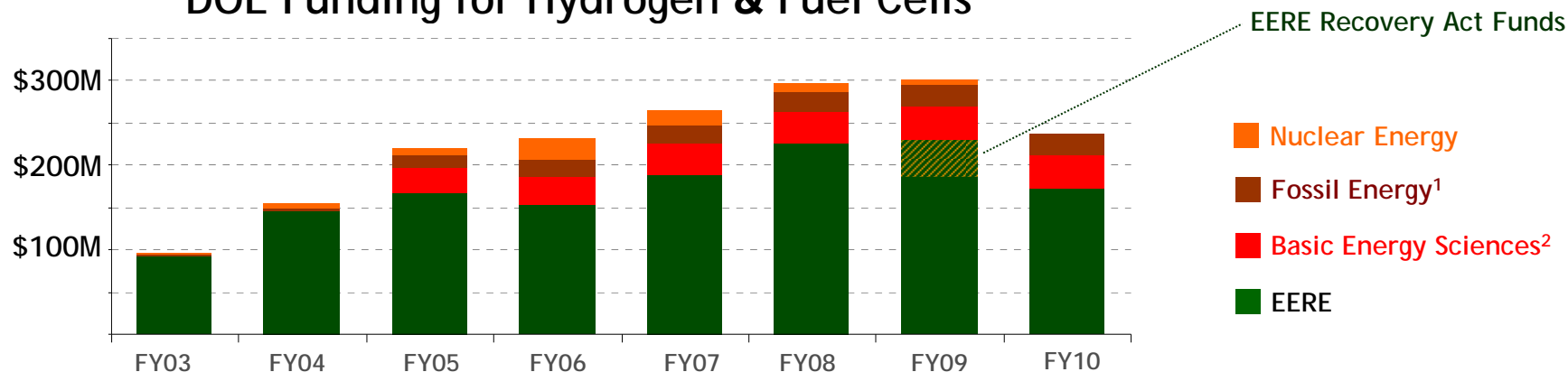
## EERE Funding for Hydrogen & Fuel Cells

▨ = Congressionally Directed Activities



\*Crosscutting activities include Safety, Codes & Standards; Education; Systems Analysis; Manufacturing R&D; and Market Transformation.

## DOE Funding for Hydrogen & Fuel Cells



<sup>1</sup> Fossil Energy (FE) funding in FY10 includes coal to hydrogen and other fuels; FE also plans \$50M for SECA in FY10.

<sup>2</sup> Exact funding for hydrogen- and fuel cell-related projects in Basic Energy Sciences to be determined. The Office of Science also plans ~\$14M for hydrogen production research in the Office of Biological and Environmental Research in FY10.

## EERE Hydrogen and Fuel Cells Budget *(in thousands)*

<i>Key Activity</i>	<b>FY 2007</b>	<b>FY 2008</b>	<b>FY 2009</b>	<b>FY 2010</b>
Hydrogen Production & Delivery R&D	33,702	38,607	10,000	15,000
Hydrogen Storage R&D	33,728	42,371	59,200	32,000
Fuel Cell Stack Component R&D	37,100	42,344	62,700	62,700
Technology Validation	39,413	29,612	14,789*	13,097
Transportation Systems R&D	7,324	7,718	6,600	3,201
Distributed Energy Systems R&D	7,257	7,461	10,000	11,410
Fuel Processor R&D	3,952	2,896	3,000	171
Safety, Codes & Standards	13,492	15,442	12,500*	8,839
Education	1,978	3,865	4,200*	2,000
Systems Analysis	9,637	11,099	7,713	5,556
Manufacturing R&D	1,928	4,826	5,000	5,000
Market Transformation	0	0	4,747	15,026
<b>Total</b>	<b>\$189,511**</b>	<b>\$206,241**</b>	<b>\$200,449</b>	<b>\$174,000</b>

