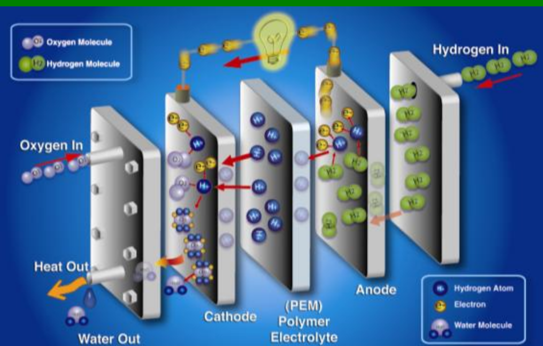
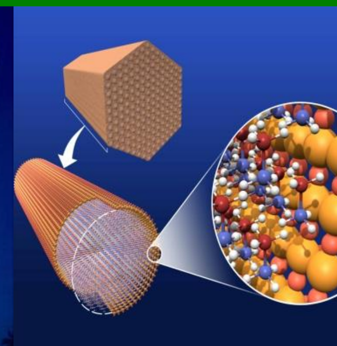
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy





Overview of Hydrogen and Fuel Cell Activities

Dr. Sunita Satyapal

Chief Engineer and Deputy Program Manager

United States Department of Energy

Fuel Cell Technologies Program

6th International Hydrogen and Fuel Cell Expo, Japan

March 3, 2010

Advancing Presidential Priorities

Energy efficiency and renewable energy research, development, and deployment activities help the Nation meet its economic, energy security, and environmental challenges concurrently.

Energy Security

- Deploy the cheapest, cleanest, fastest energy source – energy efficiency
- One million plug-in hybrid cars on the road by 2015
- Develop the next generation of sustainable biofuels and infrastructure
- Increase fuel economy standards

Economic

- Create green jobs through Recovery Act energy projects
- Double renewable energy generation by 2012
- Weatherize one million homes annually

Environmental

- Implement an economy-wide cap-and-trade program to reduce greenhouse gas emissions 80 percent by 2050
- Make the US a leader on climate change
- Establish a national low carbon fuel standard

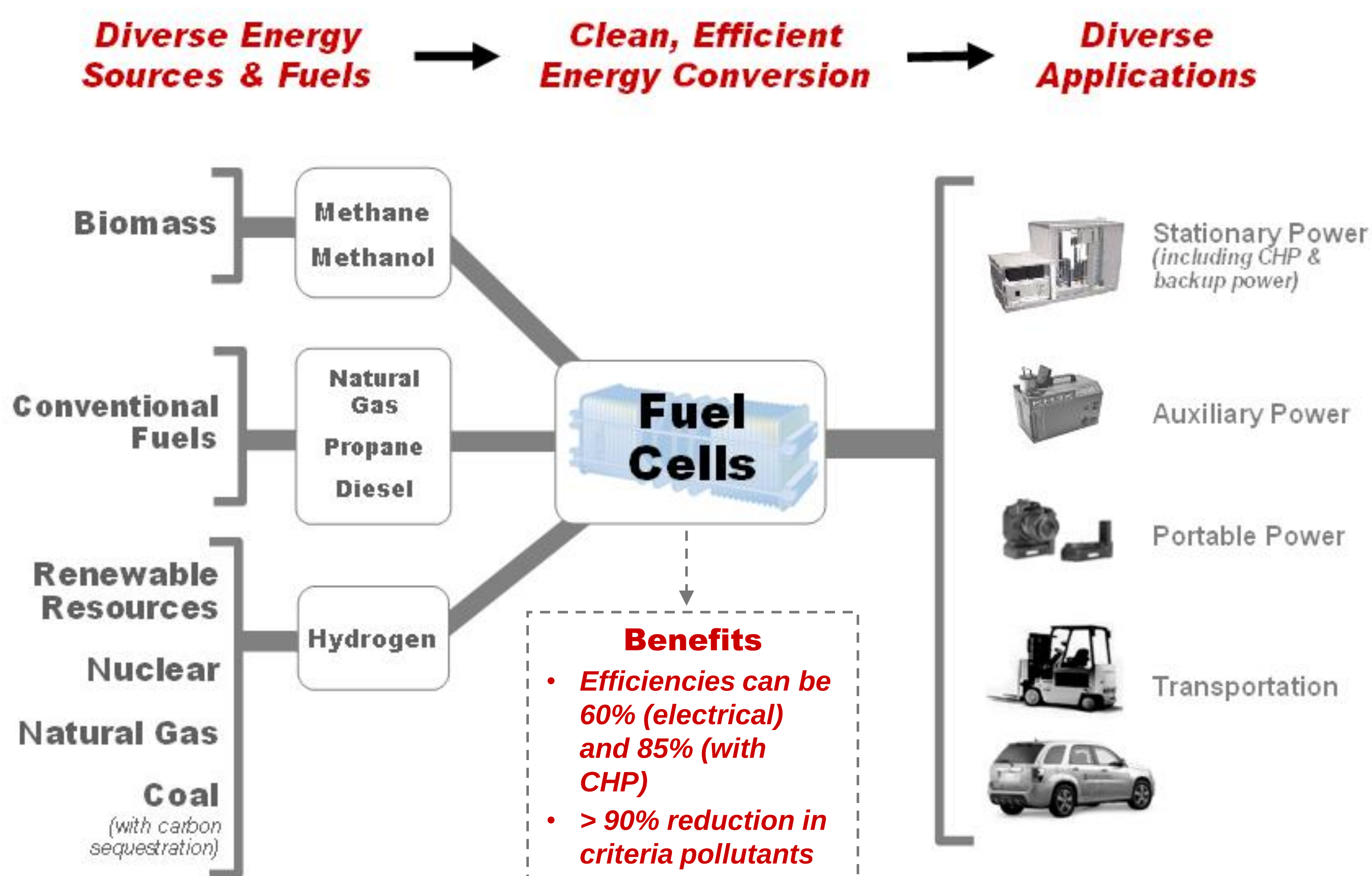
Fuel Cells: Addressing Energy Challenges

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.*



Fuel Cells — *Where are we today?*

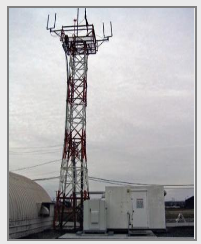
Fuel Cells for Stationary Power, Auxiliary Power, and Specialty Vehicles

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

***~75,000** fuel cells have been shipped worldwide.*

***~24,000** fuel cells were shipped in 2009 (> 40% increase over 2008).*

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



Fuel Cells for Transportation

In the U.S., there are currently:

- *> 200 fuel cell vehicles*
- *> 20 fuel cell buses*
- *~ 60 fueling stations*

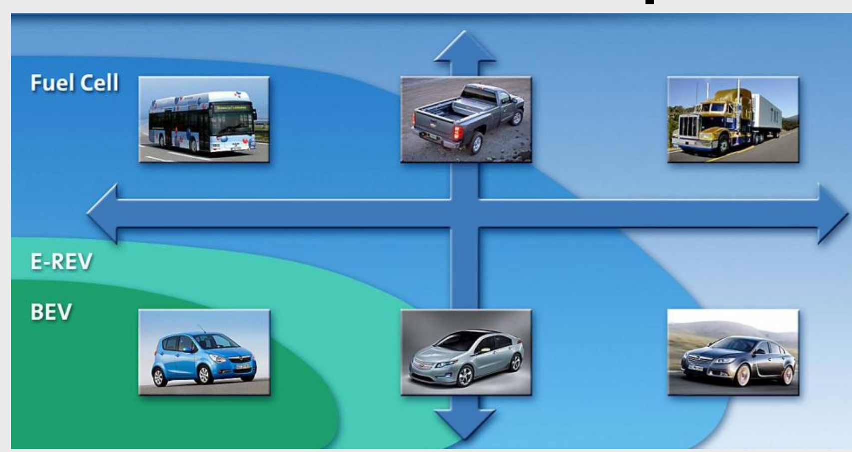
Several manufacturers—including Toyota, Honda, Hyundai, Daimler, GM, and Proterra (buses) — have announced plans to commercialize vehicles by 2015.

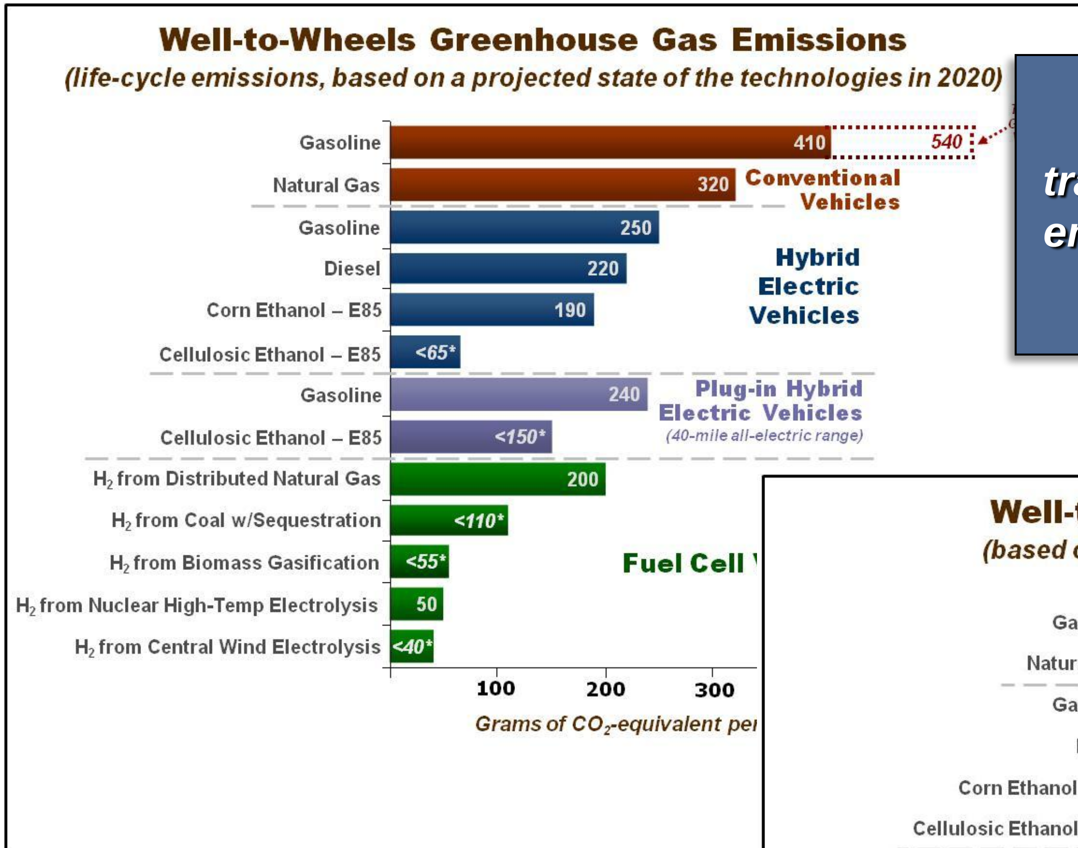
Production & Delivery of Hydrogen

In the U.S., there are currently:

- ***~9 million metric tons** of H_2 produced annually*
- ***> 1200 miles** of H_2 pipelines*

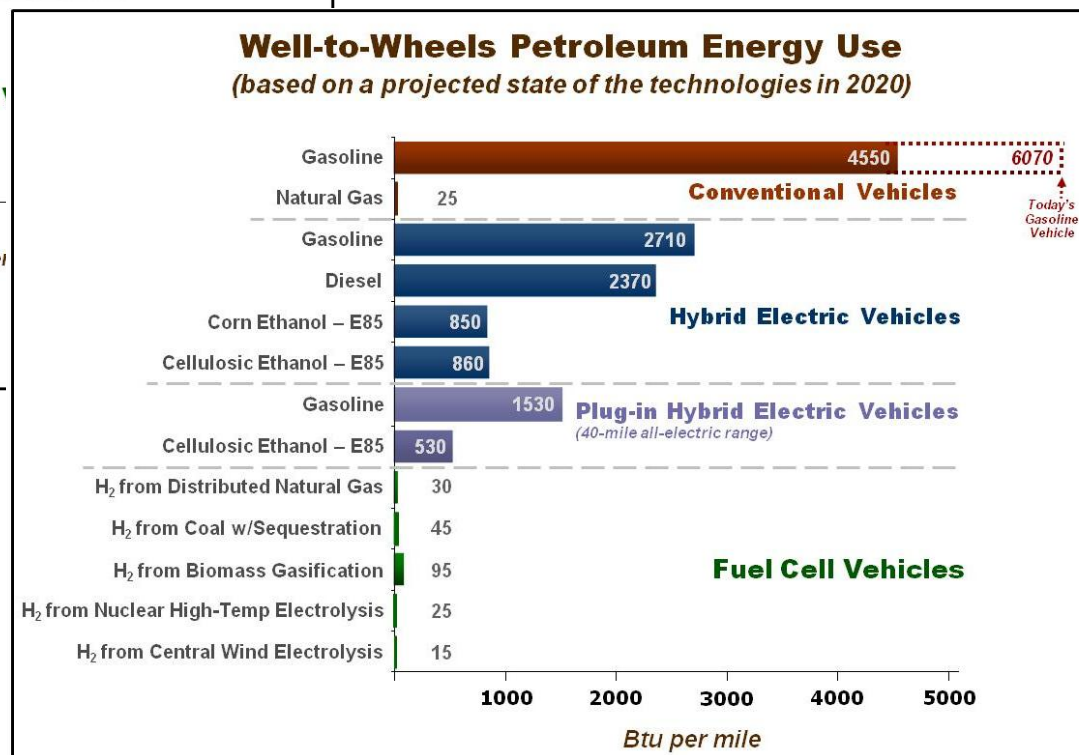
The Role of Fuel Cells in Transportation





Analysis shows DOE's portfolio of transportation technologies will reduce emissions of greenhouse gases and oil consumption.

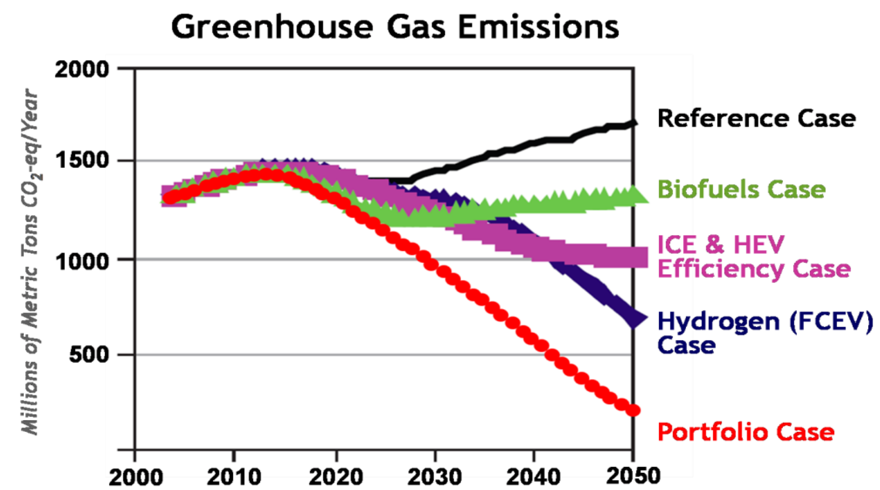
DOE Program Record #9002, www.hydrogen.energy.gov/program_records.html.

