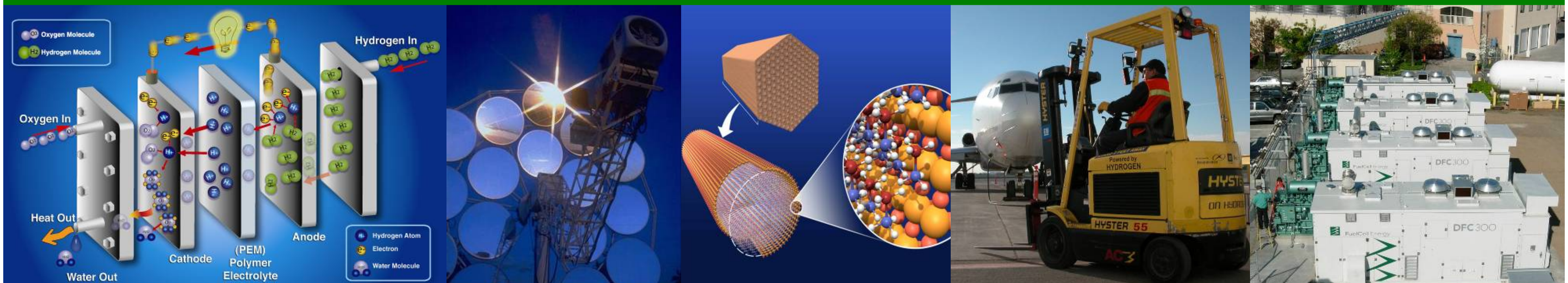
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



Overview of Hydrogen and Fuel Cell Activities

Sunita Satyapal

Acting Program Manager

DOE Fuel Cell Technologies Program

Update for HTAC

November 5, 2009

Fuel Cells — *Where are we today?*

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

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***

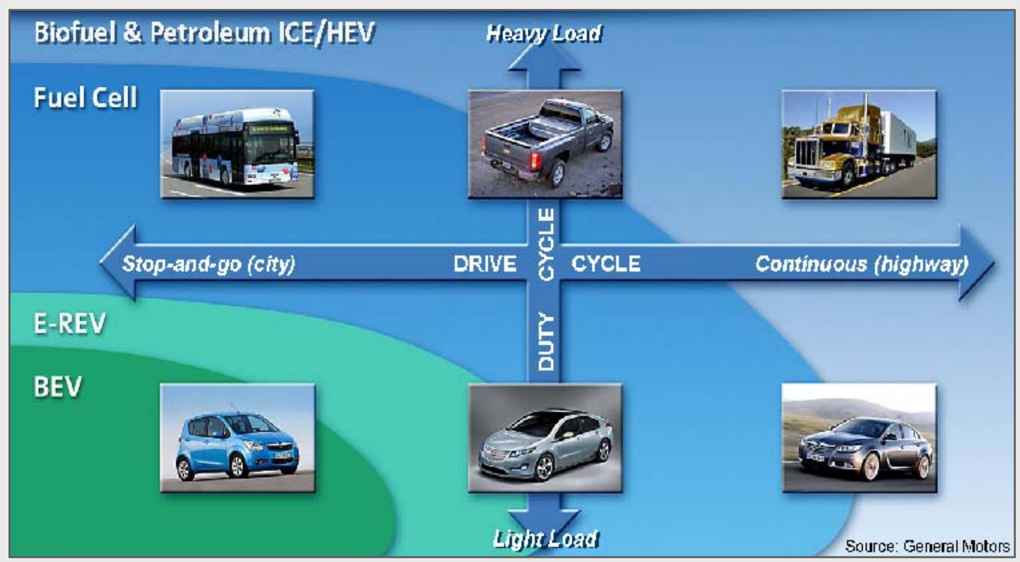
Fuel Cells for Transportation

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.



