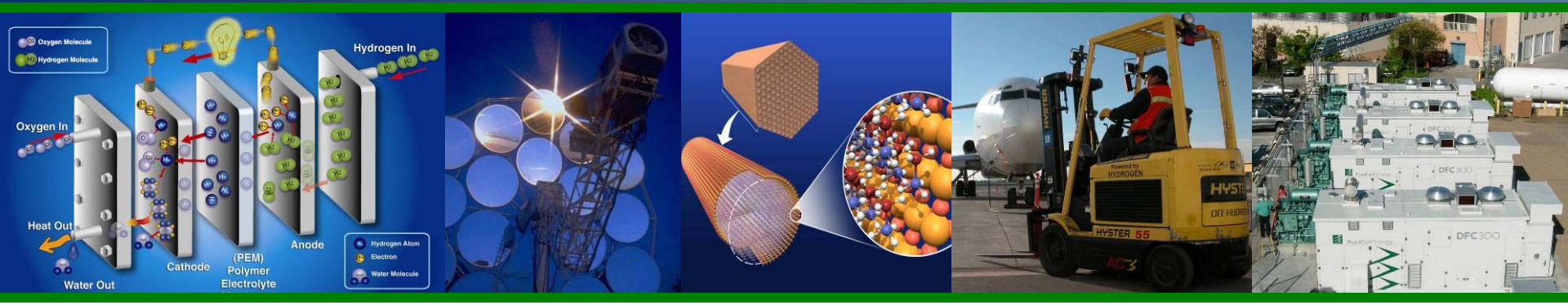
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



Overview of United States Hydrogen and Fuel Cell Activities

U.S. Department of Energy

Dr. Sunita Satyapal

Fuel Cell Technologies Program

CNG and Hydrogen Lessons Learned Workshop

December 10, 2009

Workshop Objectives

- To coordinate lessons learned from compressed natural gas and hydrogen vehicles
- Collect feedback from demonstration activities and real world applications in the United States and internationally
- Identify additional RD&D to ensure safe use of onboard and bulk storage hydrogen and compressed natural gas tanks
- Enhance domestic and international codes and standards harmonization
- Identify potential future collaborations, workshops, education and communication strategies

Hydrogen and Fuel Cells — *Where are we today?*

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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.

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

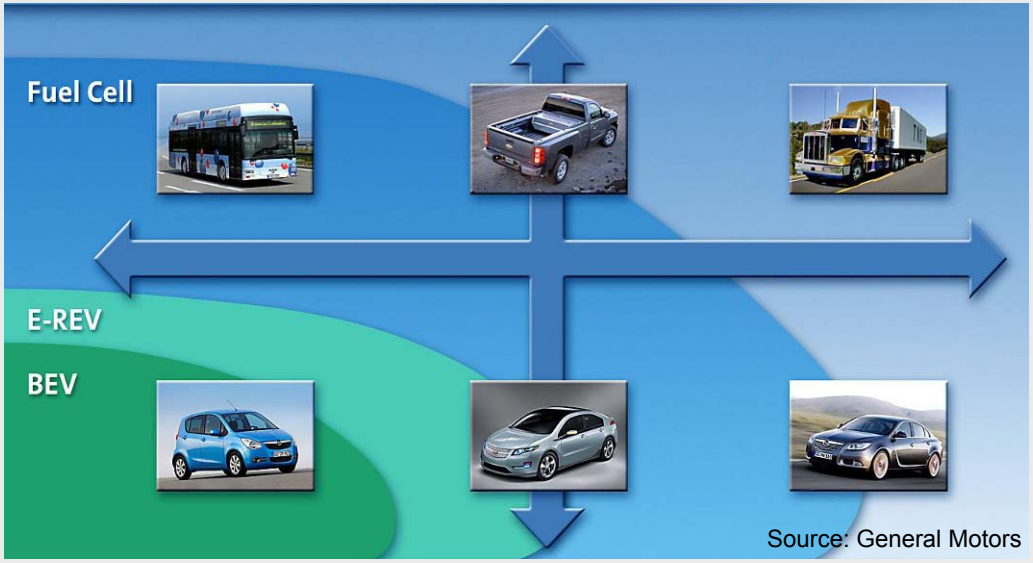
Fuel Cells for Transportation

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.



NGVs — *Where are we today?*

Natural Gas Supplies

In the U.S., there are currently:

>450K Natural Gas Wells

>300K Miles of NG pipeline

~ 90 Years of Supply

>Potential Resources: 1,836 TCF (PGC)

Proven Reserves: 245 TCF (EIA)

2008 Consumption: 23.3 TCF (EIA)

Natural Gas Fueling Stations

In the U.S., there are currently:

835 Natural Gas (CNG + LNG) fueling stations (~16K worldwide)

Natural Gas Vehicles

In North America, there are currently:

- ***~100,000 natural gas on-road vehicles (~10.5 million worldwide)***
- ***~12,000 Transit Buses***

Examples include:

8 Heavy-Duty engine models

84 Small Volume Manufacturers Models

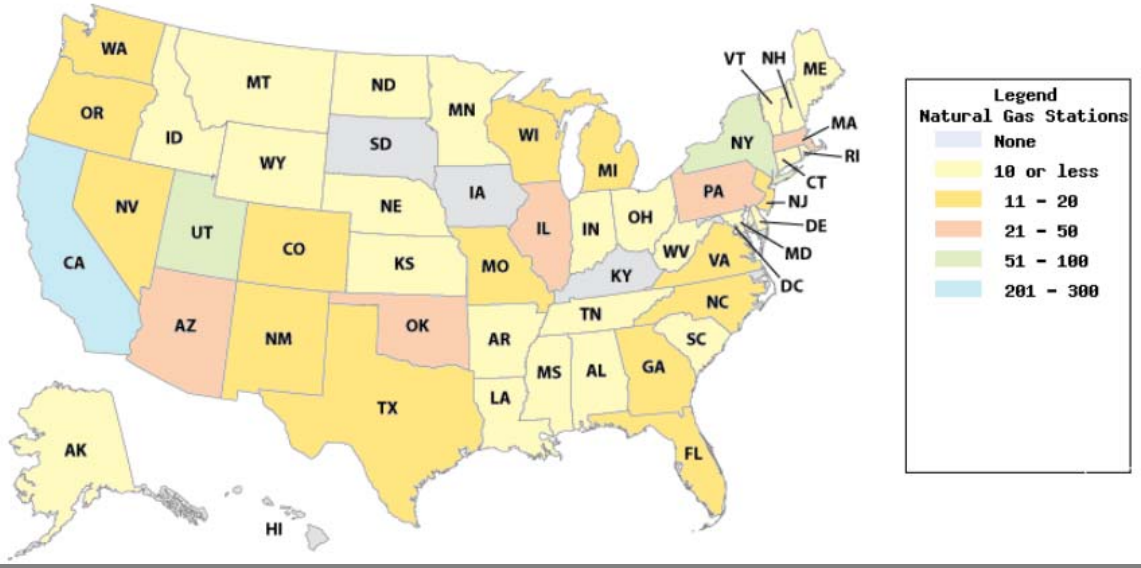
1 OEM light-duty vehicle model

> 40 OEM heavy-duty vehicle models

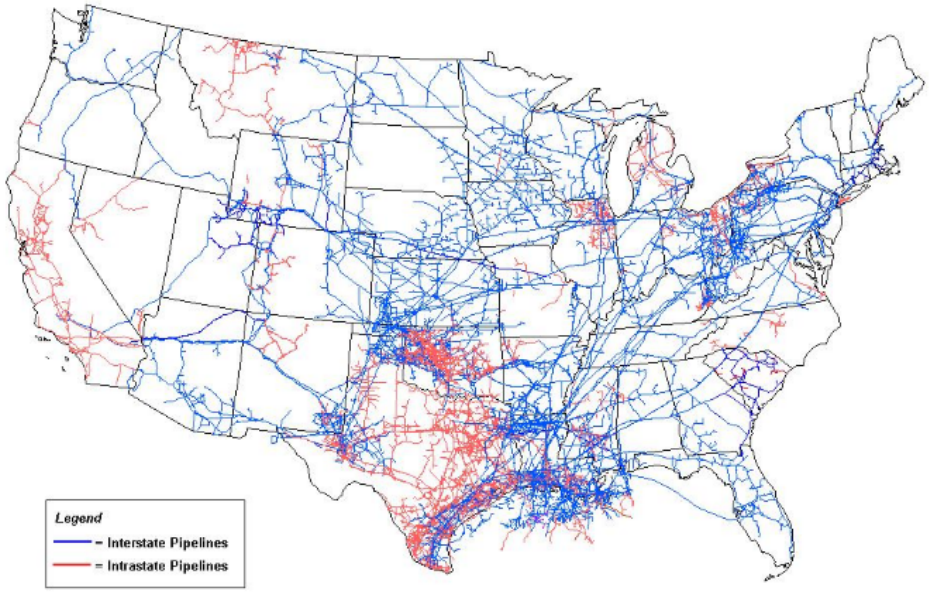
A wide-variety of products are available from light-duty OEMs, heavy-duty OEMs and Small Volume Manufacturers.

NGVs — *Where are we today?*

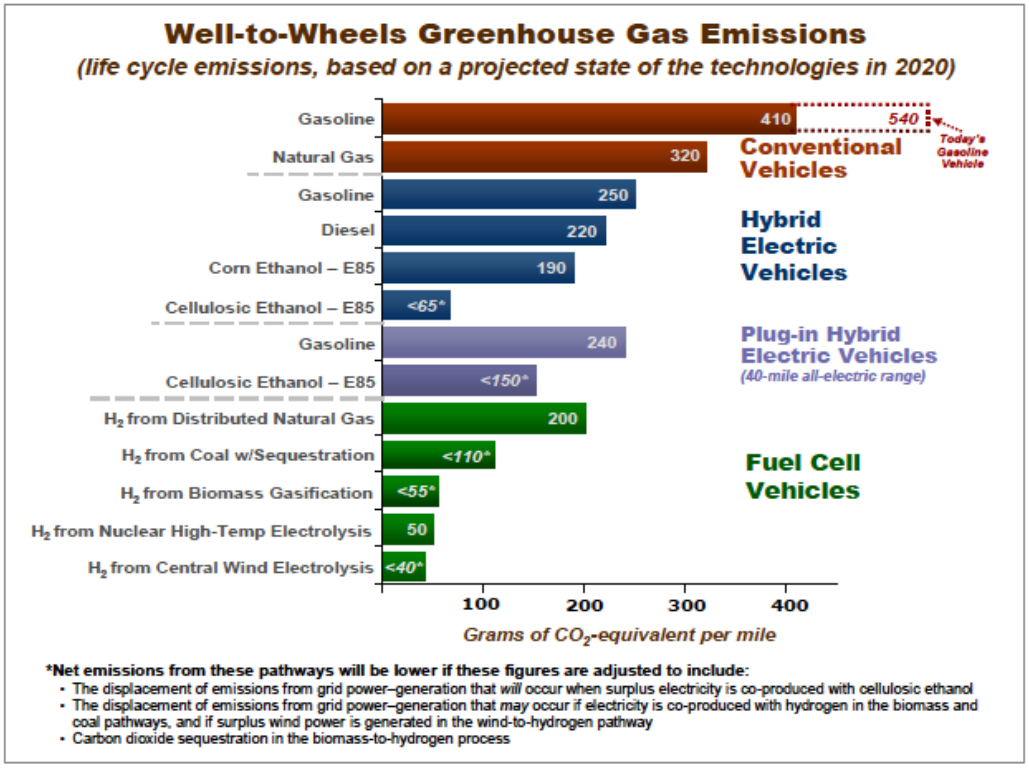
U.S. Natural Gas Fueling Station Locations