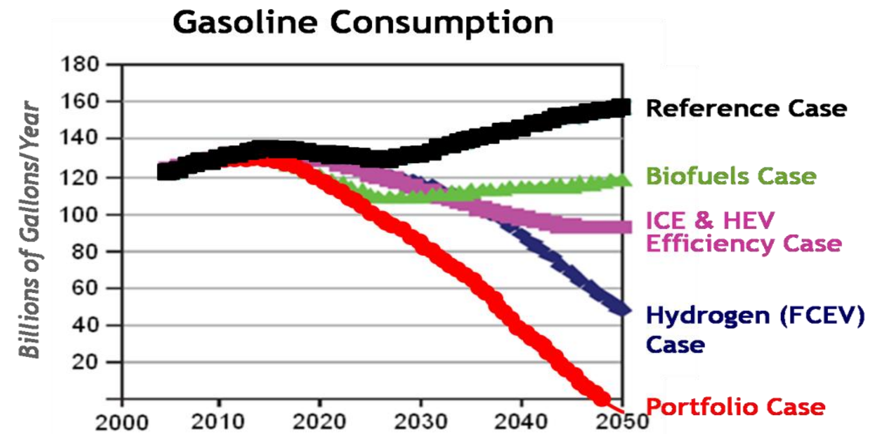


NAS study, "Transitions to Alternative Transportation Technologies: A Focus on Hydrogen," estimates costs and benefits

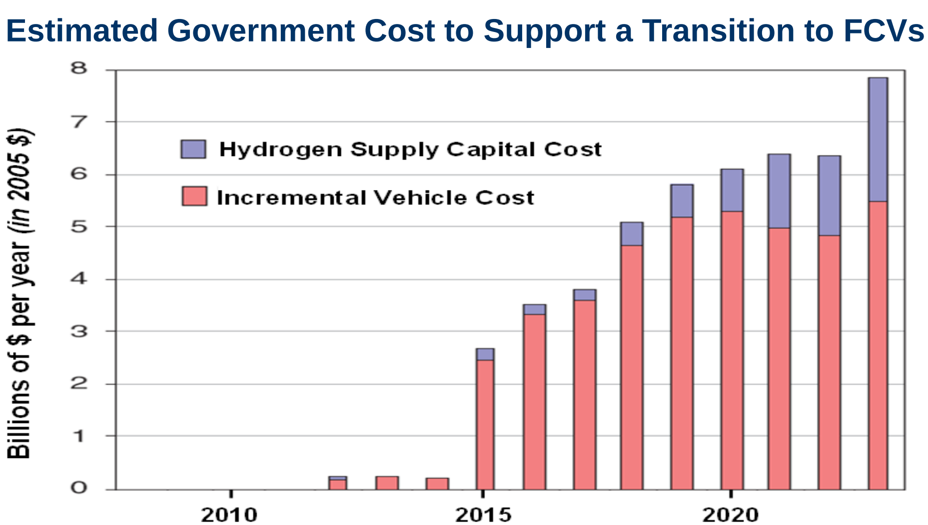
Key Findings Include:

- By 2020, there could be 2 million FCVs on the road (60 million and by 2050).
- A portfolio of technologies has the potential to reduce greenhouse gas emissions from light-duty vehicles
  - 20% of current levels—by 2050.





Source: *Transitions to Alternative Transportation Technologies: A Focus on Hydrogen*, National Academies, 2008.



Policies Promoting Fuel Cells

Some tax credits affecting fuel cells were expanded. Through new financing mechanisms, these credits can help facilitate federal deployments.

Hydrogen Fueling Facility Credit	**Increases the hydrogen fueling credit from 30% or $30,000 to 30% or $200,000.**
Grants for Energy Property in Lieu of Tax Credits	**Allows facilities with insufficient tax liability to apply for a grant instead of claiming the Investment Tax Credit (ITC) or Production Tax Credit (PTC). Only entities that pay taxes are eligible.**
Manufacturing Credit	**Creates 30% credit for investment in property used for manufacturing fuel cells and other technologies**
Residential Energy Efficiency Credit	**Raises ITC dollar cap for residential fuel cells in joint occupancy dwellings to $3,334/kW.**

Example - Executive Order 13514

On October 5, 2009 President Obama signed Executive Order 13514 – Federal Leadership in Environmental, Energy, and Economic Performance

- **Requires Agencies to:**
  - **Set GHG reduction Targets**
  - **Develop Strategic Sustainability Plans and provide in concert with budget submissions**
  - **Conduct bottom up Scope 1, 2 and 3 baselines**
  - **Track performance**

Examples:

- **Achieve** 30% reduction in vehicle fleet petroleum use by 2020
- **Requires** 15% of buildings meet the *Guiding Principles for High Performance and Sustainable Buildings* by 2015
- **Design** all new Federal buildings which begin the planning process by 2020 to achieve zero-net energy by 2030

Potential opportunities for fuel cells and other clean energy technologies….

http://www1.eere.energy.gov/femp/regulations/eo13514.html

Key Challenges

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, delivered

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.

*Metrics available/under development for various applications

Collaborations

Federal Agencies

- DOC
- DOD
- DOEd
- DOT
- EPA
- GSA
- DOI
- DHS
- NASA
- NSF
- USDA
- USPS

– *Interagency coordination through staff-level Interagency Working Group (meets monthly)*
– *Assistant Secretary-level Interagency Task Force mandated by EPACT 2005.*

Universities

~ 50 projects with 40 universities

International

- IEA Implementing agreements – 25 countries
- International Partnership for the Hydrogen Economy – 16 countries, 30 projects

DOE Fuel Cell Technologies Program*

– *Applied RD&D*
– *Efforts to Overcome Non-Technical Barriers*
– *Internal Collaboration with Fossil Energy, Nuclear Energy and Basic Energy Sciences*

Industry Partnerships & Stakeholder Assn's.

- FreedomCAR and Fuel Partnership
- National Hydrogen Association
- U. S. Fuel Cell Council
- Hydrogen Utility Group
- ~ 65 projects with 50 companies

State & Regional Partnerships

- California Fuel Cell Partnership
- California Stationary Fuel Cell Collaborative
- SC H_2 & Fuel Cell Alliance
- Upper Midwest Hydrogen Initiative
- Ohio Fuel Coalition
- Connecticut Center for Advanced Technology

National Laboratories

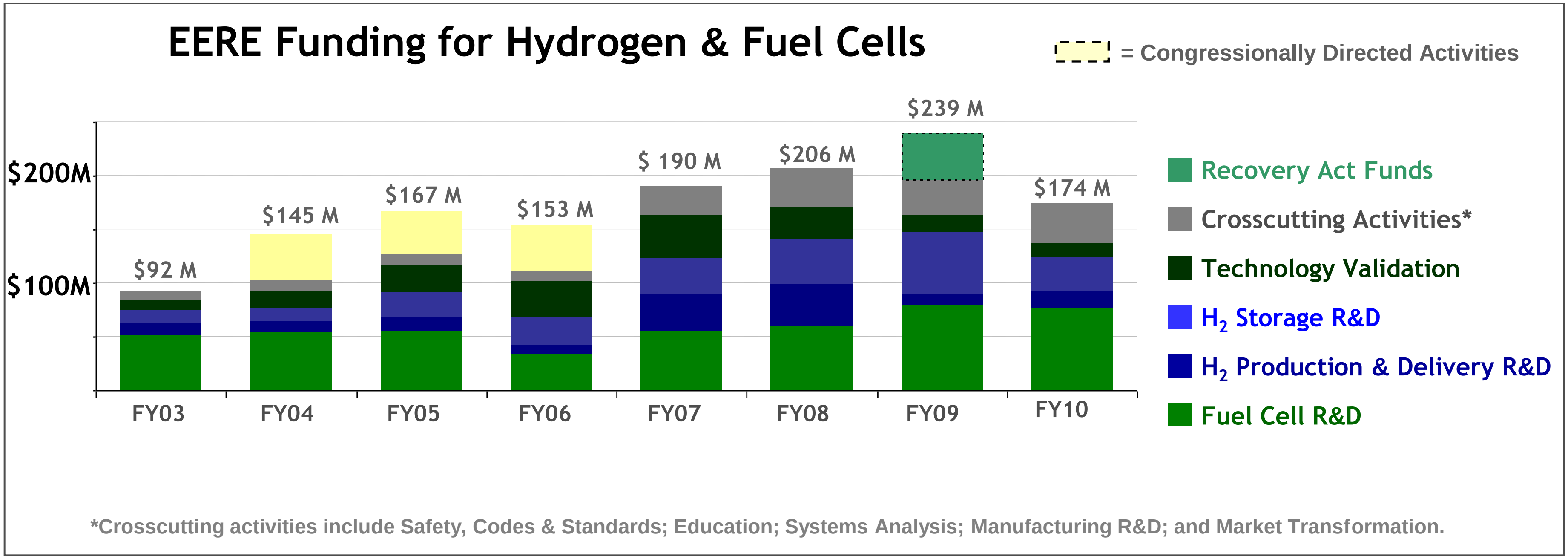
National Renewable Energy Laboratory P&D, S, FC, A, SC&S, TV
Argonne A, FC, P&D
Los Alamos S, FC, SC&S
Sandia P&D, S, SC&S
Pacific Northwest P&D, S, FC, A
Oak Ridge P&D, S, FC, A
Lawrence Berkeley FC, A
Lawrence Livermore P&D, S
Savannah River S, P&D
Brookhaven S, FC

Other Federal Labs: Jet Propulsion Lab, National Institute of Standards & Technology, National Energy Technology Lab, Idaho National Lab

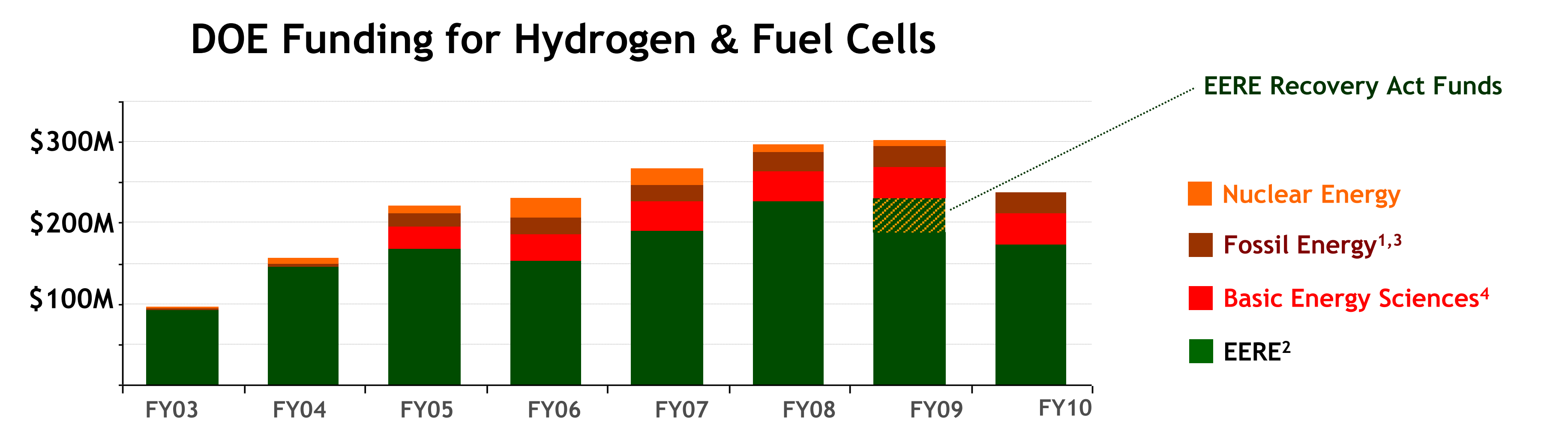
***P&D** = Production & Delivery; **S** = Storage; **FC** = Fuel Cells; **A** = Analysis; **SC&S** = Safety, Codes & Standards; **TV** = Technology Validation*

* Office of Energy Efficiency and Renewable Energy

Funding History for Fuel Cells



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



[1] All FE numbers include funding for program direction.

[2] FY09 and FY10 include SBIR/STTR funds to be transferred to the Science Appropriation; previous years shown exclude this funding.

[3] FY10 number includes coal to hydrogen and other fuels. FE also plans $50M for SECA in FY10.

[4] FY10 shows estimated funding for hydrogen- and fuel cell–related projects; exact funding to be determined. The Office of Science also plans ~$14M for hydrogen production research in the Office of Biological and Environmental Research in FY10.

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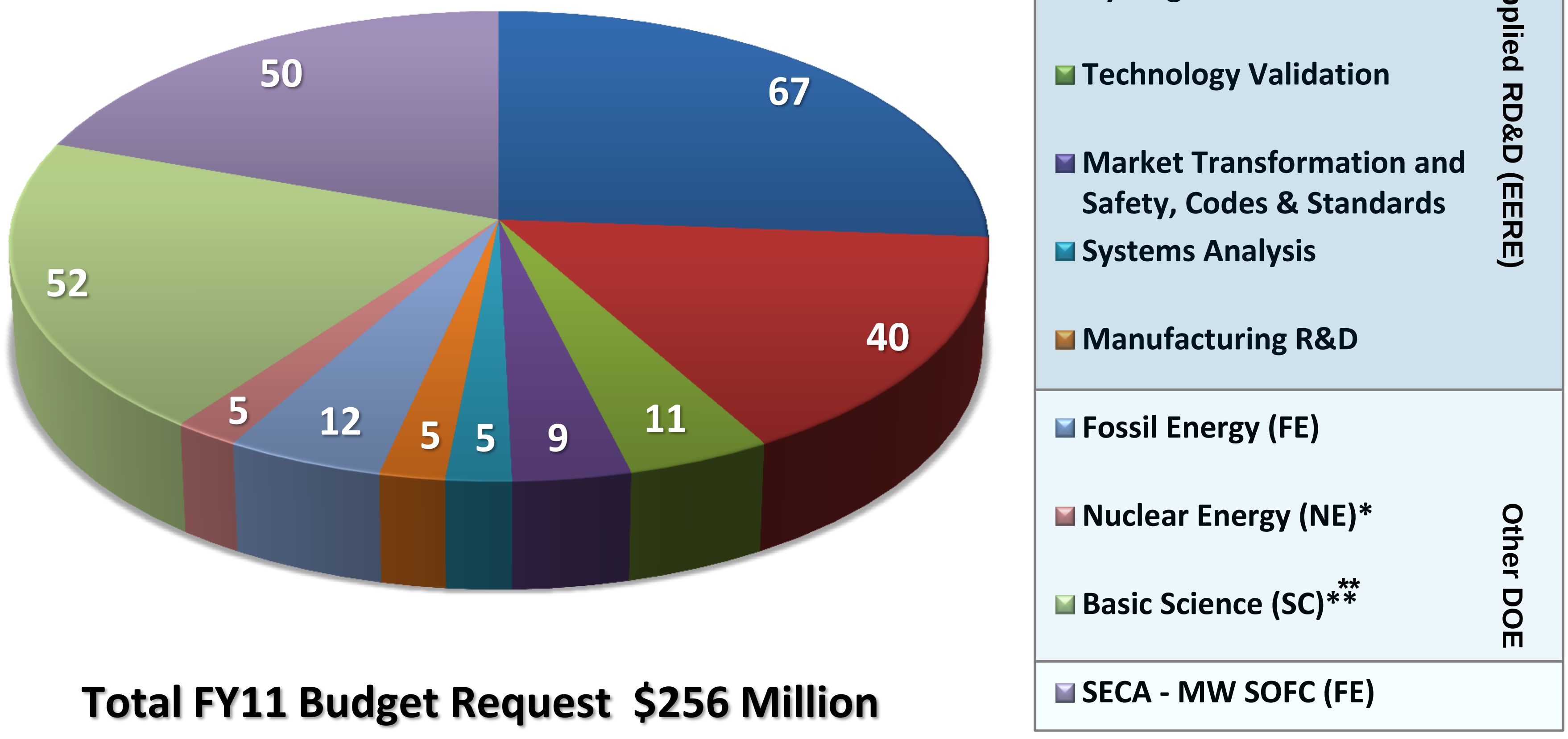
Total DOE Hydrogen and Fuel Cell Technologies FY11 Budget Request (in millions of US$)



Total FY11 Budget Request $256 Million

*NE request TBD, $5M represents FY10 funding
**SC Includes BES and BER

Fuel Cell R&D — *Metrics*

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

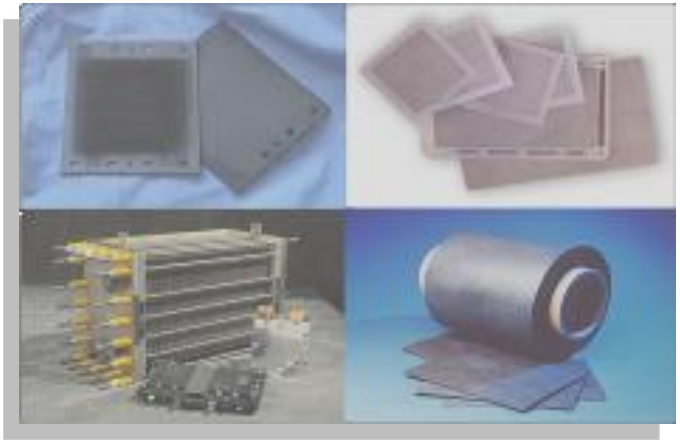
Fuel Cell R&D is focused on a broad range of applications, using a variety of technologies and fuels.