Funding History for Fuel Cells

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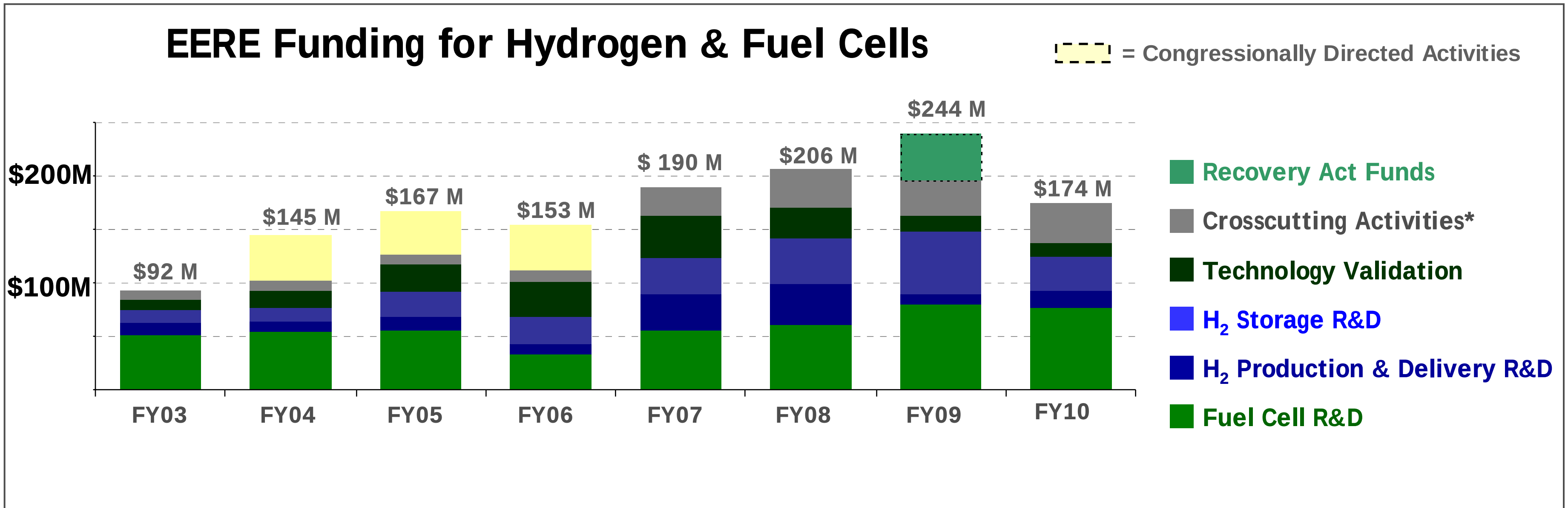
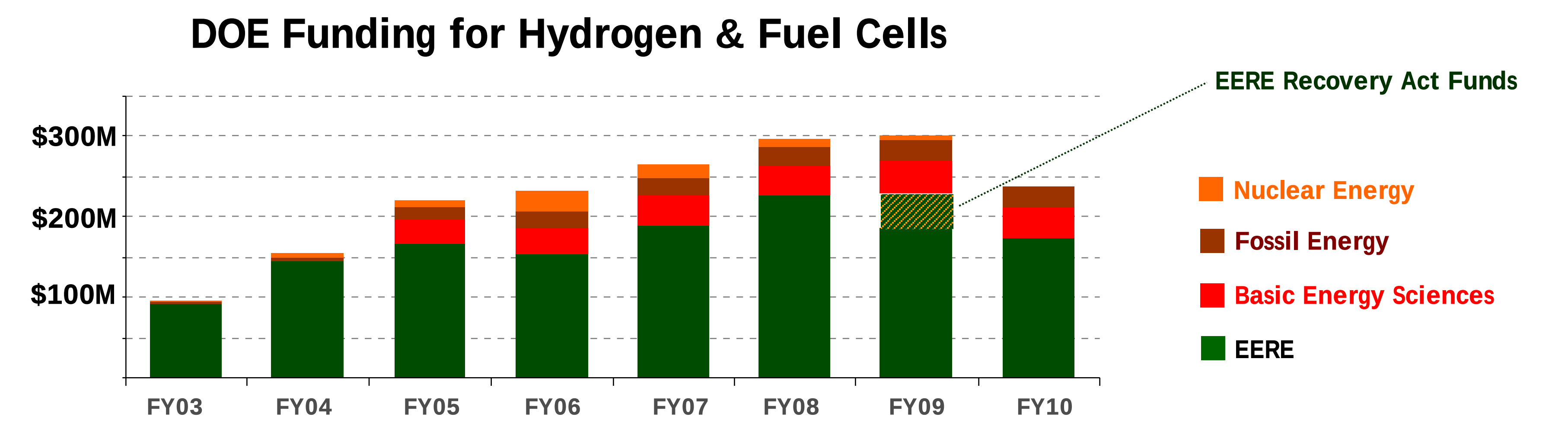


*Crosscutting activities include Safety, Codes & Standards; Education; Systems Analysis; Manufacturing R&D; and Market Transformation.



Budget — EERE Key Activities

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

EERE Hydrogen and Fuel Cells Budget *(in thousands)*				
Key Activity	**FY 2007**	**FY 2008**	**FY 2009**	**FY 2010**
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
Total	**$189,511****	**$206,241****	**$200,449**	**$174,000**

* Under Vehicle Technologies Budget in FY 2009

** FY07 and FY08 numbers exclude SBIR/STTR funding

Hydrogen & Fuel Cells Budgets: *FY07 – FY10*

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

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

[1] Does not include funding for program direction.