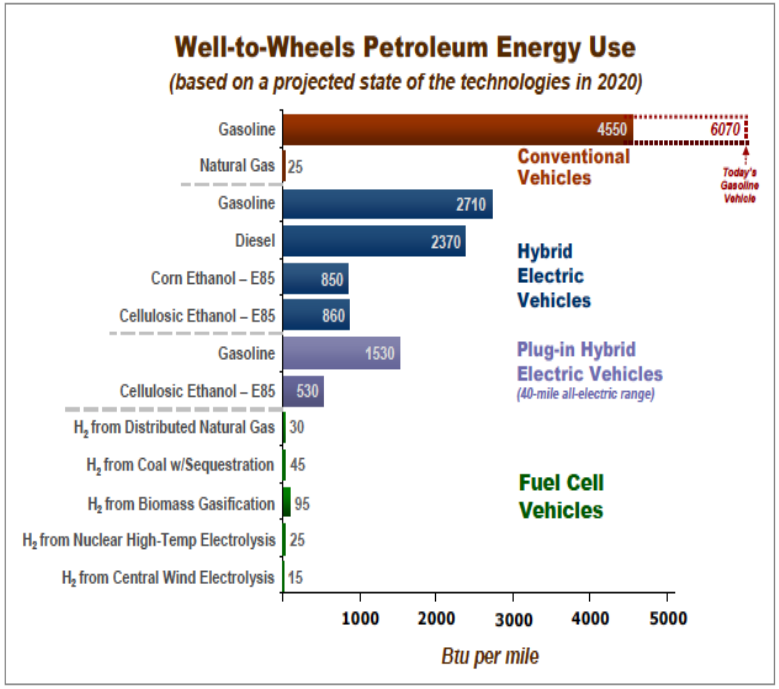


U.S. Natural Gas Pipeline Network, 2009



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





- **Analysis will be periodically updated as more data becomes available and as assumptions are validated.**

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

Key Challenges

The DOE Program has been addressing the key challenges facing the widespread commercialization of hydrogen and fuel cell technologies.

Technology Barriers*

Fuel Cell Cost & Durability

Targets*:

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

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

Fuel Cost

Target: $2 – 3 /gge, delivered for H2

Fuel 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

Fuel 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**

Example of Collaborations

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

Federal Agencies

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

– *Interagency coordination through staff-level Interagency Working Group*

– *Assistant Secretary-level Interagency Task Force mandated by EPACT 2005, led by DOE-EERE.*

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

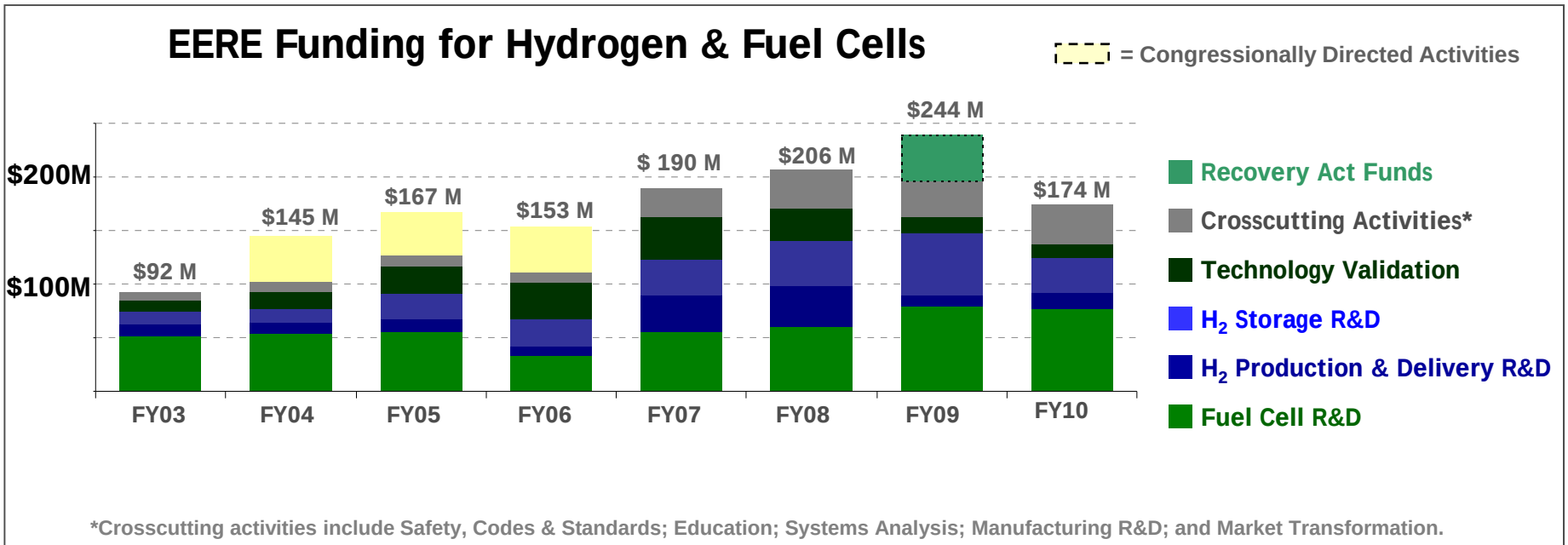
Other Federal Labs: **Jet Propulsion Lab, National Institute of Standards & Technology, National Energy Technology Lab, Idaho National Lab**