EXAMPLES OF KEY TARGETS:

Distributed Power:

- $750/kW by 2011
- 40,000-hour durability by 2011
- 40% efficiency by 2011

→ TARGETS FOR SMALL SCALE CHP ARE BEING DEVELOPED



Transportation:

- $45/kW by 2010; $30/kW by 2015
- 5,000-hour durability by 2015
- 60% efficiency

APUs:

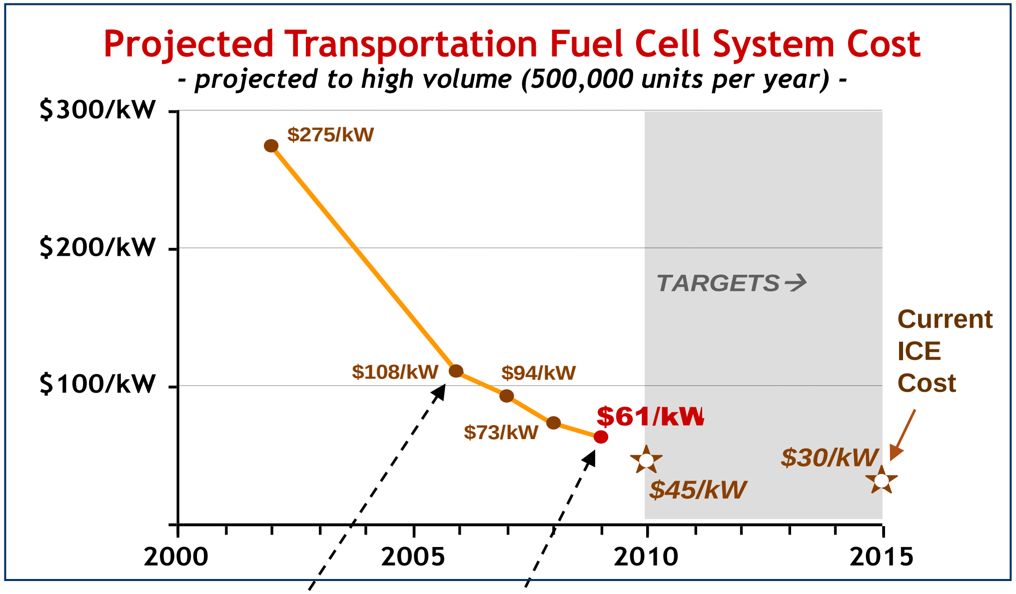
- Specific power of 100 W/kg by 2010
- Power density of 100 W/L by 2010

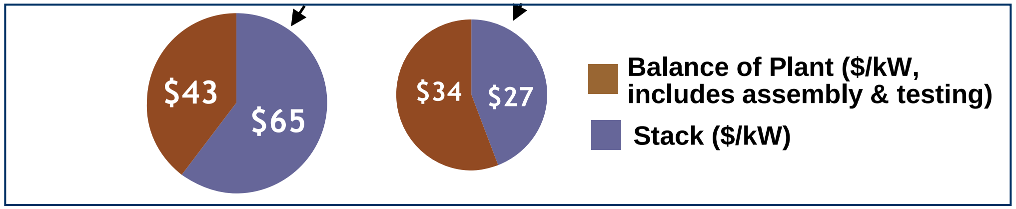
→ TARGETS FOR APUs ARE BEING REVISED

Portable Power:

- Energy density of 1,000 W-h/L by 2010

Fuel Cell R&D — *Progress*

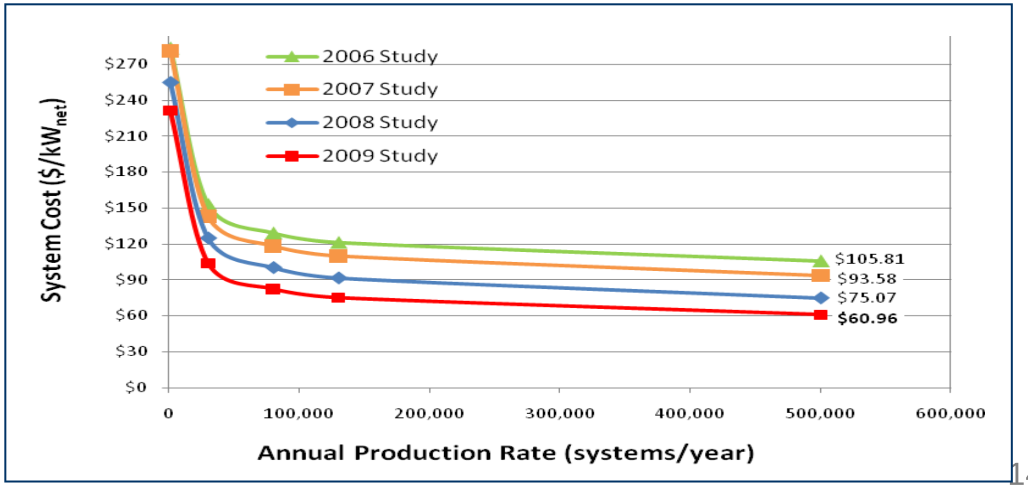




We've reduced the projected high-volume cost of fuel cells to $61/kW*

- ***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).*

***Panel found $60 – $80/kW to be a "valid estimate": http://hydrogendoedev.nrel.gov/peer_reviews.html*

Fuel Cell R&D — *Progress*

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

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

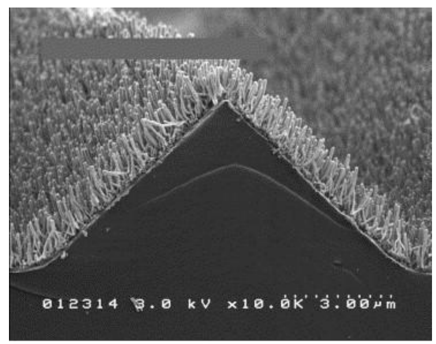
- **Reducing platinum group metal content from 0.35 to 0.18 g/kW**
- **Increasing power density from 715 to 833 mW/cm^2**

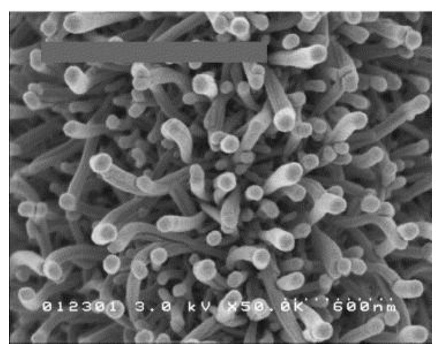
→ These advances resulted in a $10/kW cost reduction.

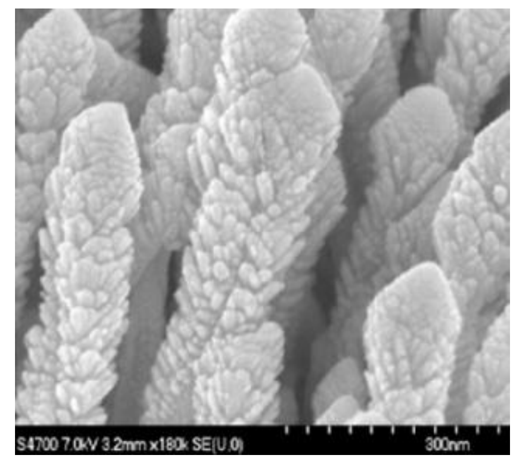
Key improvements enabled by using novel organic crystalline whisker catalyst supports and Pt-alloy whiskerettes.

There are ~ 5 billion whiskers/cm^2.

Whiskers are ~ 25 X 50 X 1000 nm.







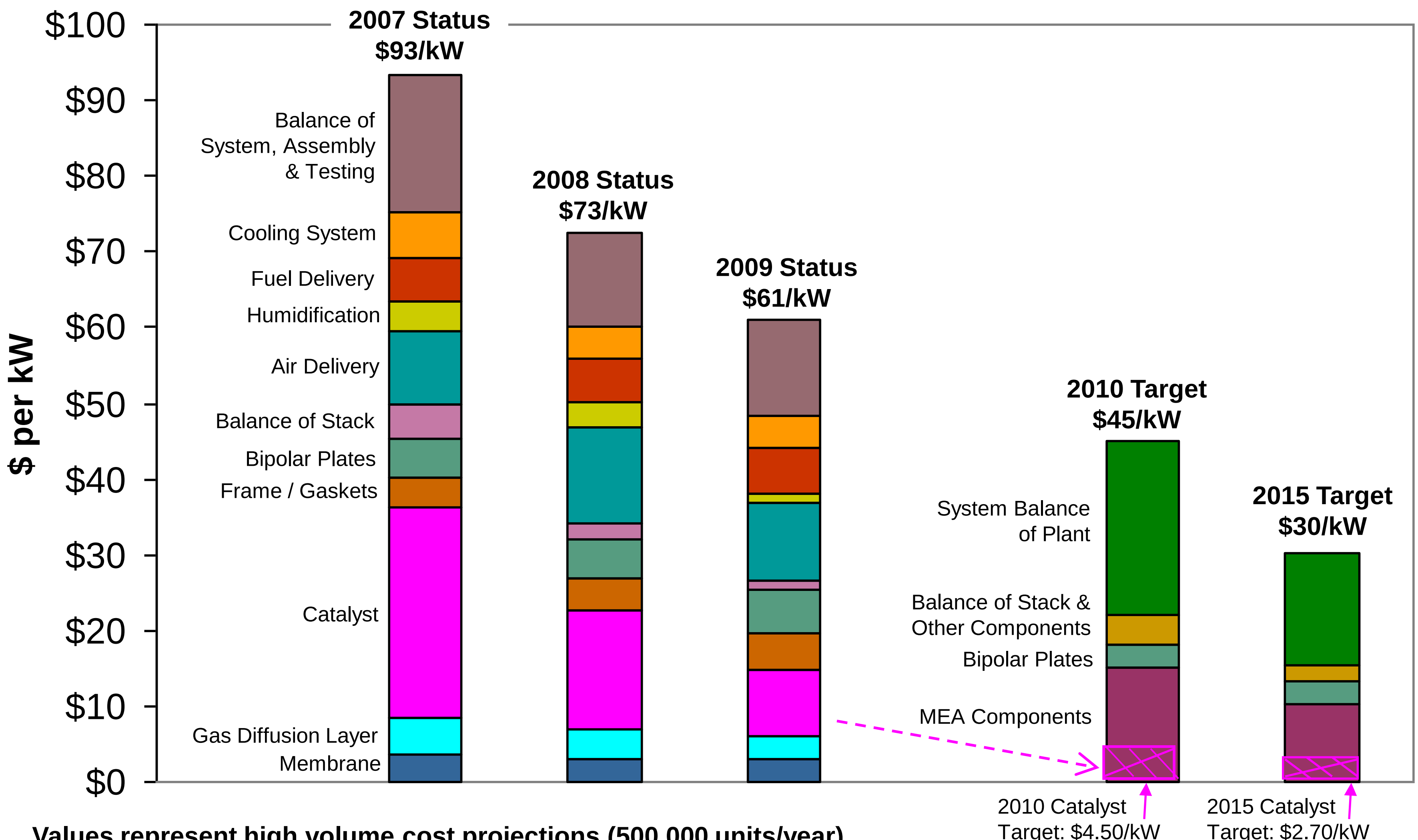
Whiskerettes:
6 nm x 20 nm

Source: 3M

Fuel Cell Cost Breakdown

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

DOE continues to track cost projections & estimated cost reductions, on track towards reaching long-term targets. Continued efforts on cost and durability are required.



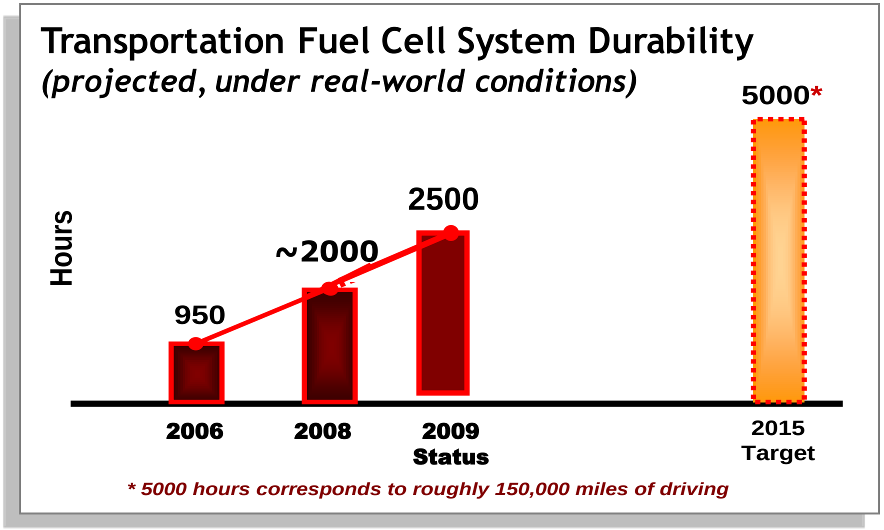
Values represent high volume cost projections (500,000 units/year).