\* Under Vehicle Technologies Budget in FY 2009

\*\* FY07 and FY08 numbers exclude SBIR/STTR funding

# Hydrogen & Fuel Cells Budgets: *FY07 – FY10*

	Funding (\$ in thousands)						
	FY 2004 Approp.	FY 2005 Approp.	FY 2006 Approp.	FY 2007 Approp.	FY 2008 Approp.	FY 2009 Approp.	FY 2010 Approp.
<b>EERE Hydrogen</b>	144,881	166,772	153,451	189,511	206,241	200,449	174,000
<b>Fossil Energy (FE)</b>	4,879	16,518	21,036	21,513	24,088	20,000 <sup>1</sup>	~25,000 <sup>1,2</sup>
<b>Nuclear Energy (NE)</b>	6,201	8,682	24,057	18,855	9,668	7,500	0
<b>Science (SC)</b>	0	29,183	32,500	36,388	36,484	38,284	~38,284 <sup>3</sup>
<b>DOE TOTAL</b>	<b>155,961</b>	<b>221,155</b>	<b>231,044</b>	<b>266,267</b>	<b>276,481</b>	<b>266,233</b>	<b>~237,284</b>

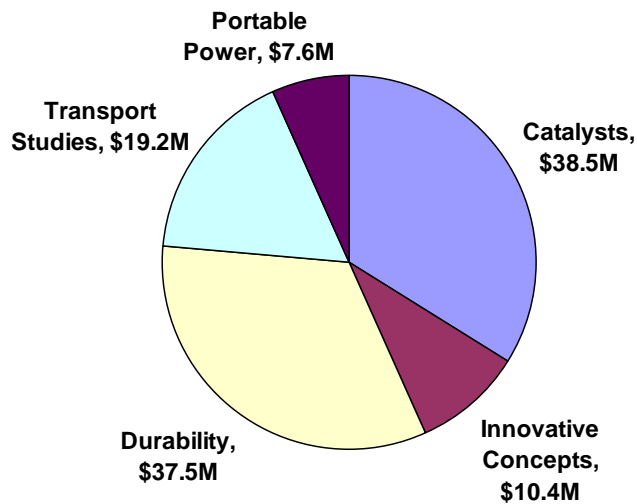
<sup>1</sup> Does not include funding for program direction.

<sup>2</sup> Includes coal to hydrogen and other fuels. Fossil Energy also plans \$50M for SECA in FY10.

<sup>3</sup> Exact funding for hydrogen- and fuel cell-related projects to be determined. The Office of Science also plans ~\$14M for hydrogen production research in the Office of Biological and Environmental Research in FY10.

# New Fuel Cell Projects

*28 innovative R&D projects kicked off, \$113M in DOE funding*



## *New projects will:*

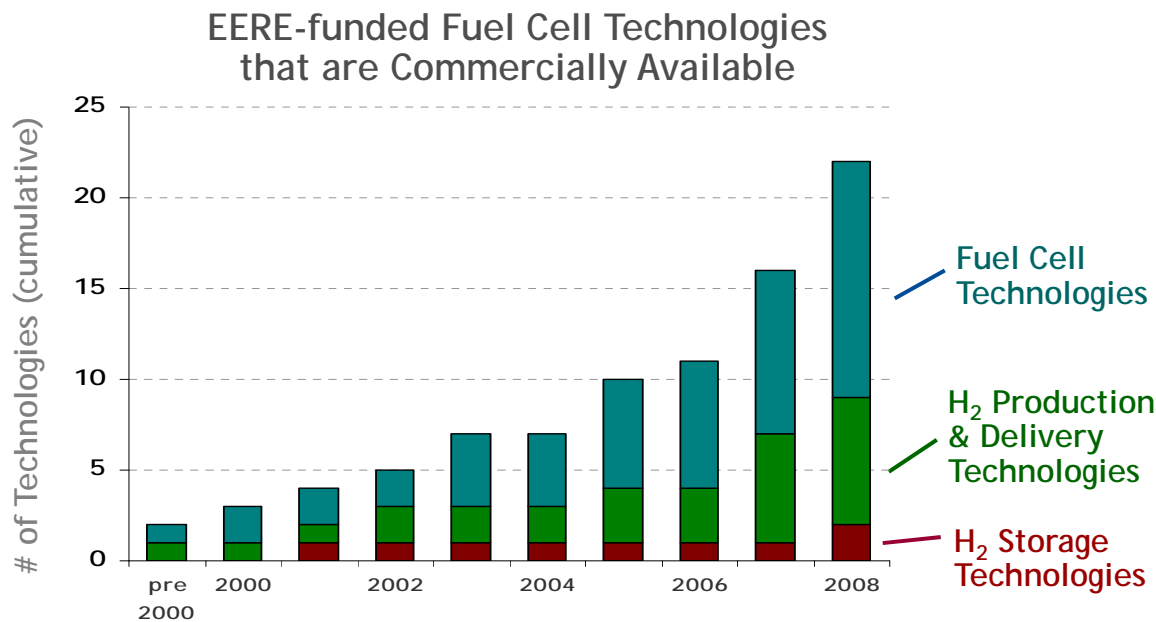
- Develop improved fuel cell catalysts
- Enhance fuel cell durability
- Characterize transport phenomena
- Optimize fuel cells for early market applications
- Develop innovative concepts leading to a new generation of fuel cell technology