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**

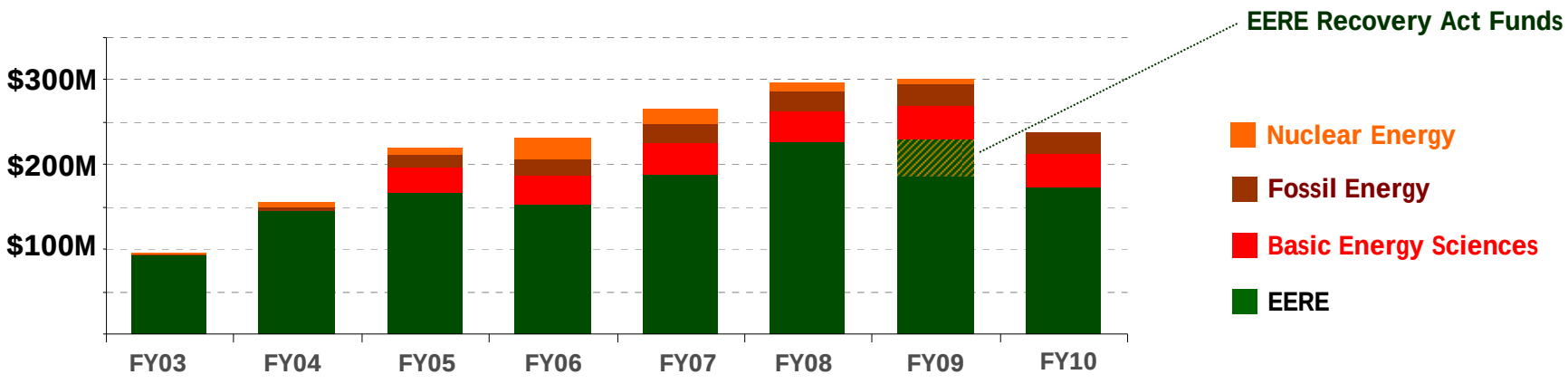
DOE Funding History

EERE Funding for Hydrogen & Fuel Cells



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

DOE Funding for Hydrogen & Fuel Cells



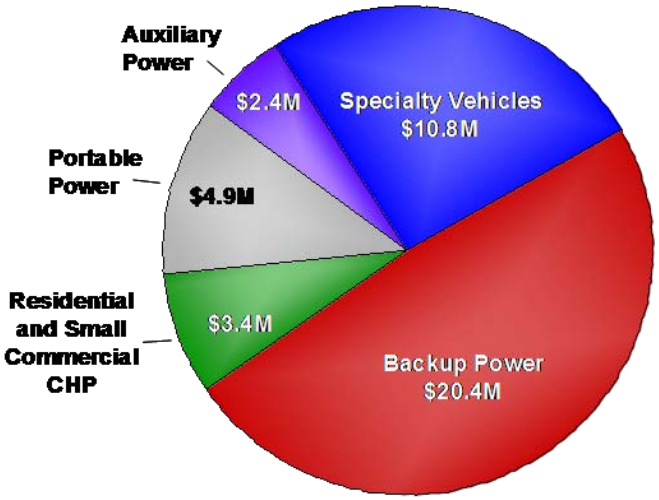
Recovery Act Funding for Fuel Cells

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

DOE announced more than $40M from the American Recovery and Reinvestment Act to fund 13 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.



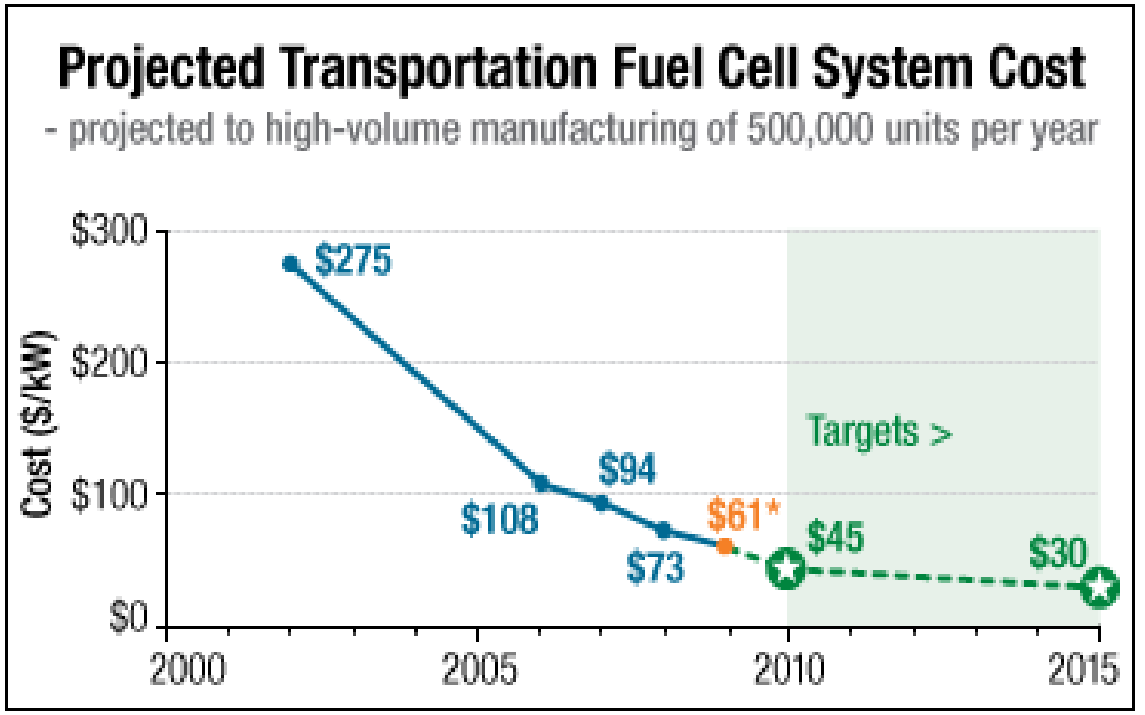
Approximately $72 million in cost-share proposed by industry participants—for a total of nearly $114 million.

Examples of Projects

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	$1.8 M	Backup Power
MTI MicroFuel Cells	$2.4 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
ReliOn Inc.	$8.6 M	Backup Power
Sprint Comm.	$7.3 M	Backup Power
Sysco of Houston	$1.2 M	Specialty Vehicle

Hydrogen Fuel Cell R&D — *Example of Progress*

- **We've reduced the cost of producing hydrogen by > 40% since 2003**
- **We've reduced the high volume cost of fuel cells by > 75% since 2002**
- **We've more than doubled FC durability since 2006**
- **High pressure tanks can enable driving ranges of > 300 miles**
- **Validated 140 FCVs and 20 stations**
  - **> 2.3 million miles traveled**



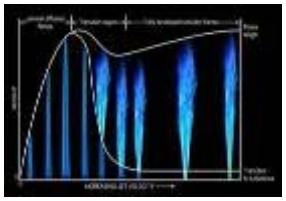
http://www1.eere.energy.gov/hydrogenandfuelcells/accomplishments.html

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 hands-on training for emergency responders