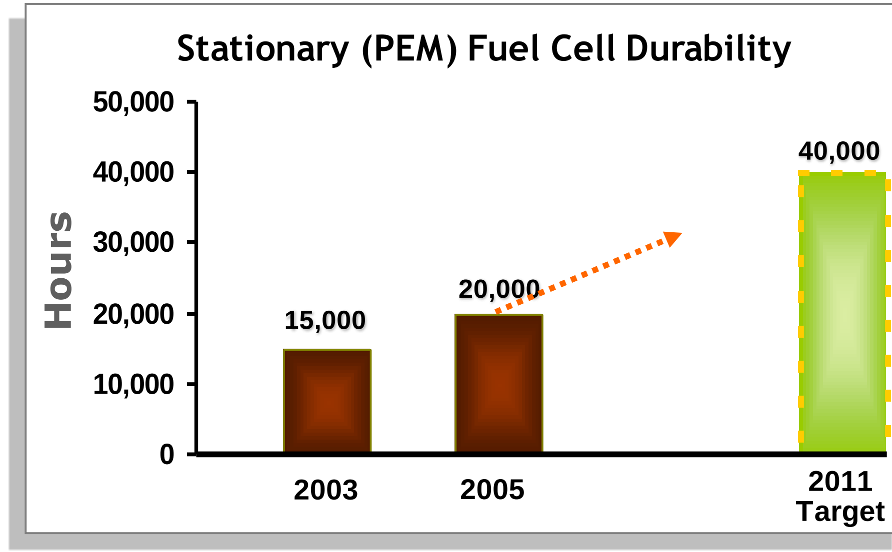
U.S. Department of Energy

Fuel Cell R&D — *Progress*

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

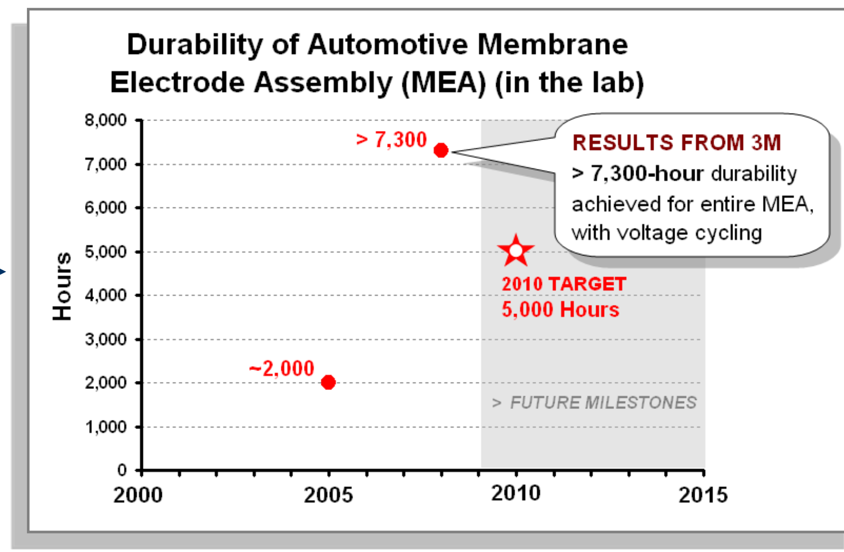
We've greatly increased durability—including more than doubling the demonstrated durability of transportation fuel cells.





Demonstrated >7,300-hour durability →

This exceeds our target for MEA durability, in single-cell testing—and has the potential to meet the 2010 target for MEAs in a fuel cell system.



Hydrogen Production R&D

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

The Program is developing technologies to produce hydrogen from clean, domestic resources at reduced cost.

KEY PRODUCTION OBJECTIVE: Reduce the cost of hydrogen (delivered & untaxed) to $2 – 3 per gge (gallon gasoline equivalent)

Projected* High-Volume Cost of Hydrogen (Delivered) — Status & Targets

($/gallon gasoline equivalent [gge], untaxed)

NEAR TERM:

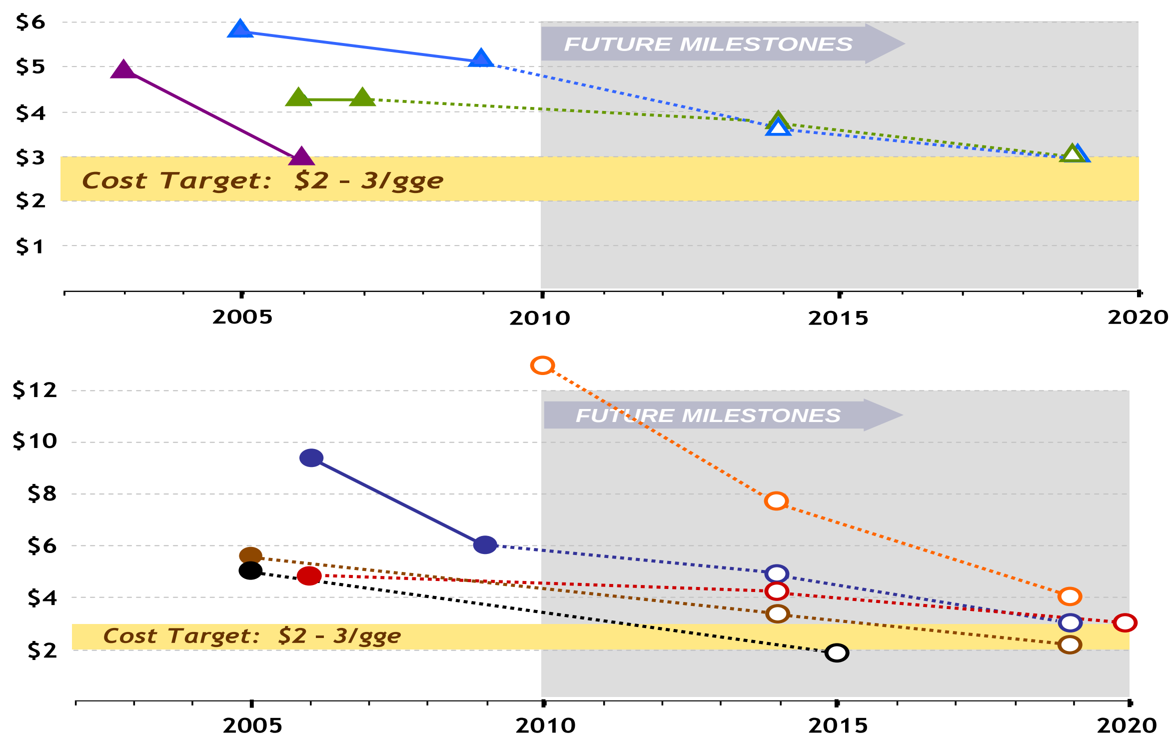
Distributed Production

- Natural Gas Reforming
- Bio-Derived Renewable Liquids
- Electrolysis

LONGER TERM:

Centralized Production

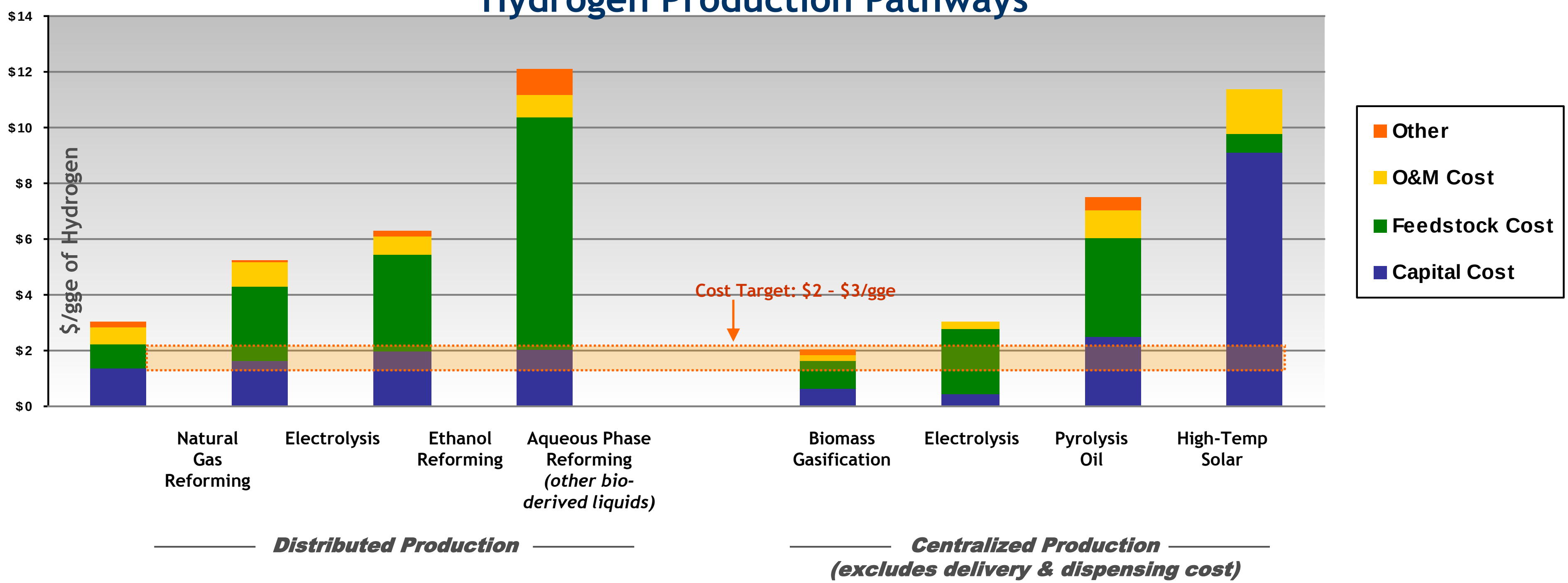
- Biomass Gasification
- Central Wind Electrolysis
- Coal Gasification with Sequestration
- Nuclear
- Solar High-Temp. Thermochemical Cycle



* **Distributed production** status and targets assume station capacities of 1500 kg/day, with 500 stations built per year.
Centralized production values assume the following plant capacities: biomass gasification—155,000 to 194,000 kg/day; central wind electrolysis—50,000 kg/day; coal gasification—308,000 kg/day; nuclear—768,000 kg/day; and solar high-temperature thermochemical—100,000 kg/day. Values for the status of centralized production assume $3/gge delivery cost, the while targets shown assume delivery cost targets are met ($1.70/gge in 2014 and <$1/gge in 2019).

A number of production technologies are under development but more R&D is required to meet cost targets for all pathways. Cost targets are being evaluated.

Modeled High-volume Cost of Major Hydrogen Production Pathways



Key Assumptions:

Distributed pathways: 500 units/year and station capacity of 1500 kg/day

Central Biomass: ~150,000 kg/day, 90% operating capacity

Central Electrolysis: ~ 50,000 kg/day, 98% operating capacity, $0.045/kWh, $50M depreciable capital cost

Pyrolysis oil: 1,500 kg/day, mixture of pyrolysis oil and methanol cost ~$0.34/kg mixture

Solar thermochemical: 100,000 kg/day, 70% operating capacity (uses thermal and chemical storage to overcome diurnal limitations to get to 70%)

Current Low-volume Costs (e.g., 10 kg/day, single-station): > $30/gge

New concept under development—Tri-generation: produces heat, power and H_2 (if required) using high-temp fuel cell. Can potentially reduce cost to ~ $5/gge & help address infrastructure challenges.

Hydrogen Delivery R&D

The Program is developing technologies to deliver hydrogen from centralized production facilities, efficiently and at low cost.

KEY OBJECTIVE

Reduce the cost of delivering hydrogen to < $1/gge

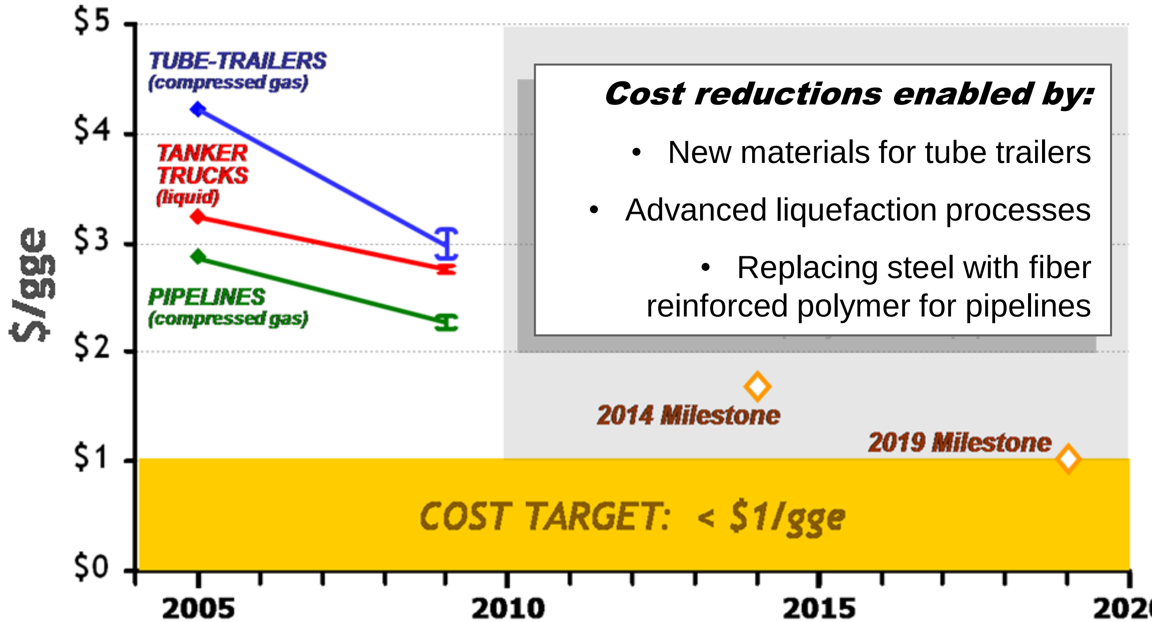
PROGRESS

We've reduced the projected cost of hydrogen delivery

- ***~30% reduction in tube-trailer costs***
- ***>20% reduction in pipeline costs***
- ***~15% reduction liquid hydrogen delivery costs***

Projected Cost of Delivering Hydrogen

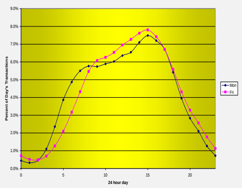
- assuming high-volume deliveries & widespread market penetration -



Assumptions: Sacramento, with 20% market penetration; 147 stations (1000 kg/day per station); plant 62 miles from city gate; 10 days off-peak storage (geologic storage for tube-trailers and pipelines, liquid storage for tanker-trucks). Costs include all processes from the production site through dispensing (for 350-Bar onboard storage), expressed in 2005 dollars. **Model:** HDSAM (www.hydrogen.energy.gov/h2a_delivery.html). **Date:** January 2010.