## 55 participating organizations:

3M	Indiana University – Purdue University Indianapolis	Queen's University
Argonne National Lab	Ion Power	Sandia National Lab
Arkema	Jet Propulsion Lab	Southern Illinois University
Ballard Power Systems	Johnson Matthey Fuel Cells	Stanford University
Brookhaven National Lab	Lawrence Berkeley National Lab	SUNY Albany
Brown University	Los Alamos National Lab	SUNY Stony Brook
Case Western Reserve University	Massachusetts Institute of Technology	Tech-Etch Inc
Colorado School of Mines	Michigan Technological University	TreadStone Technologies
Dalhousie University	National Renewable Energy Laboratory	United Technologies Research Center
dpoint Technologies	Northeastern University	University of CA Riverside
Engineered Fibers Technology	Nuvera Fuel Cells	University of Connecticut
Gas Technology Institute	Oak Ridge National Lab	University of Hawaii
General Motors Corporation	Orion Industries	University of New Mexico
Georgia Institute of Technology	Penn State University	University of South Carolina
Giner Electrochemical Systems	Plug Power	University of Texas Austin
Hawaii Natural Energy Institute	PolyFuel	University of Wisconsin Madison
IBIS Associates	QuantumSphere	UTC Power
Illinois Institute of Technology		Versa Power Systems
		Virginia Tech
		W. L. Gore & Associates

***We are tracking the commercial success  
of technologies developed by the Program.***

Accelerating Commercialization:  
**An increasing number of EERE-funded fuel  
cell technologies have been entering the  
market.**



PATENTS resulting from  
EERE-funded R&D:

**118 patents reviewed:**

- 60 fuel cell patents
- 37 hydrogen production/delivery patents
- 21 storage patents

Results will be documented  
in a report by Pacific  
Northwest National Lab:

**“Pathways to Commercial  
Success: Technologies and  
Products Supported by the  
Hydrogen, Fuel Cells and  
Infrastructure Technologies  
Program”**