Growing number of C&S published

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)*

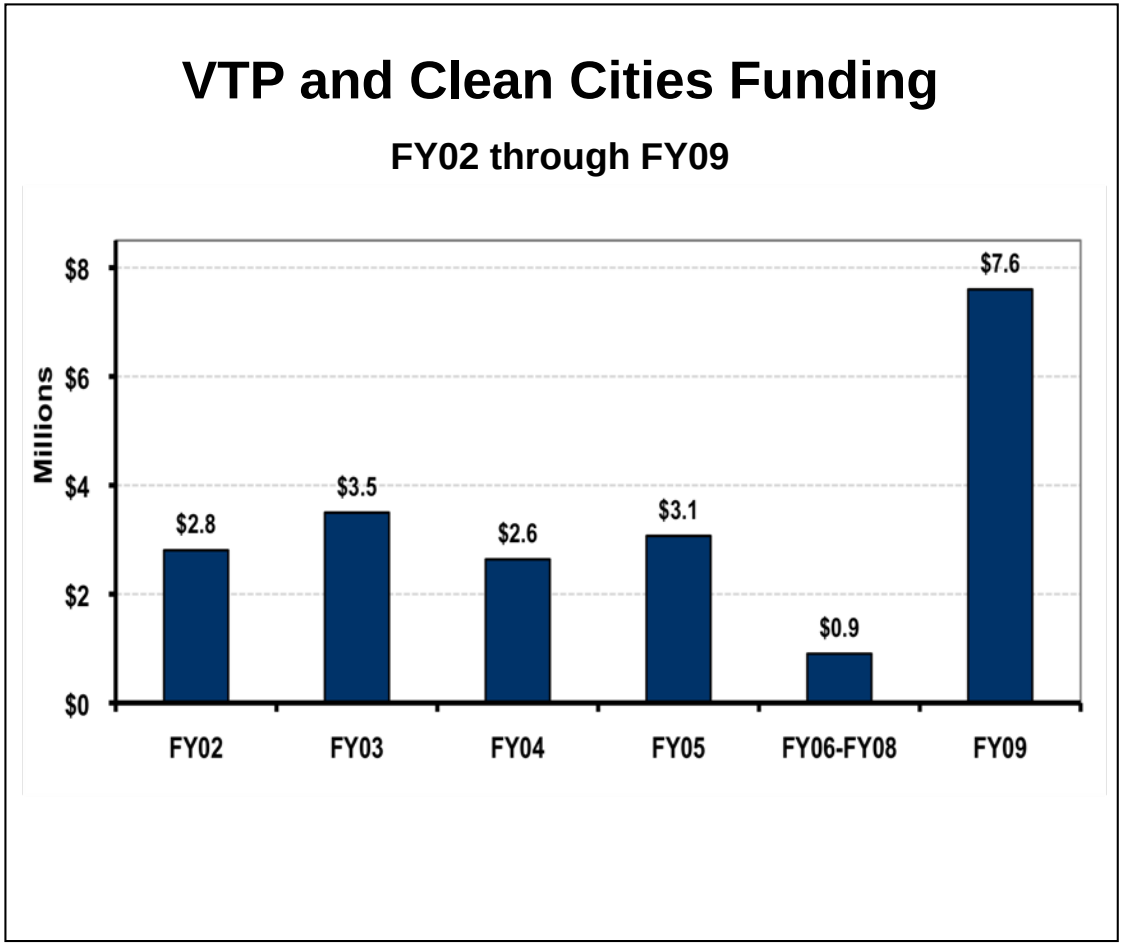
Launched courses for code officials and first responders (>7000 users)

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

Conducted workshops to help state officials identify deployment opportunities

VTP and Clean Cities funding related to NGV

- $ 5M for new NGV RD&D projects
  - Solicitation anticipated in Spring 2010
- $ 300 M for ARRA projects that included multiple alternative fuel technologies
  - ~80% included NGV technologies
- $ 4 M in other Clean Cities awards specific to Natural Gas Vehicle deployment and infrastructure
- $ 3.6 M in grants for education and outreach projects for all alternative fuels
  - Includes some for NGVs



Example of 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 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***

Key Program Documents

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 early 2010***

Annual Merit Review & Peer Evaluation Report

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

→ ***Next edition to be published in Fall 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

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

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

Next Annual Review: June 7 – 11, 2010

Washington, D.C.

http://annualmeritreview.energy.gov/

www.hydrogen.energy.gov

Thank you

www.hydrogen.energy.gov

Back-Up Slides

Hydrogen Production & Delivery 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.

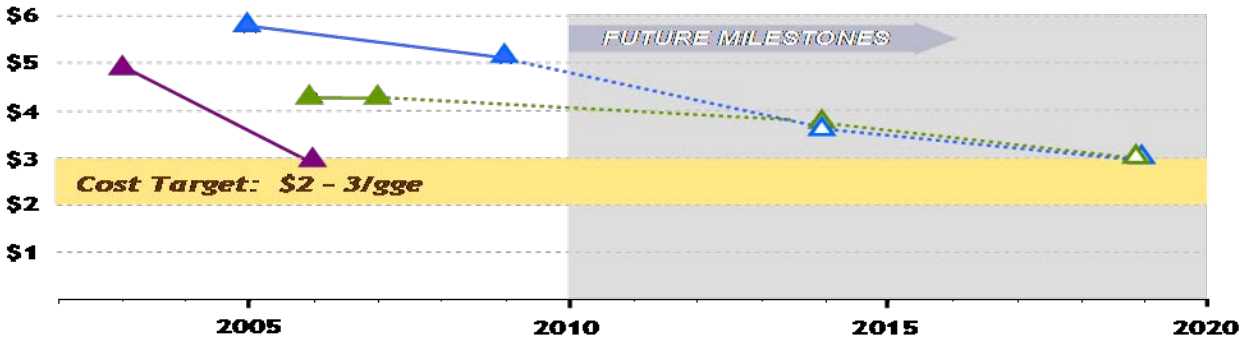
KEY PRODUCTION OBJECTIVE: **Reduce the cost of hydrogen (delivered & untaxed) to $2 – 3 per gge (gallon gasoline equivalent)**