Hydrogen Delivery R&D

Potential near and long term solutions to meet delivery cost targets



Analysis

Pipelines

Liquefaction

Tube Trailers

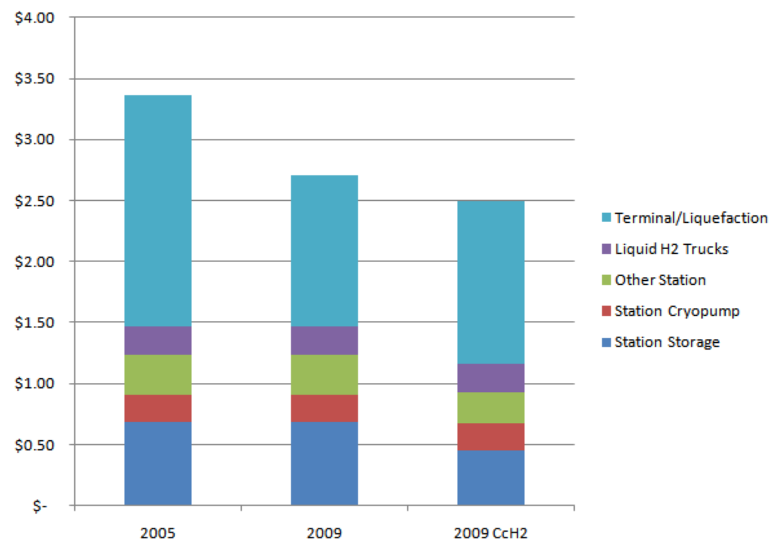
Compression

Other

Examples of Challenges

- Cost & performance
- H_2 quality cleanup
- Upstream issues
  - Transmission costs are highly variable depending on region
  - Geologic storage availability and proximity
  - Balancing production sites and delivery infrastructure
- Institutional barriers
- Local opposition, codes & standards, jurisdictions

__Example of Modeled High Volume Hydrogen Delivery Cost:__ **$2.71-$2.88/gge (preliminary estimate)**



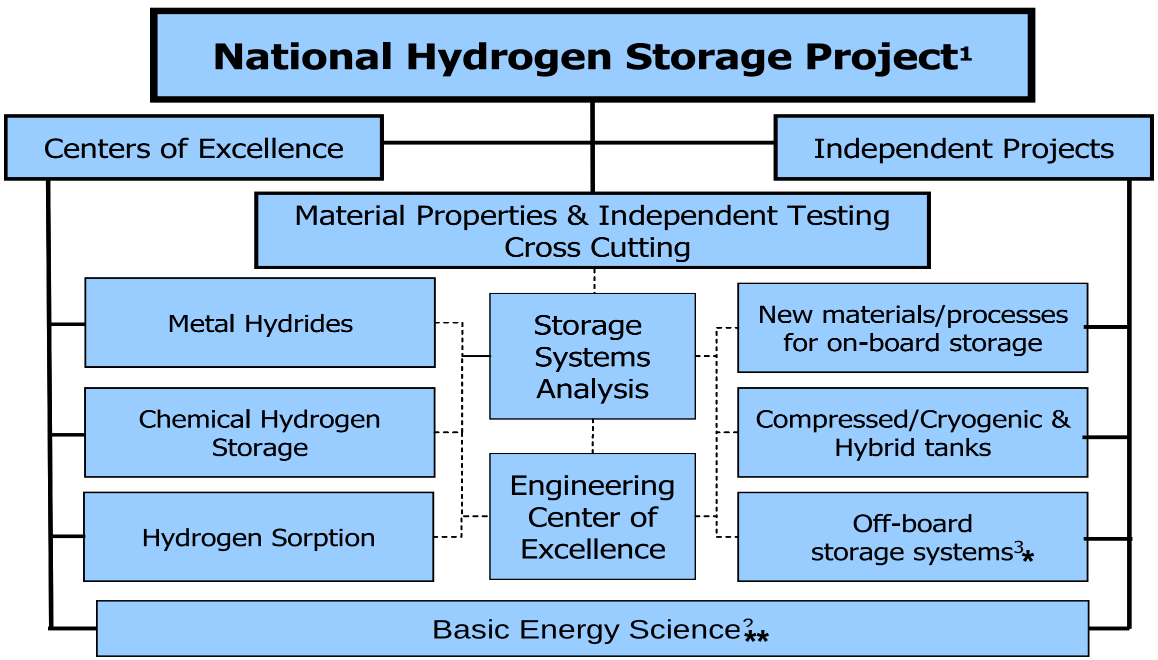
Hydrogen Storage R&D

DOE has focused on materials R&D and has identified several promising new materials— providing more than 50% improvement in capacity since 2004.

KEY OBJECTIVE

> 300-mile driving range in all vehicle platforms, without compromising passenger/ cargo space, performance, or cost

- **High pressure tanks are viable for early market penetration and have already demonstrated > 300 mile range (e.g. 430 miles)**
- **Long term approaches focus on low-pressure materials approaches**



* Coordinated with Delivery R&D subprogram **Conducted by the DOE Office of Science

The National Hydrogen Storage Project involves the efforts of 45 universities, 15 federal labs, and 13 companies.

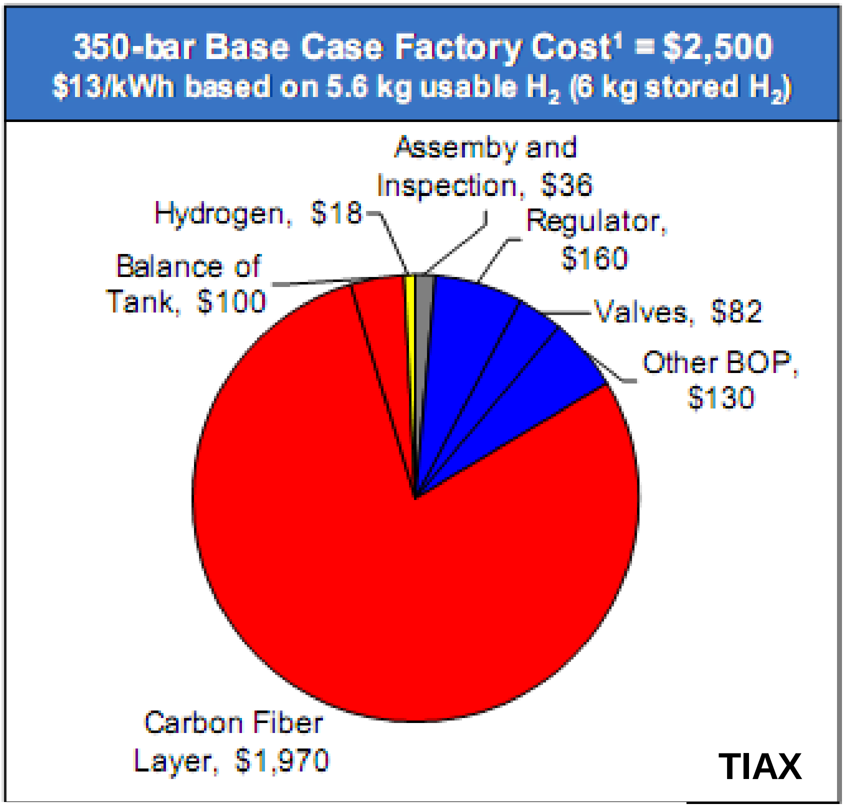
- **Assessed and updated targets as planned — based on real-world experience with vehicles, weight and space allowances in vehicle platforms, and needs for market penetration**
- **Developed and evaluated more than 350 materials approaches**
- **Launched the Storage Engineering Center of Excellence — to address systems integration and prototype development; efforts coordinated with materials centers of excellence**

H2 Storage Tanks

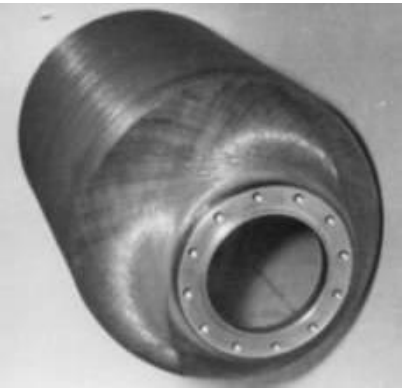
Tanks are viable and have demonstrated excellent performance and safety. Cost must be reduced while maintaining capacity and performance.

Example - 350 bar compressed:

- The carbon fiber composite layer can account for about 75% system costs;
- Reduction strategies can include:
  - reducing fiber precursor costs;
  - reducing fiber manufacturing costs;
  - increasing fiber strength so less required;
  - optimizing fiber utilization through improved winding;
  - using different materials.



[1] Cost estimate in 2005 USD. Includes processing costs.



Hydrogen Storage R&D: *Progress*

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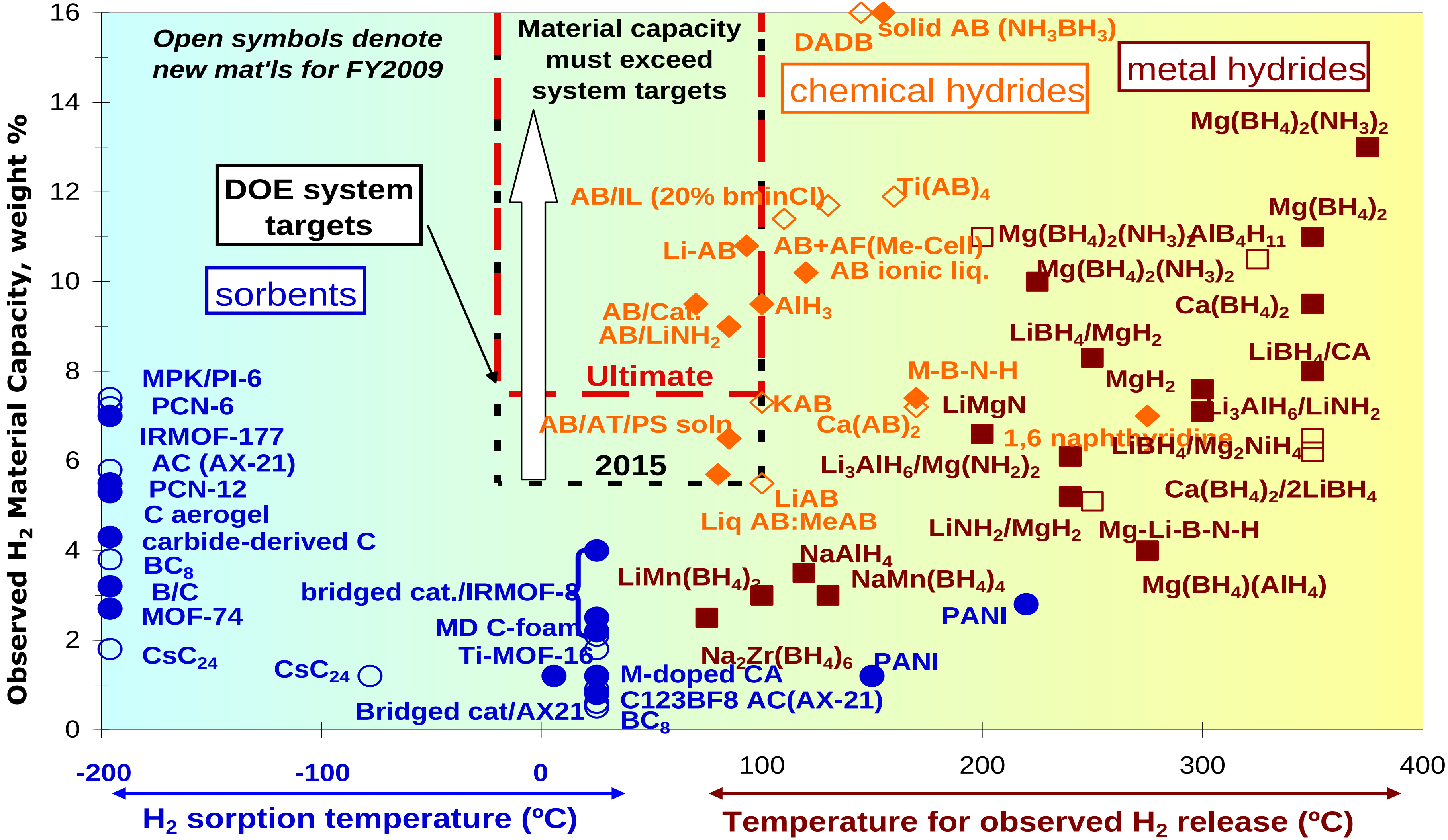
In just *five years* of accelerated investment, DOE has made significant progress and identified a number of materials with potential to meet DOE targets.



U.S. Department of Energy

DOE: G. Thomas (2007), G. Sandrock (2008), B. Bowman (2009)

Examples of Down-Selections

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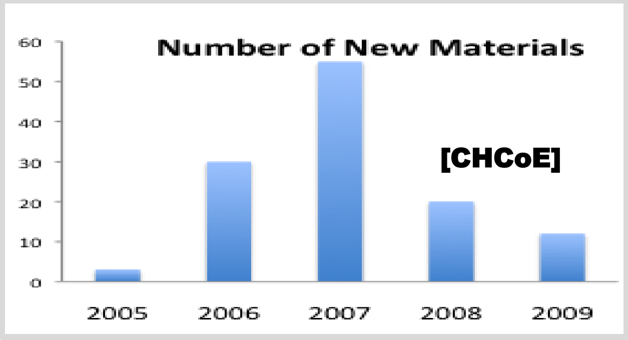
Down-selection of material systems continues on a regular basis.

Chemical Hydrogen Storage

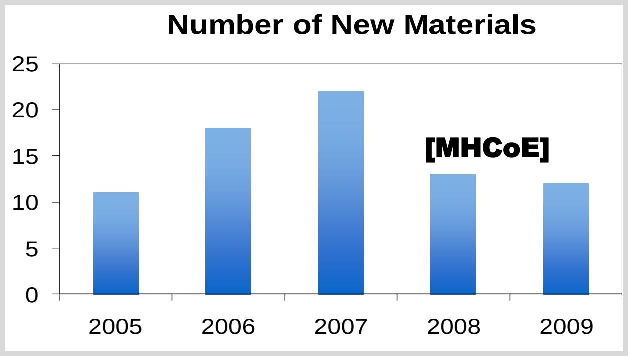
- ~ 120 materials/combinations have been examined
- ~ 85% discontinued
- ~ 15% still being investigated—many derivatives of Ammonia Borane (AB), or mixture of AB with additives



Metal Hydrides

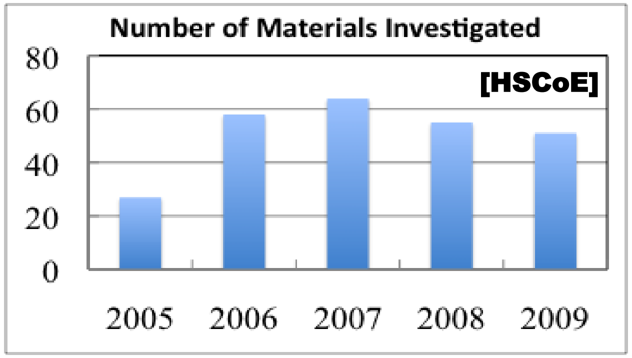
More than 75 distinct material systems assessed experimentally—not including catalyst/additive studies

- ~ 45% discontinued
- ~ 55% still being investigated



Hydrogen Sorption

- ~ 160 materials investigated
- ~ 65% discontinued
- ~ 35% still being investigated



The Program is demonstrating key technologies to validate their performance in integrated systems, under real-world conditions.

DOE Vehicle/Infrastructure Demonstration

Four teams in 50/50 cost-shared projects with DOE Vehicle Technologies Program

- **140 fuel cell vehicles and 20 fueling stations demonstrated**
- **More than 2.3 million miles traveled**
- **More than 115,000 kg of hydrogen produced or dispensed***
- **Analysis by NREL shows:**
  - **Efficiency: 53 – 58% (>2x higher than gasoline internal combustion engines)**
  - **Range: ~196 – 254 miles**
  - **Fuel Cell System Durability:**

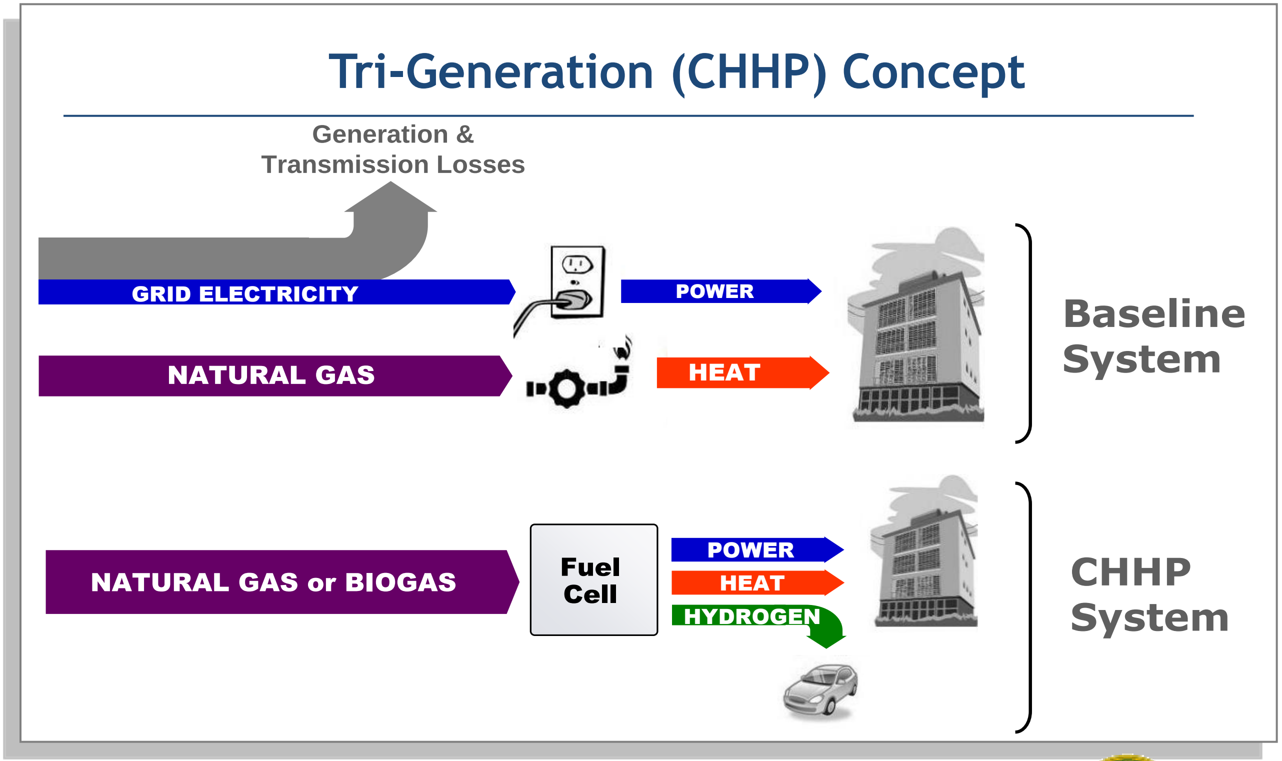
    ~ 2,500 hrs (~75,000 miles)

****includes hydrogen not used in the Program's demonstration vehicles***

We are also demonstrating stationary fuel cells and evaluating real-world forklift and bus fleet data (DOD and DOT collaboration).