# Fuel Cell R&D — Progress

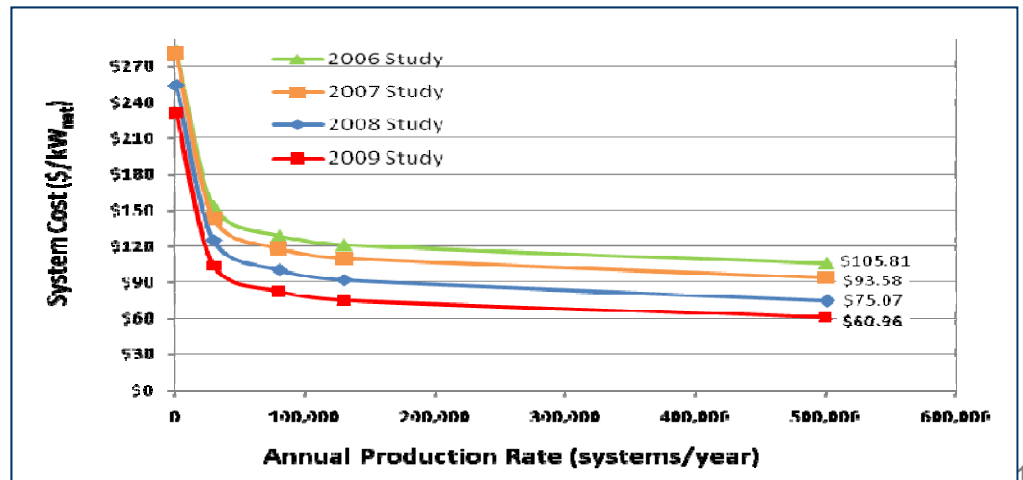
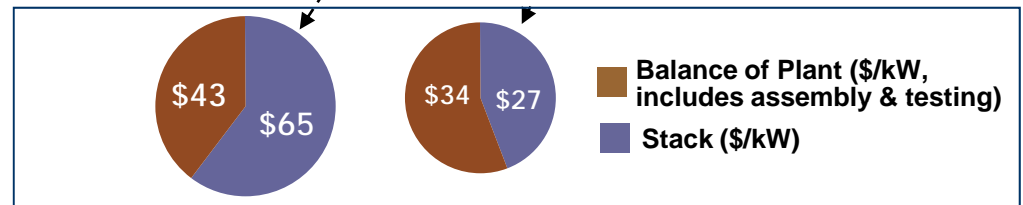
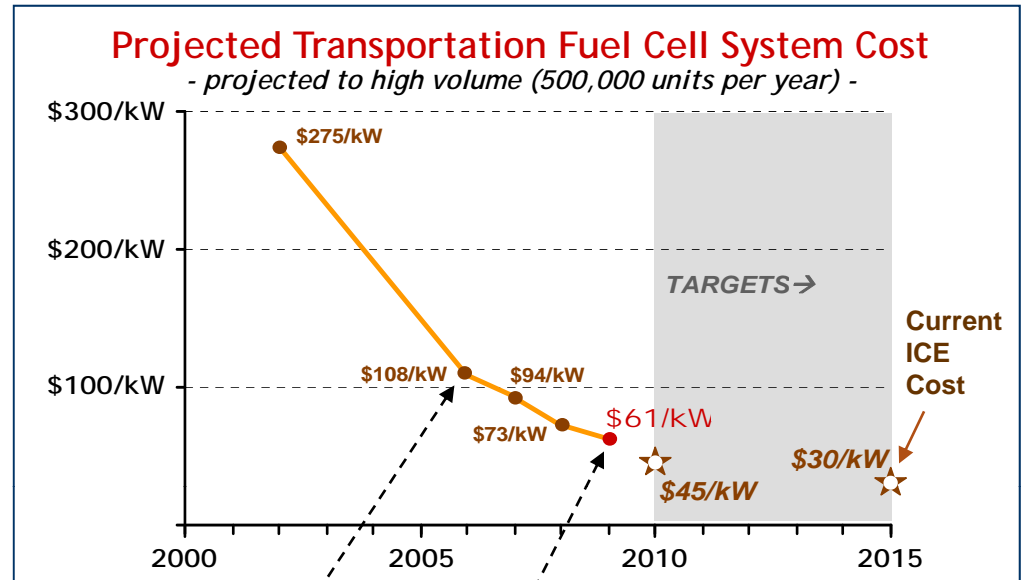
We've reduced the cost of fuel cells to \$61/kW\*

- **More than 35% reduction in the last two years**
- **More than 75% 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.

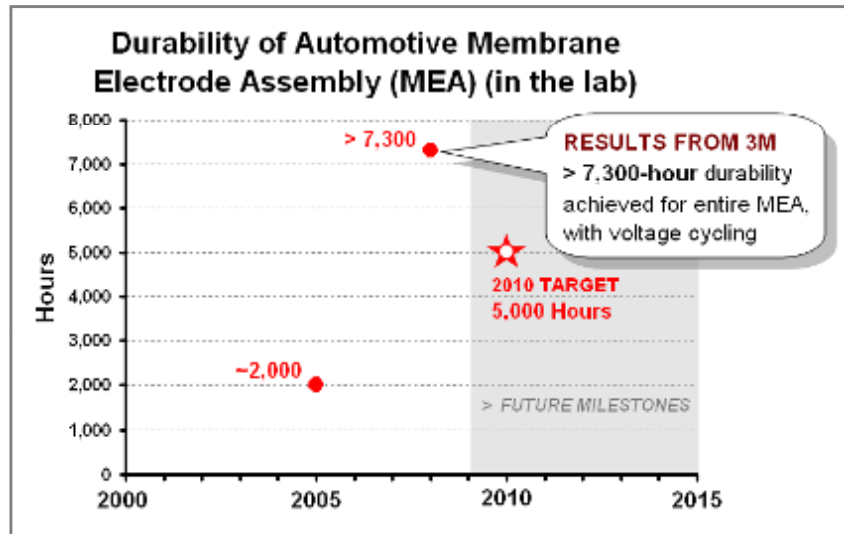
\*Based on projection to high-volume manufacturing (500,000 units/year). Breakdown by DTI, Inc.