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

– $/gallon gasoline equivalent (gge), untaxed –

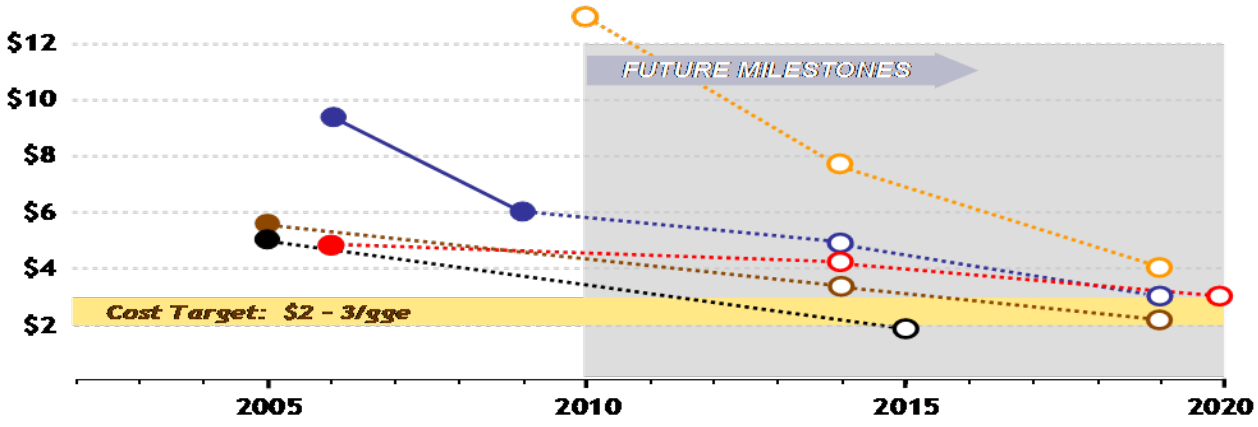
NEAR TERM:
Distributed Production

- H_2 from Natural Gas
- H_2 from Bio-Derived Renewable Liquids
- H_2 from Electrolysis



LONGER TERM:
Centralized Production

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



* Distributed status and targets assume station capacities of 1500 kg/day, with 500 stations built per year. Status and targets for centralized production assume the following production 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.

Hydrogen Production – Fossil

Hydrogen Energy International Commercial Demonstration of Advanced IGCC with Carbon Capture

- 257 MWe (net) IGCC in Kern County, CA
- 90% CO_2 capture (2,000,000 tons/year) sequestered in an EOR application
- DOE - $308 million
- Total - $2,840 million
- Construction start: March 2011
- Demonstration start: 2015

IGCC with Hydrogen Turbine and Full Integrated Carbon Capture & Sequestration

FutureGen Path Forward:

- DOE to pursue the FutureGen project in Mattoon, Illinois with the FutureGen Industrial Alliance
- Goal is to capture & permanently sequester at least 1 million metric tons/year CO_2
- DOE to contribute $1.073 Billion ($1 billion American Recovery and Reinvestment Act of 2009 funds)

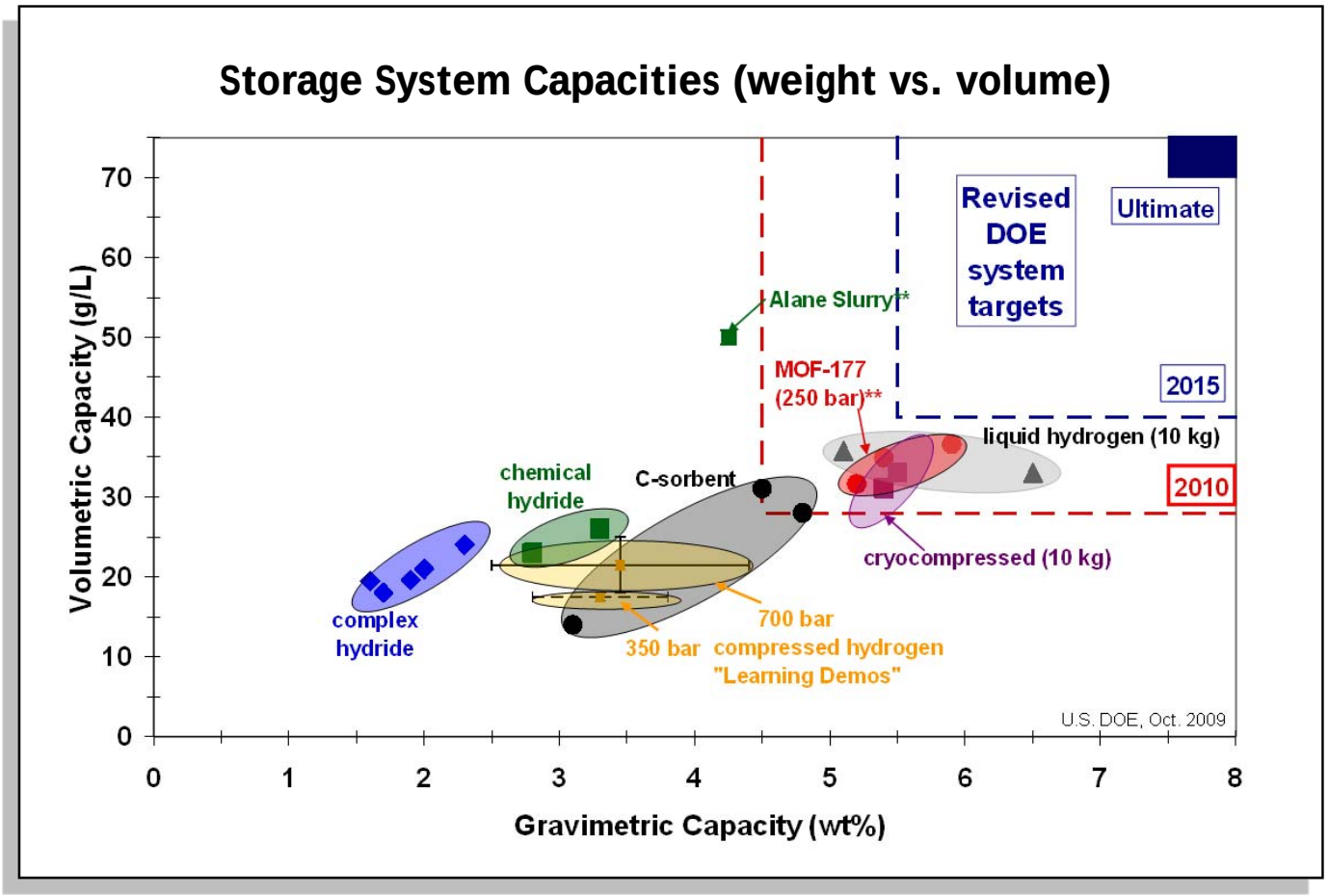
Next Steps Include:

- A rapid restart of preliminary design activities
- Completion of a site-specific preliminary design and updated cost estimate
- Expansion of the Alliance sponsorship group
- Development of a complete funding plan
- Potential additional subsurface characterization

http://www.futuregenalliance.org/

Storage R&D

- High pressure tanks are viable for early market penetration and demonstrate > 300 mile range
- Long term approaches focus on low-pressure materials approaches



- 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**

Technology Validation

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

Demonstrations are essential for validating the performance of technologies in integrated systems, under real-world conditions.

DOE Vehicle/Infrastructure Demonstration

Four teams in 50/50 cost-shared projects with DOE




- **140 fuel cell vehicles and 20 fueling stations demonstrated**
- **> 2.3 million miles traveled, > 115,000 kg H_2 produced or dispensed**
- **Analysis by NREL shows:**
  - **Efficiency:** 53 – 59% **(>2x higher than gasoline engines)**
  - **Range:** ~196 – 254 miles
  - **Fuel Cell System Durability:** ~ 2,500 hrs **(~75,000 miles)**

Demonstrations of Specialty Vehicles: *NREL is collecting operating data from federal deployments and Recovery Act projects—to be aggregated, analyzed, and reported industry-wide.*

→ **Will include data such as:** reliability & availability; time between refueling; operation hours & durability; efficiency; H_2 production; refueling rate; costs (installation, operation, and lifecycle); and others.

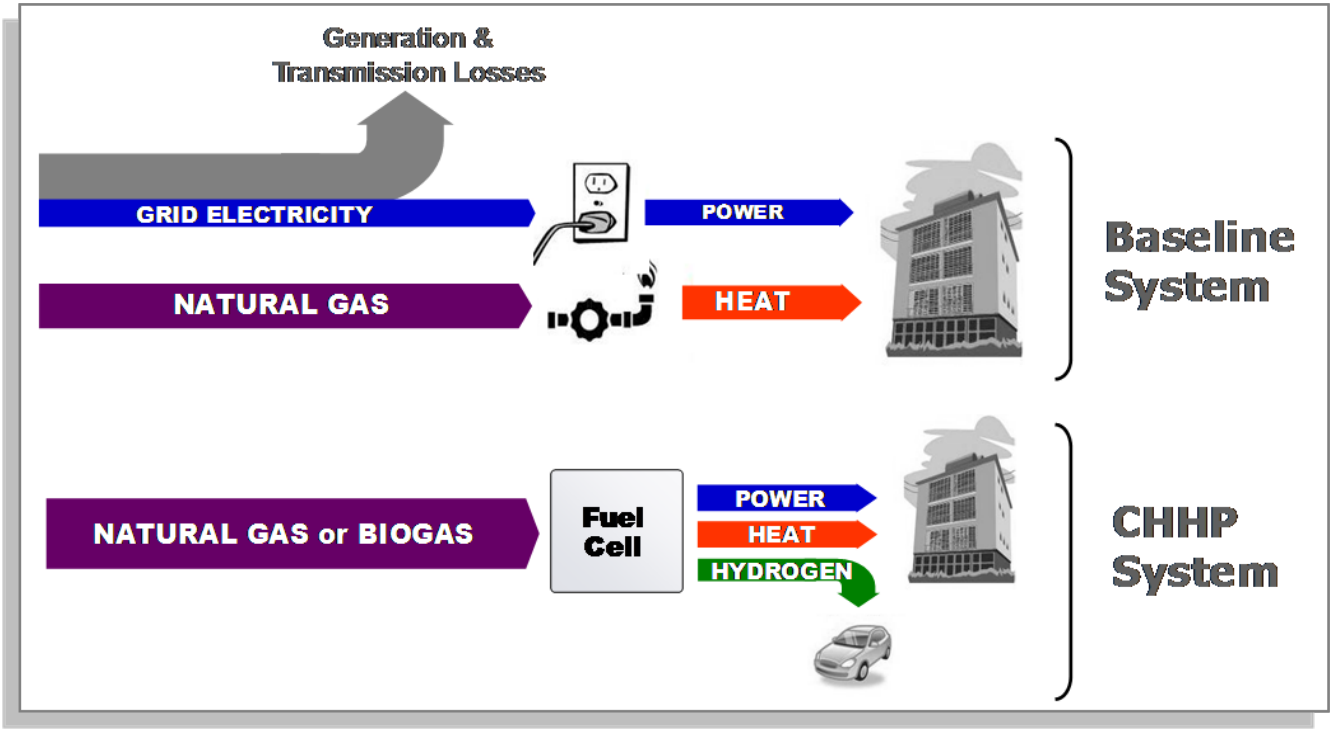
→ 40 forklifts at a Defense Logistics Agency site have already completed 7,000 refuelings in 7 months.