We are participating in a project to demonstrate a combined heat, hydrogen, and power (CHHP) system using biogas.

- System has been designed, fabricated and shop-tested.
- Improvements in design have led to higher H_2-recovery (from 75% to >85%).
- On-site operation and data-collection planned for FY09 – FY10.



Combined heat, hydrogen, and power systems can:

- ***Produce clean power and fuel for multiple applications***
- ***Provide a potential approach to establishing an initial fueling infrastructure***

Public-Sector Partners:

South Coast Air Quality Management District

California Air Resources Board

Fuel Cell Energy & Air Products

Technology Validation: Fuel Cell Bus Evaluation

NREL has collected data for DOE and FTA on 8 FCBs in service at 4 sites:

- **AC Transit**
- **SunLine**
- **CTTRANSIT**
- **VTA**

Traveled:

~ 368,000 miles

Dispensed:

72,931 kg H_2

<table>
<tr><th colspan="19">NREL Hydrogen Bus Evaluations for DOE and FTA</th></tr>
<tr><th rowspan="2">Site/Location</th><th rowspan="2">State</th><th rowspan="2">Eval. Funding</th><th colspan="4">2009</th><th colspan="4">2010</th><th colspan="4">2011</th><th colspan="4">2012</th></tr>
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<tr><td>AC Transit/ SF Bay Area</td><td>CA</td><td rowspan="5">DOE Technology Validation</td><td></td><td></td><td></td><td></td><td colspan="8">CA ZEB Advanced Demo</td><td></td><td></td><td></td><td></td></tr>
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<tr><td>SunLine/ Thousand Palms</td><td>CA</td><td></td><td></td><td></td><td></td><td></td><td colspan="8">Advanced FCB Project</td><td></td><td></td><td></td></tr>
<tr><td>CTTRANSIT/ Hartford</td><td>CT</td><td colspan="4">FCB Demo</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>City of Burbank/ Burbank</td><td>CA</td><td></td><td></td><td></td><td></td><td></td><td colspan="4">Burbank FCB</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>AC Transit/ Oakland</td><td>CA</td><td rowspan="8">FTA National Fuel Cell Bus Program</td><td colspan="5">Accel.Test</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>SunLine/ Thousand Palms</td><td>CA</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="8">American FCB Demo</td></tr>
<tr><td>CTTRANSIT/ Hartford</td><td>CT</td><td></td><td></td><td></td><td></td><td colspan="8">Nutmeg Hybrid FCB Demo</td><td></td><td></td><td></td><td></td></tr>
<tr><td>USC, CMRTA/ Columbia
UT/ Austin</td><td>SC,
TX</td><td></td><td></td><td></td><td></td><td colspan="8">Hybrid FCB</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Logan Airport / Boston</td><td>MA</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="8">MA H2 FCB Demo</td></tr>
<tr><td>Albany / NY</td><td>NY</td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="4">Light-wt FCB</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>TBD / NY</td><td>NY</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="8">NYPA H2 Powered FCB</td></tr>
<tr><td>SFMTA / San Francisco</td><td>CA</td><td></td><td></td><td></td><td></td><td></td><td colspan="5">FC APU Hybrid</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Demonstration sites color coded by geographic area: Northern California, Southern California, New England, New York, Southeast, South

National Fuel Cell Bus Program

Fuel economy results: 39% to 141% better than diesel and CNG buses

www.nrel.gov/hydrogen/proj_tech_validation.html

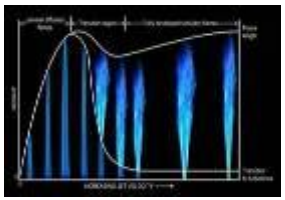
Estimate of data collection/evaluation - schedule subject to change based on progress of each project

Safety, Codes & Standards *and* Education

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

Safety, Codes & Standards

- ***Facilitating the development & adoption of codes and standards for fuel cells***
- ***Identifying and promoting safe practices industry-wide***



ACTIVITIES

Develop data needed for key codes & standards (C&S)

Harmonize domestic and international C&S

Simplify permitting process

Promote adoption of current C&S and increase access to safety information

→

PROGRESS (key examples)

Published Web-based resources, including: *Hydrogen Safety Best Practices Manual; Permitting Hydrogen Facilities*

Through R&D, enabled harmonized domestic and international Fuel Quality Specifications

Developed safety course for researchers and held permitted workshops that reached >250 code officials

Growing number of C&S published (primary building & fire codes 100% complete)

Education: *We are working to increase public awareness and understanding of fuel cells.*

ACTIVITIES

Educate key audiences to facilitate demonstration, commercialization, and market acceptance

→

PROGRESS (key examples)

Launched courses for code officials and first responders (>7000 users)

Conducted seminars and developed fact-sheets and case studies for end-users

Conducted workshops to help state officials identify deployment opportunities

Examples of Early Market Applications

Fuel Cells for Backup Power ...

- Provide longer continuous run-time, greater durability than batteries
- Require less maintenance than batteries or generators
- *May provide <u>substantial cost-savings</u>* over batteries and generators

A 1-kW fuel cell system has been providing power for this FAA radio tower near Chicago for more than three years.

(Photo courtesy of ReliOn)

Fuel Cells for Material Handling Equipment ...

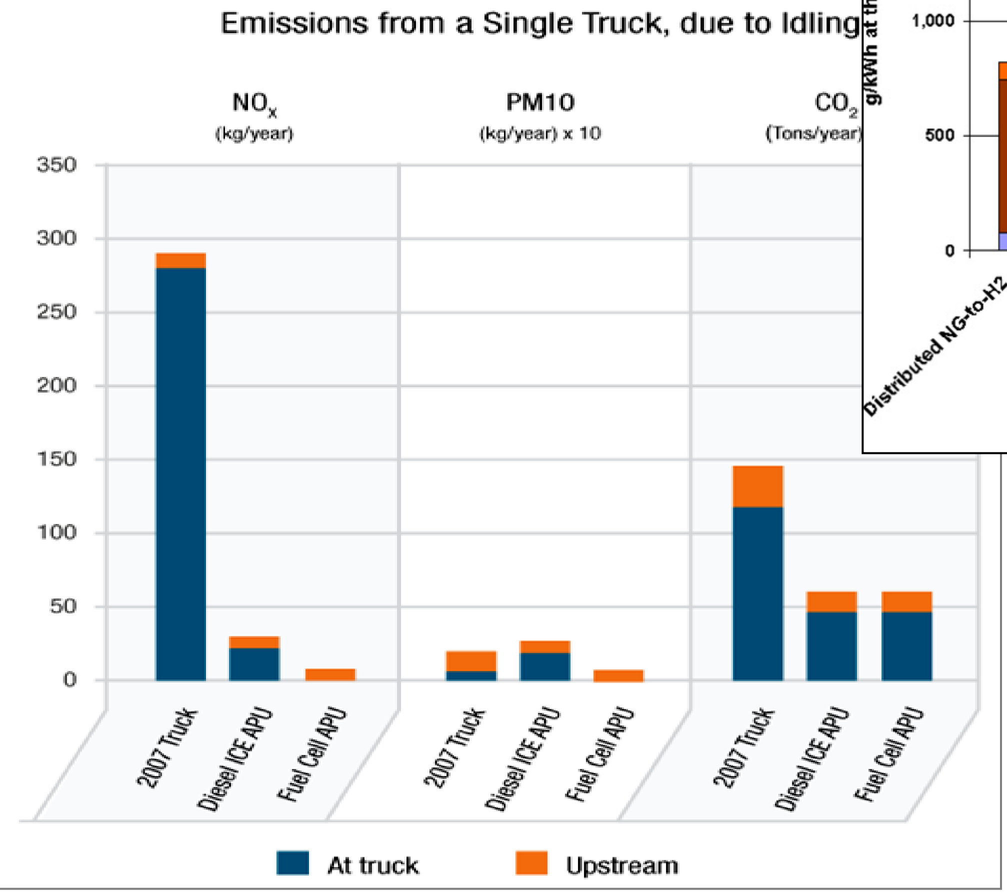
- Allow for rapid refueling — much faster than changing-out or recharging batteries
- Provide constant power without voltage drop
- Eliminate need for space for battery storage and chargers
- *May provide <u>substantial cost-savings</u>* over battery-powered forklifts

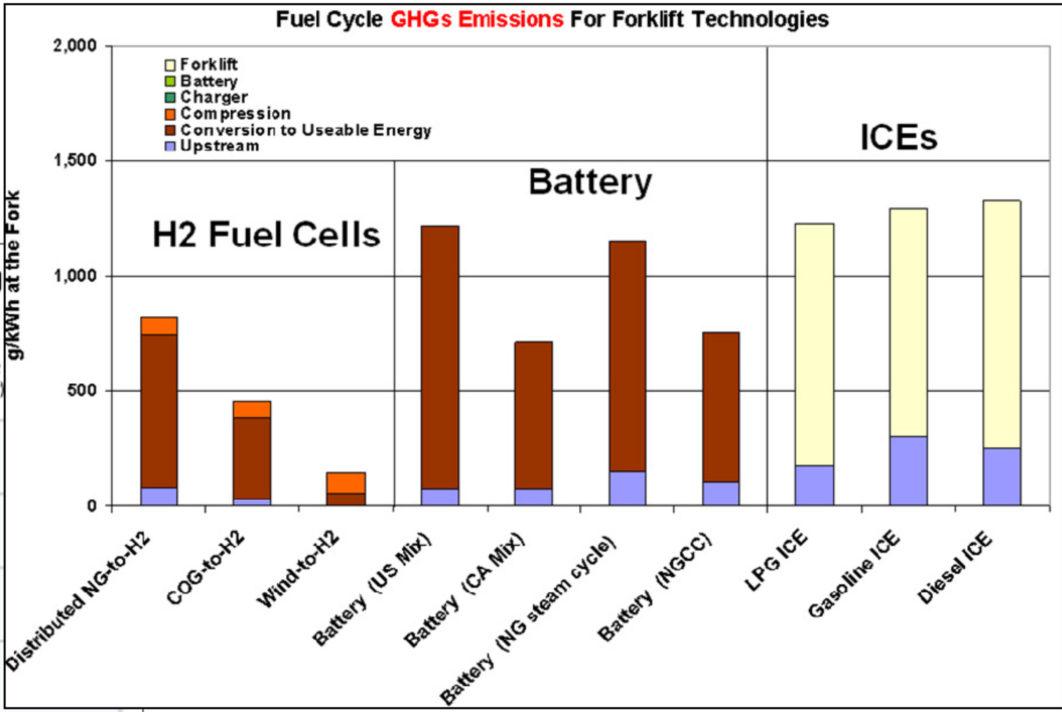
Photo courtesy of Hydrogenics

Fuel Cells for Data Centers ...

- Provide high-quality, reliable, grid-independent on-site critical load power
- Improve the effectiveness of data center power use by 40%, with combined heat-and-power (for cooling and heating)
- Produce no emissions
- Have low O&M requirements
- Can be remotely monitored

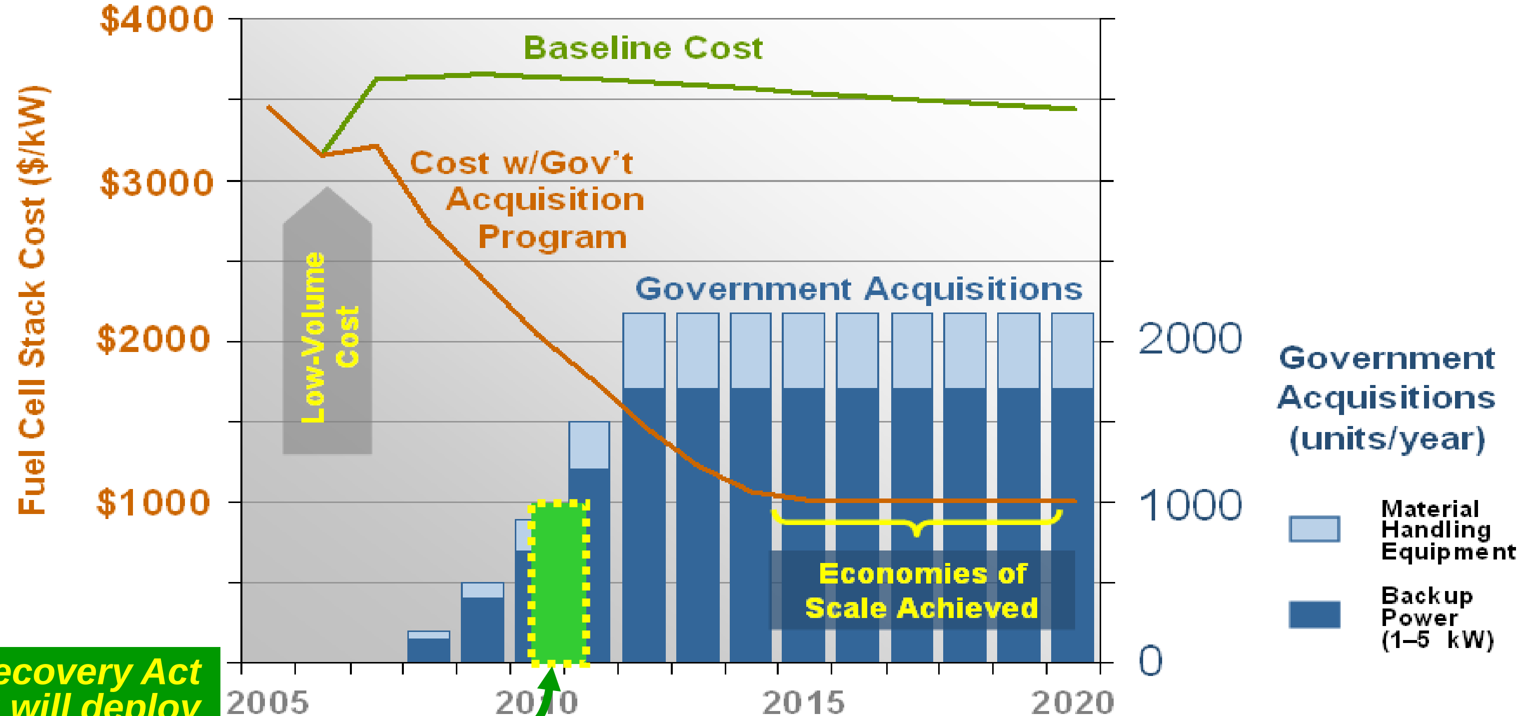
Fuel Cells can provide significant emissions reductions in forklift and APU applications





Government acquisitions could significantly reduce the cost of fuel cells through economies of scale, and help to support a growing supplier base.