\*\*Panel found \$60 – \$80/kW to be a “valid estimate”:  
[http://hydrogenodev.nrel.gov/peer\\_reviews.html](http://hydrogenodev.nrel.gov/peer_reviews.html)



# Major Technology Pathways: Status of Fuel Cells

*In addition to reducing cost, we've also demonstrated durability of greater than 7,300 hours in a single cell.*



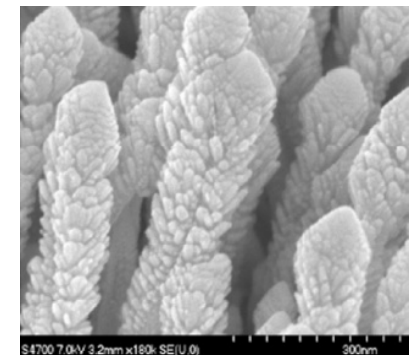
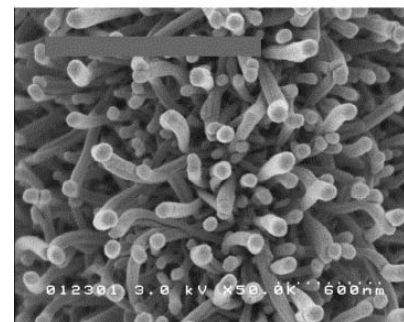
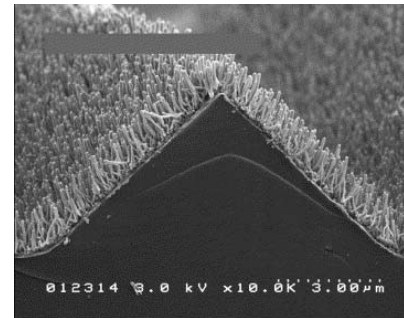
➔ 3M has also demonstrated 5,000 hour durability while simultaneously meeting the platinum loading target.

- Key improvements enabled by using novel organic crystalline whisker catalyst supports and Pt-alloy whiskerettes.
- There are ~ 5 billion whiskers/cm<sup>2</sup>.
- Whiskers are ~ 25 X 50 X 1000 nm.

From 2008 to 2009, key cost reductions were made by:

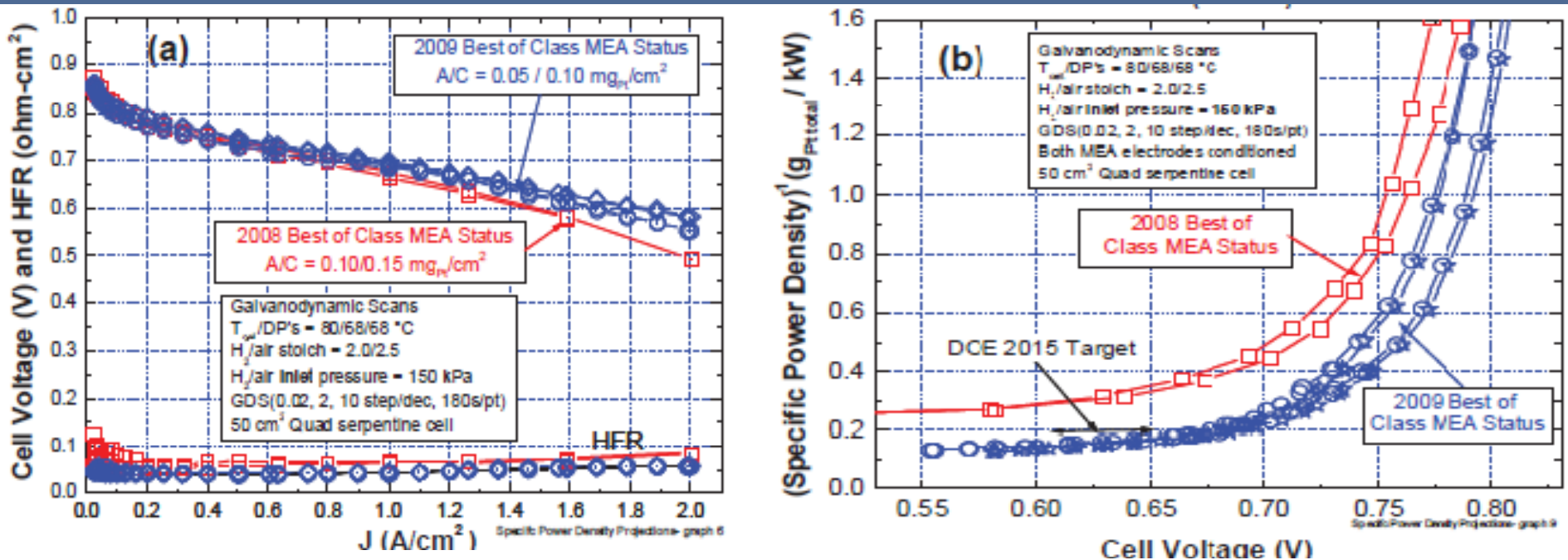
- Reducing platinum group metal content from 0.35 to 0.18 g/kW
- Increasing power density from 715 to 833 mW/cm<sup>2</sup>

➔ These advances resulted in a \$12.00/kW cost reduction.



Whiskerettes: 6 nm x 20 nm

## Platinum Loading Targets Achieved with NSTF-Containing MEA – 3M

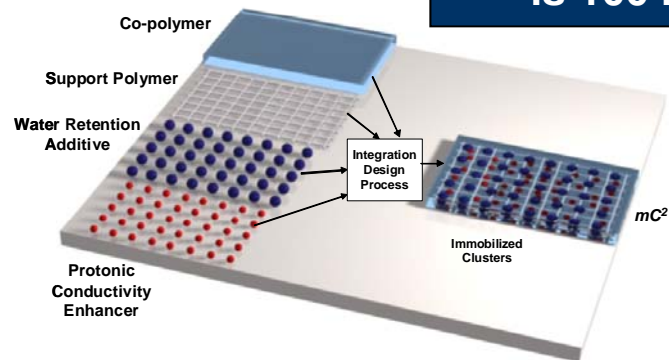


Both graphs highlight a comparison of 2008 and 2009 galvanodynamic polarization curves showing improved performance at lower PGM loading.

- 3M has achieved the Platinum Group Metal (PGM) loading (0.2 mg PGM/cm<sup>2</sup>) and the specific power density (0.2 g PGM/kW) targets in 50cm<sup>2</sup> single cells and stacks
- 3M improved cell performance with reduced Pt loading by
  - improving mass transport to the catalyst at high current density and by reducing membrane thickness
  - nano structured thin film (NSTF) PtCoMn ternary alloy on both the anode and cathode sides of a 3M PEM
- NSTF MEA lifetime of more than 7300 hours demonstrated. This result exceeds the 5000 hour durability target (*though demonstrated in a single cell, not a stack*)

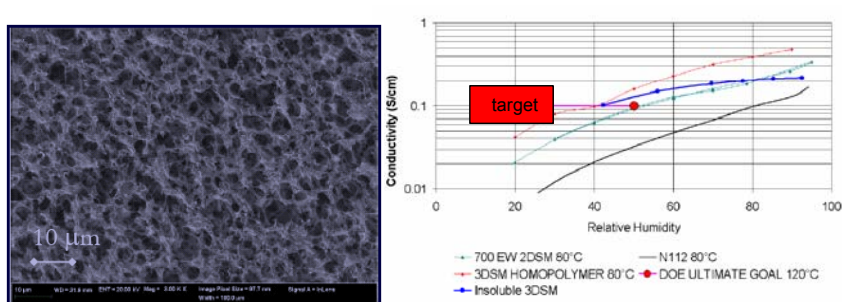
## Membrane Conductivity Interim Target Met By Case Western, Colorado School of Mines, Fuel Cell Energy, Giner, & Vanderbilt University