Other Demonstrations: *DOE is also evaluating real-world bus fleet data (DOD and DOT collaboration) and demonstrating stationary fuel cells — e.g., tri-generation (combined heat, hydrogen & power w biogas).*

Technology Validation – *Tri-Gen Highlight*

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

- **System has been designed, fabricated and shop-tested (>6,000 hrs).**
- **On-site operation and data-collection planned to begin in FY10.**



Preliminary Test Results

- **Coproduced 5 to 10 lb/hr H_2 with > 200 kW electricity**
- **Estimated hydrogen recovery at 80 to 85%**
- **Product purity <0.2 ppm CO; <2 ppm CO_2**

Combined heat, hydrogen, and power systems (CHHP) can:

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

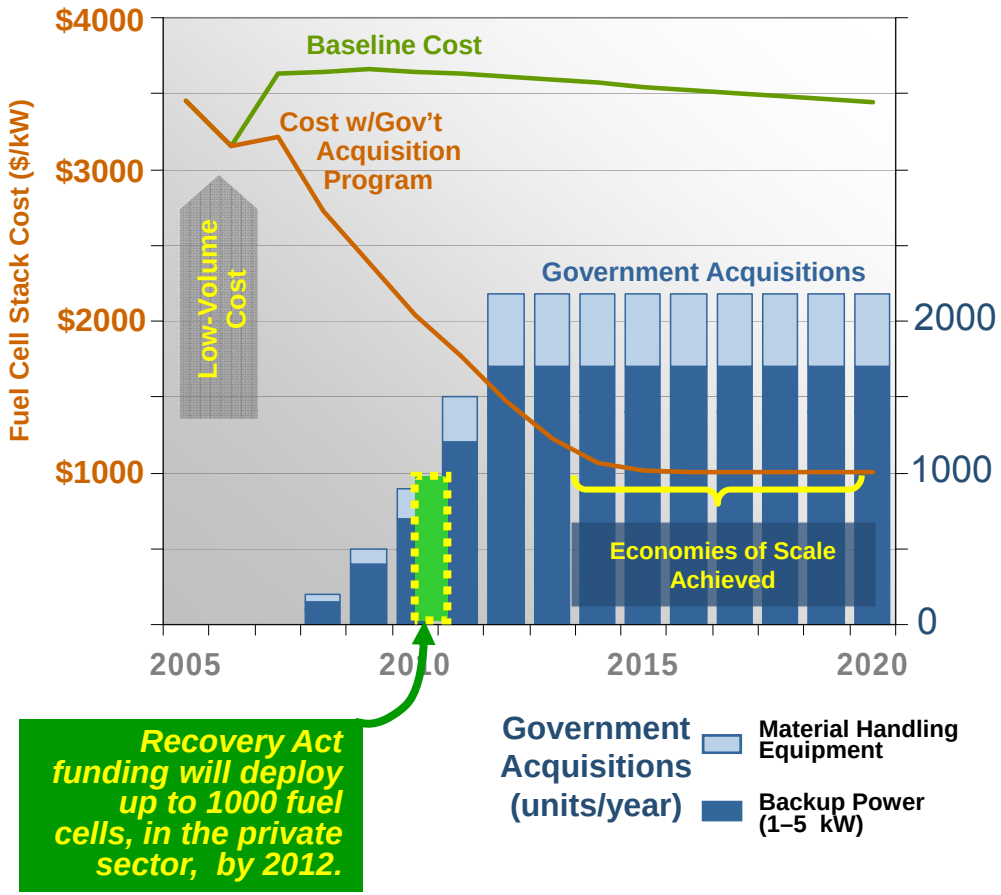
Market Transformation activities seek to overcome barriers to commercialization

	BARRIERS
Market/Industry	Lack of domestic supply base and high volume manufacturing.
	Low-volume capital cost is >2-3x of targets
	Policies — e.g., many early adopters not eligible for $3,000/kW tax credit
Delivery Infrastructure	Significant investment needed—~$55B gov't funding required over 15 years for ~5.5M vehicles ($~10B for stations)*
Codes and Standards	Complicated permitting process. 44,000 jurisdictions
	H_2-specific codes needed; only 60% of component standards specified in NFPA codes and standards are complete
	Need for domestic and international consistency
Education	>7,000 teachers trained; online tools average 300-500 visits/month, but negative public perception and safety concerns remain.

*2008 National Academies Study, *Transitions to Alternative Transportation Technologies—A Focus on Hydrogen*

ADDRESSING BARRIERS—Example:

A government acquisition program could have a significant impact on fuel cell stack costs



Source: David Greene, ORNL; K.G. Duleep, Energy and Environmental Analysis, Inc., *Bootstrapping a Sustainable North American PEM Fuel Cell Industry: Could a Federal Acquisition Program Make a Difference?,* 2008.

New and Expanded Policy Mechanisms

Some tax credits affecting fuel cells have recently been 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.**
Fuel Cell Investment Tax Credit	**Increases the investment tax credit to 30%, up to $3,000/kW for business installations, and extends the credit from 2008 to 2016.**

Examples of Activities in Other Agencies

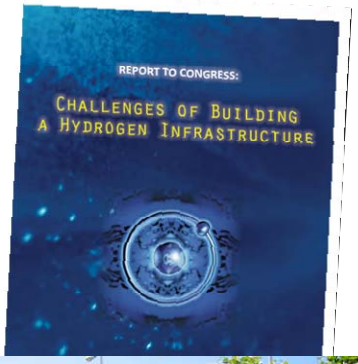
CHP	Tri-gen pilot at Fort Lewis, WA using WWTP digester gas.
Portable	Several tactical programs developing fuel cells for increased power, energy supply, and reduced weight burden on extended missions.
Backup	Nearly 100 5-kW units planned at various Army locations
Material Handling	DLA – 40 fuel cell forklifts deployed, 60 more planned at various locations
Transp.	Fuel cell bus at Fort Lewis, WA. Planning several H2 ICE bus deployments

Backup Power	16 5-kW backup power units to support National Weather Service atmosphere modeling.

Stationary Power	2 5-kW SOFCs at a National Park in OH, providing grid-independent power.

Examples of Activities in Other Agencies

Backup	~25 fuel cells installed for remote telecom backup, with ~25 additional units planned (FAA)
Transp.	National Fuel Cell Bus demonstration; recent report to congress on infrastructure.



Stationary/ Backup	8 Plug Power units in field test at the Glenn Research Center in Cleveland, OH.

CHP	250-kW fuel cell for CHP at mail processing facility in CA.
Transp.	Fuel cell vehicles used for mail distribution in CA and VA.

Backup	5-kw fuel cell for backup power at Denver Federal Center.
Other	New “Innovative Energy Solutions” Schedule makes it easier for Federal Agencies to purchase fuel cell systems.