Impact of Government Acquisitions on Fuel Cell Stack Costs (for non-automotive fuel cells)



Source: ORNL

Recovery Act funding will deploy up to 1000 fuel cells, in the private sector, by 2012.

We are facilitating the adoption of fuel cells across government and industry:

- **100 fuel cells are being deployed, through interagency agreements.**
- **More interagency agreements under development.**

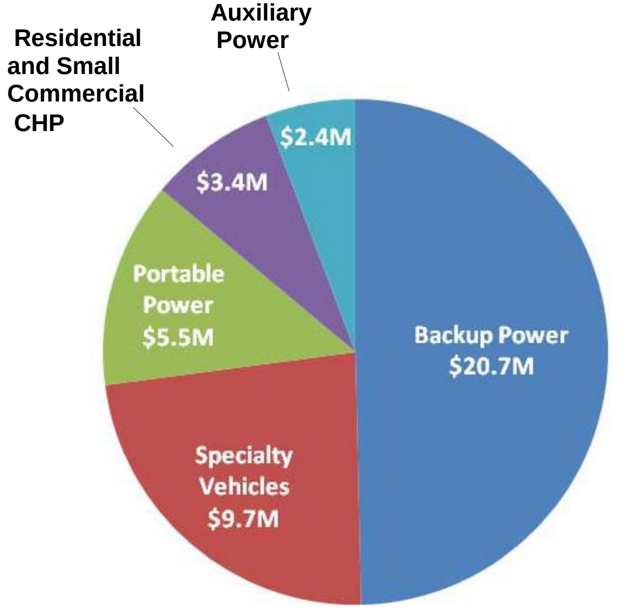
Recovery Act Deployments

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

DOE announced ~$40 million from the American Recovery and Reinvestment Act to fund 12 projects to deploy more than 1,000 fuel cells — to help achieve near term impact and create jobs in fuel cell manufacturing, installation, maintenance & support service sectors.

FROM the LABORATORY to DEPLOYMENT:

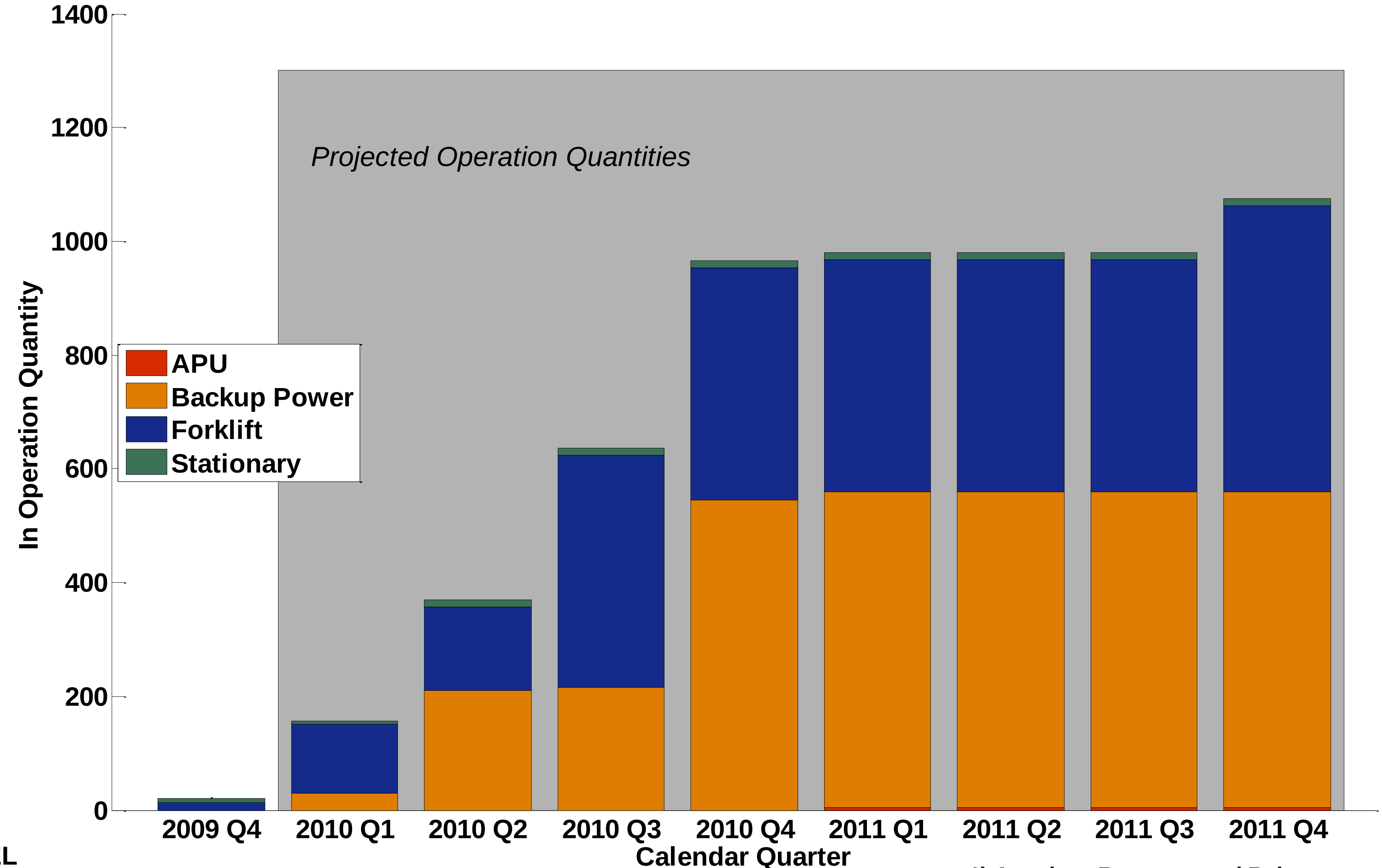
DOE funding has supported R&D by all of the fuel cell suppliers involved in these projects.



Approximately $51 million in cost-share proposed by industry participants—for a total of nearly $93 million.

COMPANY	AWARD	APPLICATION
Delphi Automotive	$2.4 M	Auxiliary Power
FedEx Freight East	$1.3 M	Specialty Vehicle
GENCO	$6.1 M	Specialty Vehicle
Jadoo Power	$2.2 M	Backup Power
MTI MicroFuel Cells	$3.0 M	Portable
Nuvera Fuel Cells	$1.1 M	Specialty Vehicle
Plug Power, Inc. (1)	$3.4 M	CHP
Plug Power, Inc. (2)	$2.7 M	Backup Power
University of North Florida	$2.5 M	Portable
ReliOn Inc.	$8.5 M	Backup Power
Sprint Comm.	$7.3 M	Backup Power
Sysco of Houston	$1.2 M	Specialty Vehicle

ARRA Fuel Cell Deployment Estimates



NREL

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1) American Recovery and Reinvestment Act

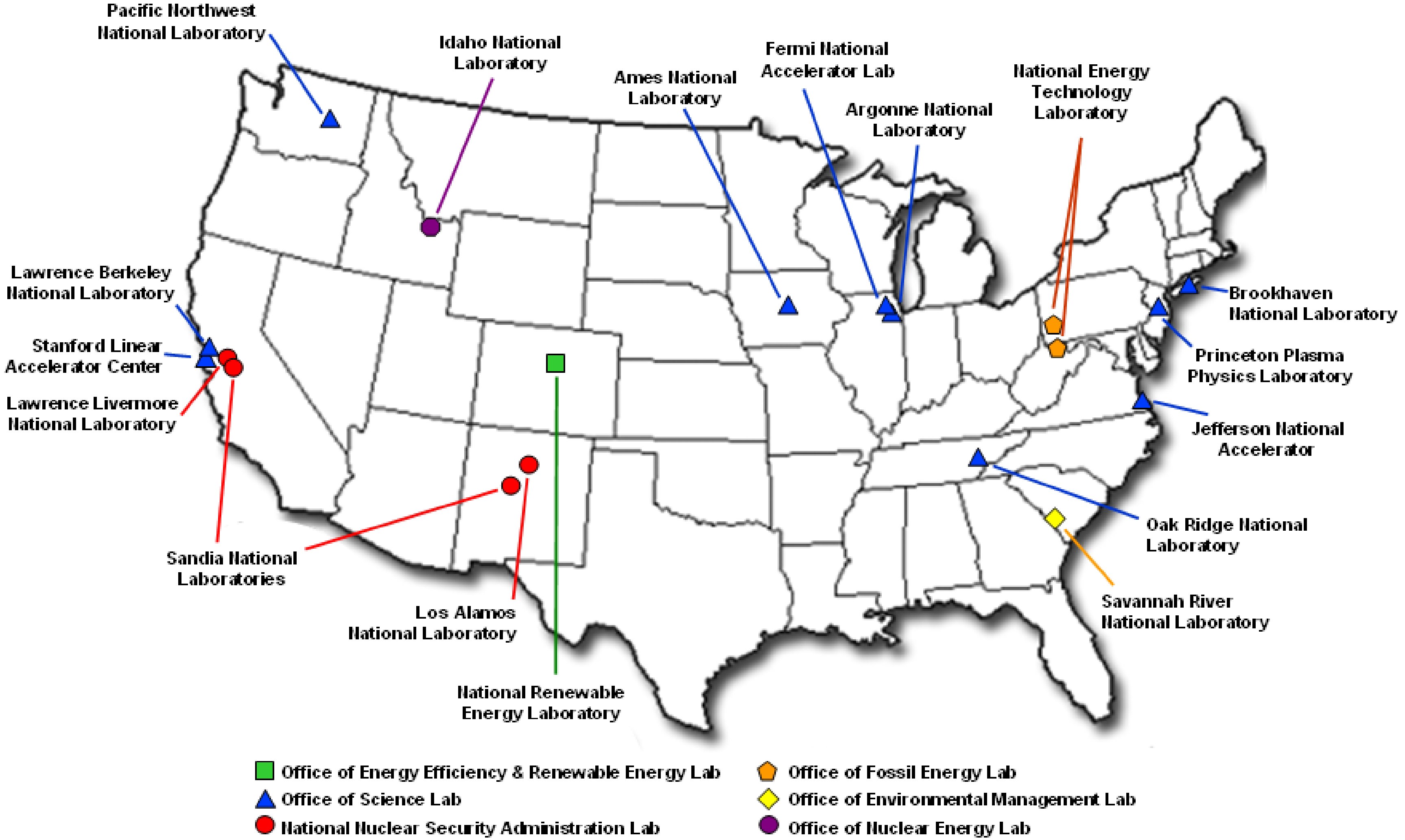
Preliminary estimates. DOE will continue to update status as units are delivered

http://www1.eere.energy.gov/hydrogenandfuelcells/applications.html

Market Transformation - Examples

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

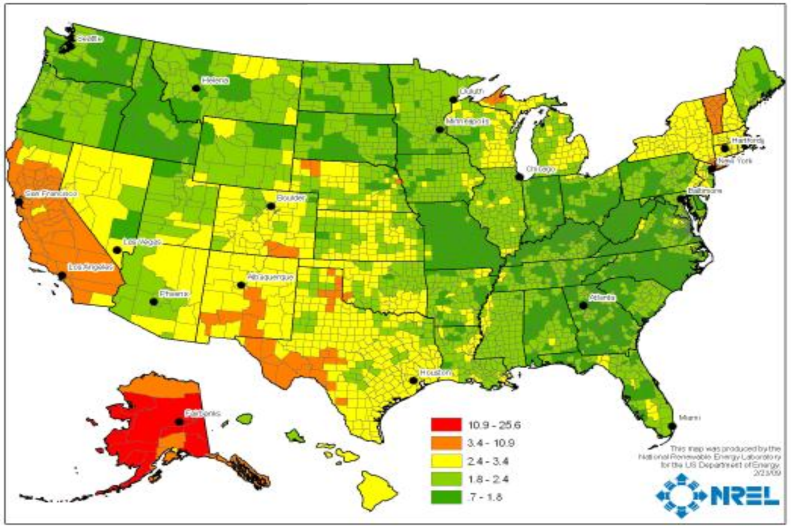
Potential deployments at DOE facilities: We are investigating the possibility of using fuel cells for primary power where high electricity costs and RPS constraints exist.



Systems Analysis: *Commercialization*

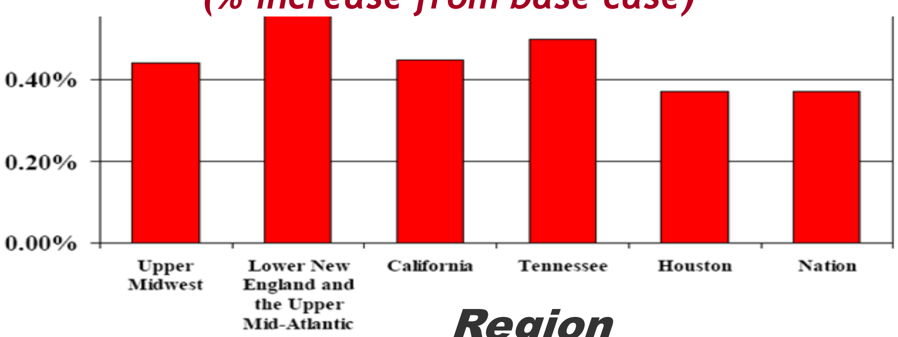
We are assessing the costs and benefits of various technology pathways and identifying key technological gaps, by conducting:

Life-cycle analysis, Emissions analysis, Environmental analysis, Systems integration analysis

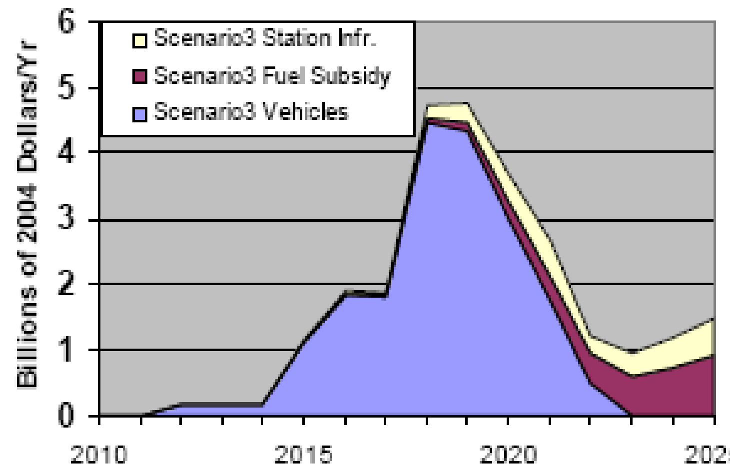


Areas with a high ratio of electricity cost to natural gas cost provide the best opportunities for stationary fuel cells.