**2009 High-Temperature Membrane Target is 100 mS/cm at 120 °C and 50% RH**



**Fuel Cell Energy (FCE) Multi-Component System with Functionalized Additives**

- **FCE** co-polymer is an advanced perfluorinated sulfonic acid with significantly (~3X) higher conductivity than state-of-the-art polymers
- Conductivity enhancer is designed to provide an alternate conduction pathway, especially at extreme temperatures
- Durability testing of the composite has not been initiated so the need for a support structure has not been established



**Giner Electrochemical Systems (GES) Filled Polymer Matrix Dimensionally Stable Membrane**

- **GES** Dimensionally Stable Membrane (DSM) swells only in thickness direction
  - 700 EW DSM passes DOE mechanical durability (RH cycling) tests
- Key Remaining Challenges:
- Thinner membranes needed to meet area-specific resistance targets
- Lower EW ionomers needed to meet 120°C, low RH targets

*Targets are continually assessed and refined.*

Recent Request for Information (RFI) on **proposed technical and cost targets for fuel cells for combined heat and power and auxiliary power applications** generated responses from 18 entities, including a variety of industrial and government laboratory representatives.

Based on responses, a **revised set of targets has been prepared** that will appear in final form in the next revision of the Fuel Cell Technologies program Multi-Year Research, Development and Demonstration Plan, which is due to be released in 2010.

Technical Targets: 1 – 10 kW<sub>e</sub> Fuel Cell **Auxiliary Power Units** Operating on Standard Ultra-low Sulfur Diesel Fuel

	2008 Status	2012	2015	2020
Electrical efficiency at rated power <sup>[1]</sup>	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 <sup>[2]</sup>	\$750/kW	\$700/kW	\$600/kW	\$500/kW
Transient response (10 - 90% rated power)		4 min	3 min	2 min
Start-up time from 20°C ambient temperature	50 min	30 min	10 min	5 min
Degradation with cycling <sup>[3]</sup>	2.6%/1000 h	2%/1000 h	1.3%/1000 h	1%/1000 h
Operating lifetime <sup>[4]</sup>	~3000 h	10,000 h	15,000 h	20,000 h
System availability	97%	97.5%	98%	99%

<sup>[1]</sup> Regulated DC net/LHV of fuel.

<sup>[2]</sup> Cost 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 (250 MW in 5-kW modules).

<sup>[3]</sup> Based on operating cycle to be released in 2010.

<sup>[4]</sup> Time until >20% net power degradation

*Targets are continually assessed and refined.*

Technical Targets: 1 – 10 kW<sub>e</sub> Residential **Combined Heat and Power** Fuel Cells Operating on Natural Gas<sup>[1]</sup>

	2008 Status	2012	2015	2020
Electrical effi. at rated power <sup>[2]</sup>	34%	40%	42.5%	45%
CHP energy efficiency <sup>[3]</sup>	80%	85%	87.5%	90%
Factory Cost <sup>[4]</sup>	\$750/kW	\$650/kW	\$550/kW	\$450/kW
Transient response (10 - 90% rated power)	5 min	4 min	3 min	2 min
Start-up time from 20°C ambient temperature	60 min	45 min	30 min	20 min
Degradation with cycling <sup>[5]</sup>	< 2%/1000 h	0.7%/1000 h	0.5%/1000 h	0.3%/1000 h
Operating lifetime <sup>[6]</sup>		30,000 h	40,000 h	60,000 h
System availability	97%	97.5%	98%	99%

<sup>[1]</sup> Standard utility natural gas delivered at typical residential distribution line pressures

<sup>[2]</sup> Regulated AC net/LHV of fuel.

<sup>[3]</sup> Only heat available at 80 °C or higher is included in CHP energy efficiency calculation.

<sup>[4]</sup> Cost 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 (250 MW in 5-kW modules).

<sup>[5]</sup> Based on operating cycle to be released in 2010.

<sup>[6]</sup> Time until >20% net power degradation.

**See also Tuesday LRD24 PEMFC session, 4:30-5:00pm**

**Donna Ho, “The U.S. Department of Energy’s Activities in Stationary, APU and Portable Power Fuel Cells”**

- Discusses worldwide trends in units shipped and financing in 2007
- Identifies trends for each major application area
- Focuses on North American and U.S. markets
- Update to be released in December 2009



<http://www.nrel.gov/docs/fy09osti/46023.pdf>

## ***Joint DOE Fuel Cell Technologies / Fossil Energy MCFC/PAFC Workshop*** (held yesterday)

- Targeted R&D needs for technologies and FC stacks for enhanced performance, lower cost and improved durability
- Results expected to be published in January 2010

## ***RFI on R&D Needs*** (Potential pre-solicitation meeting Jan/Feb 2010)

- **Balance of Plant Component Development**

(Transportation Systems, Stationary Systems, Fuel Processors for Stationary Systems)

- **Stack Component Integration**

(Integration of Components into Stacks, Integration of Components into MEAs)

- **Other Innovative Concepts**

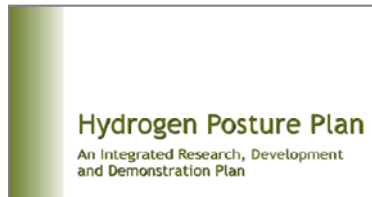
(Long-Term Technologies and Alkaline Fuel Cells)

## ***Workshop on Bus Targets and Gaps*** (date TBD)

***Check websites below for announcements:***

[www.hydrogen.energy.gov](http://www.hydrogen.energy.gov)

[www.hydrogenandfuelcells.energy.gov](http://www.hydrogenandfuelcells.energy.gov)

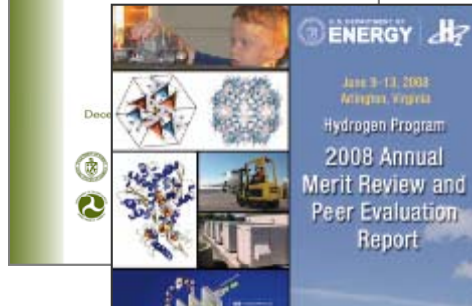


## Fuel Cell Program Plan

*Outlines a coordinated plan for fuel cell activities in the Department of Energy*

→ **Replacement for current Posture Plan**

→ **To be released in late 2009**

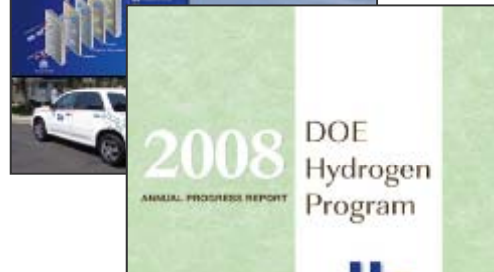


## Annual Merit Review & Peer Evaluation Report

*Summarizes the comments of the Peer Review Panel at the Annual Merit Review and Peer Evaluation Meeting*

→ **Latest edition released November 2009**

[www.hydrogen.energy.gov/annual\\_review09\\_report.html](http://www.hydrogen.energy.gov/annual_review09_report.html)



## Annual Progress Report

*Summarizes activities and accomplishments within the Program over the preceding year, with reports on individual projects*

→ **Next edition to be published in Fall 2009**

[www.hydrogen.energy.gov/annual\\_progress.html](http://www.hydrogen.energy.gov/annual_progress.html)



## Annual Merit Review Proceedings

*Includes downloadable versions of all presentations at the Annual Merit Review*

→ **Latest edition released June 2009**

[www.hydrogen.energy.gov/annual\\_review09\\_proceedings.html](http://www.hydrogen.energy.gov/annual_review09_proceedings.html)

**Next Annual Review: June 7-11, 2010**

**Washington, D.C.**

# Thank you

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**<http://www.eere.energy.gov/hydrogenandfuelcells>**