Successful Commercialization Will Have Significant Impact on Employment *(% increase from base case)*



Cost of Incentives *(for vehicles and fueling stations)* **Will Average Less than $3 billion/year over 15 years***



****This is substantially lower than the cost of alternative fuel incentives already in place.***

Assessing the Potential for Micro CHP

Inexpensive Natural Gas

Natural Gas Cost ($/kWh)	
WYOMING	$ 0.029
ALASKA	$ 0.030
UTAH	$ 0.032
COLORADO	$ 0.035
MONTANA	$ 0.038
NORTH DAKOTA	$ 0.039
IDAHO	$ 0.040
SOUTH DAKOTA	$ 0.040
NEW MEXICO	$ 0.042
CALIFORNIA	$ 0.042

Price of electricity

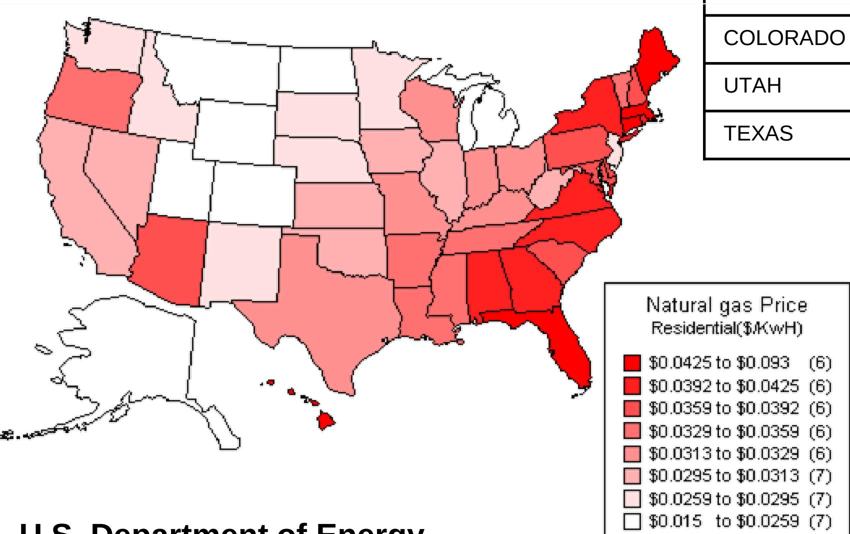
Price of natural gas

Energy Price Ratio	
ALASKA	5.03
CALIFORNIA	3.47
CONNECTICUT	3.33
NEW YORK	3.23
NEW JERSEY	3.03
MASSACHUSETTS	2.88
WYOMING	2.80
COLORADO	2.75
UTAH	2.70
TEXAS	2.68

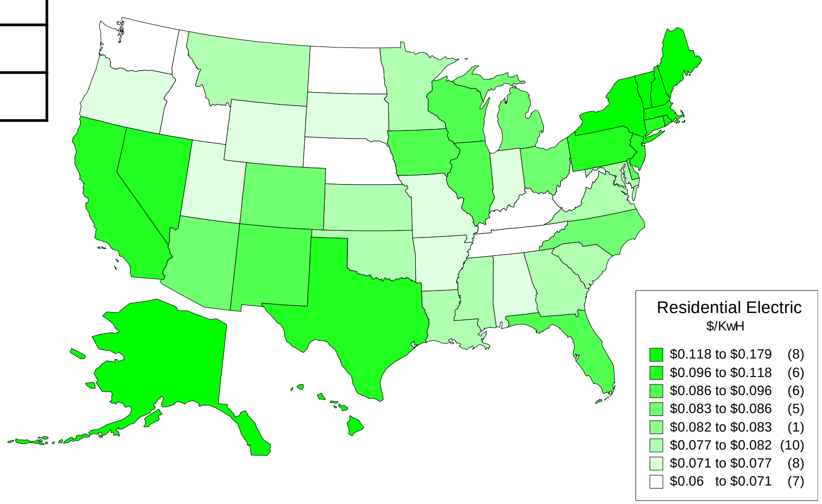
Expensive Electricity

Electricity Cost ($/kWh)	
HAWAII	$ 0.235
CONNECTICUT	$ 0.194
NEW YORK	$ 0.181
MASSACHUSETTS	$ 0.165
NEW JERSEY	$ 0.159
ALASKA	$ 0.153
MAINE	$ 0.151
NEW HAMPSHIRE	$ 0.150
CALIFORNIA	$ 0.146
VERMONT	$ 0.146

Natural Gas Prices



Electricity Prices

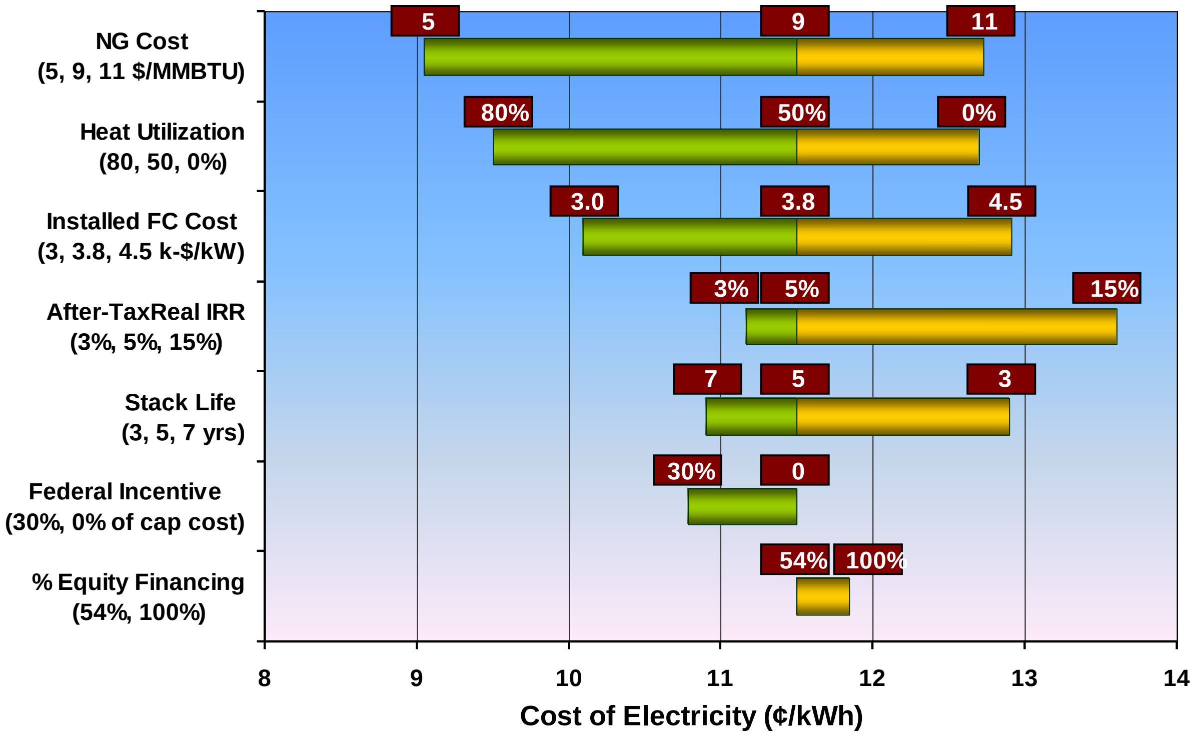


Stationary Fuel Cells – Cost analysis

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

Analysis efforts are underway, to provide information on potential costs and benefits of a variety of stationary fuel cell applications.

Example: Cost of Electricity from Commercial-Scale Stationary Fuel Cell



Performance Parameters

System Electric Efficiency	= 45% (LHV Basis)
System Total Efficiency	= 77% (LHV Basis)
System Size	= 1,400 kW
System Life	= 20 years
Capital cost	= $3.5 million
Installed cost	= $5.3 million

Financial Assumptions

Startup year	= 2010
Financing	= 54% equity
Interest rate	= 7%
Financing period	= 20 years
After-tax Real IRR	= 5%
Inflation rate	= 1.9%
Total tax rates	= 38.9%
Depreciation schedule	= 7 years (MACRS)
Payback period	= 11 years

Stack replacement cost distributed annually

Operation Assumptions

System utilization factor	= 95%
Restacking cost	= 30% of installed cap. cost
Heat value	= cost of displaced natural gas from 80% efficient device

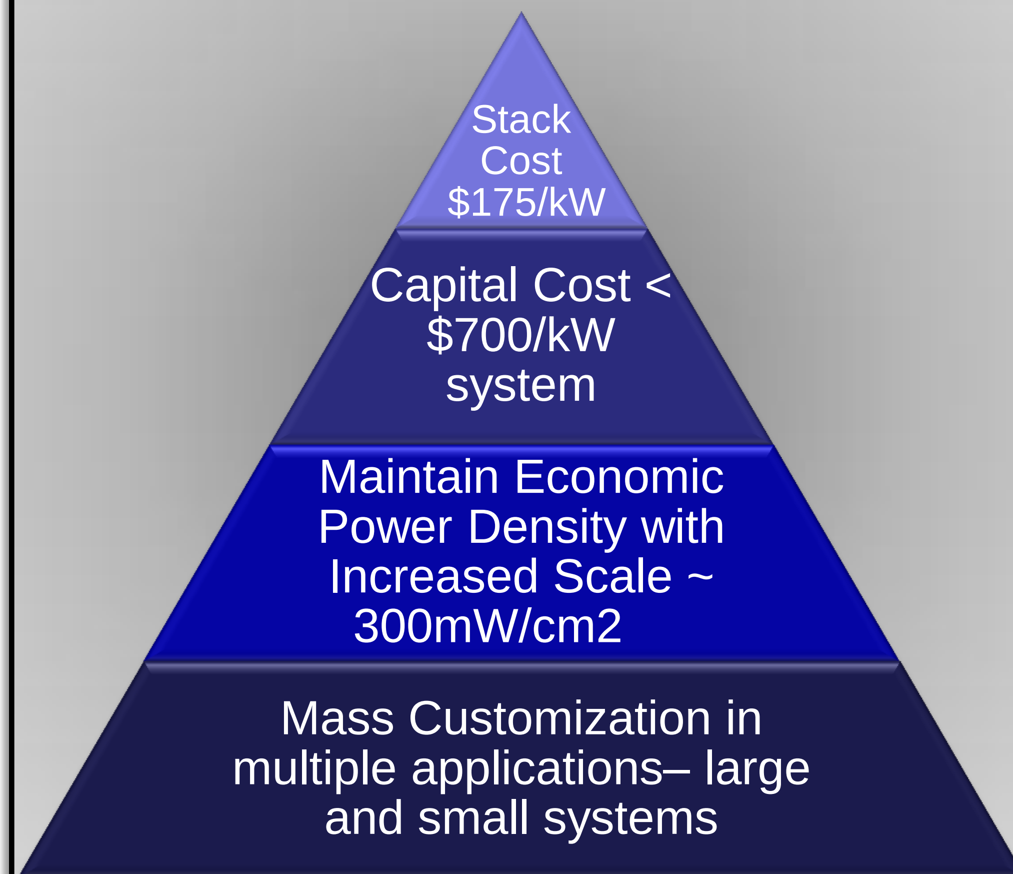
Source: NREL Fuel Cell Power Model

Example for MCFC 1.4 MW

Advanced (Coal) Power Systems Goals

- **2010**:
  - **45-50% Efficiency (HHV)**
  - **99% SO_2 removal**
  - **NOx< 0.01 lb/MM Btu**
  - **90% Hg removal**
- **2012**:
  - **90% CO_2 capture**
  - ***<10% increase in COE with carbon sequestration***
- **2015**
  - **Multi-product capability (e.g, power + H_2)**
  - **60% efficiency (measured without carbon capture)**

SECA 2010 Performance Assessment Rating Tool (OMB)



http://www.netl.doe.gov/technologies/coalpower/fuelcells/seca/

Example: California

- **Hydrogen Fueling Stations**
  - > **20 stations currently operating**
  - **~ 10 additional stations planned**

- **Hydrogen Fuel Cell Vehicle Deployments: CA Fuel Cell Partnership is assessing the potential to deploy over**
  - **4,000 vehicles by 2014**
  - **50,000 vehicles by 2017**

http://www.fuelcellpartnership.org/

Potential H2 Communities in Southern California

Key Partnerships

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 Hydrogen and Fuel Cells in the 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***

International Partnership for Hydrogen and Fuel Cells in the Economy

Representatives from 16 member countries & the European Commission

- **Facilitates international collaboration on RD&D and education**
- **Provides a forum for advancing policies and common codes and standards**
- **Guided by four priorities:**
  1. Accelerating market penetration and early adoption of hydrogen and fuel cell technologies and their supporting infrastructure
  2. Policy and regulatory actions to support widespread deployment
  3. Raising the profile with policy-makers and public
  4. Monitoring technology developments

Current Activities:

- IPHE Infrastructure Workshop (Sacramento, 2010)
- Published Demonstration and Deployment Map on Web site (www.iphe.net)
- Released final report on IEA-IPHE Infrastructure Workshops
- Working on "Hydrogen & Fuel Cells for the 21st Century" — a policy brief and technology status update for IPHE countries
- Coordination on 31 international projects
- Fuel Cell Cost Analysis Comparison
- Global IPHE Project Development:
  - Hydrogen Highways
  - Youth Education (WHEC 2010)
  - Waste/Excess Hydrogen Analysis

International Energy Agency – Implementing Agreements

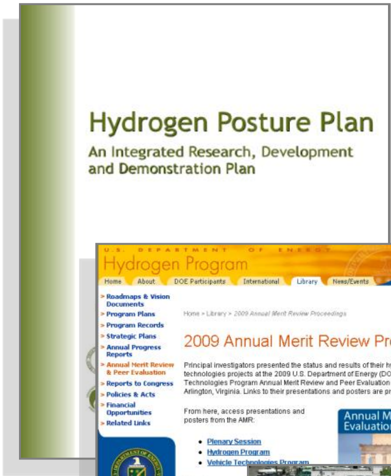
Advanced Fuel Cells Implementing Agreement: 19 member countries currently implementing six annexes

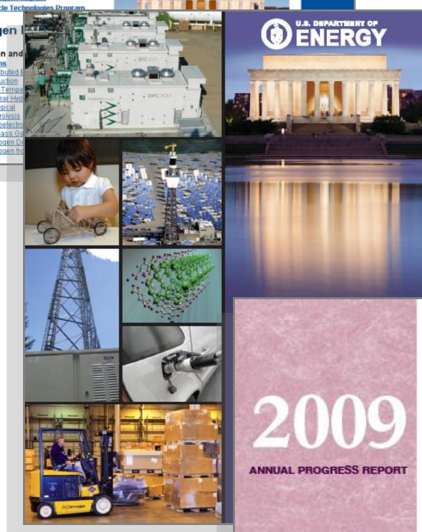
Hydrogen Implementing Agreement: 21 member countries, plus the European Commission currently implementing nine tasks

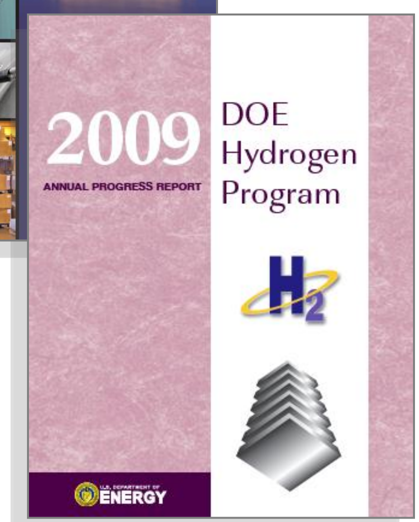
Other Collaborations

Joint Technology Initiative (JTI); **MOUs** (NEDO-AIST-LANL); **Bi-lateral agreements**

Key Program Documents







Fuel Cell Program Plan

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

→ ***Replacement for current* Hydrogen Posture Plan**

→ ***To be released in 2010***

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

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 October 2009***

www.hydrogen.energy.gov/annual_review08_report.html

Annual Progress Report

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

→ ***Latest edition published November 2009***

www.hydrogen.energy.gov/annual_progress.html

Next Annual Review: June 7 – 11, 2010

Washington, D.C.

http://annualmeritreview.energy.gov/

Thank you

http://www.eere.energy.gov/hydrogenandfuelcells

Sunita.Satyapal@ee.doe.gov