[2] Includes coal to hydrogen and other fuels. Fossil Energy also plans $50M for SECA in FY10.

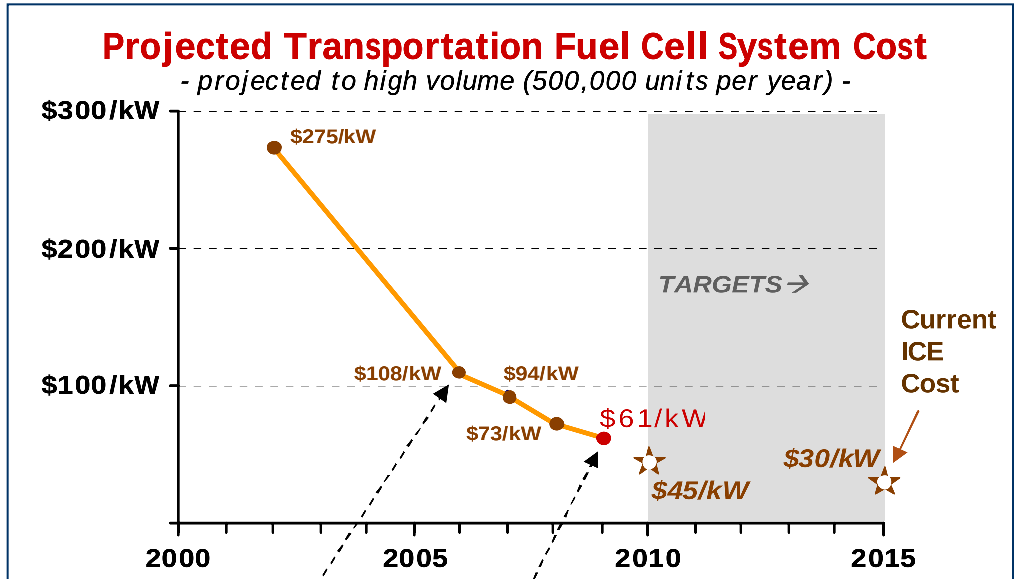
[3] Exact funding for hydrogen- and fuel cell–related projects to be determined. The Office of Science also plans ~$14M for hydrogen production research in the Office of Biological and Environmental Research in FY10.

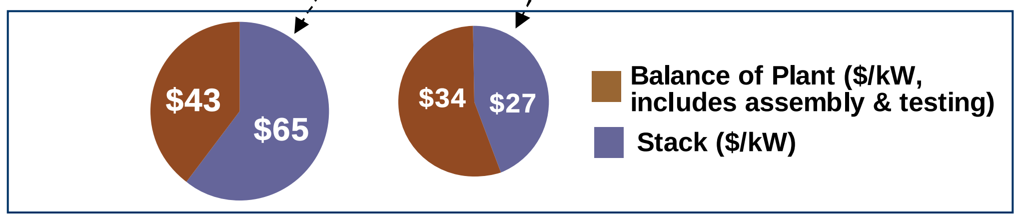
Fuel Cell R&D — *Progress*

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

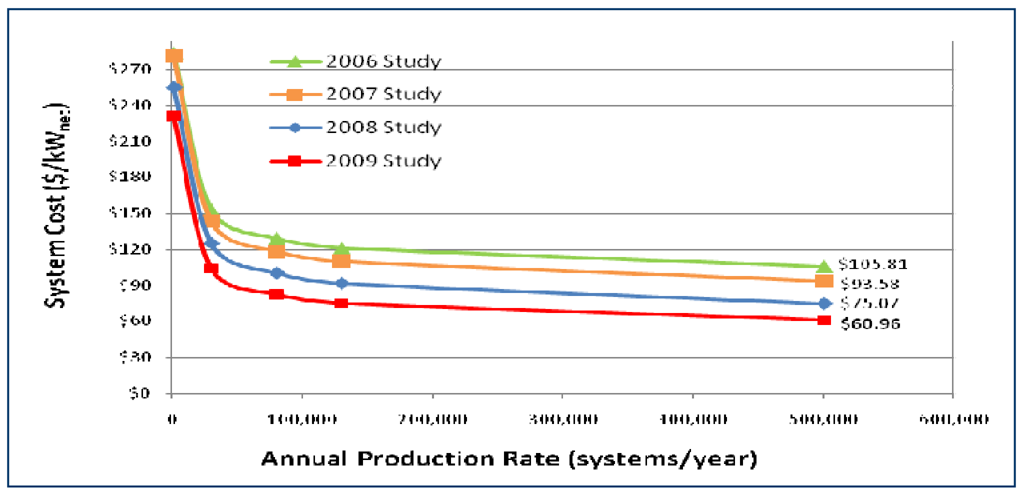
We've reduced the cost of fuel cells to $61/kW*

- ***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.

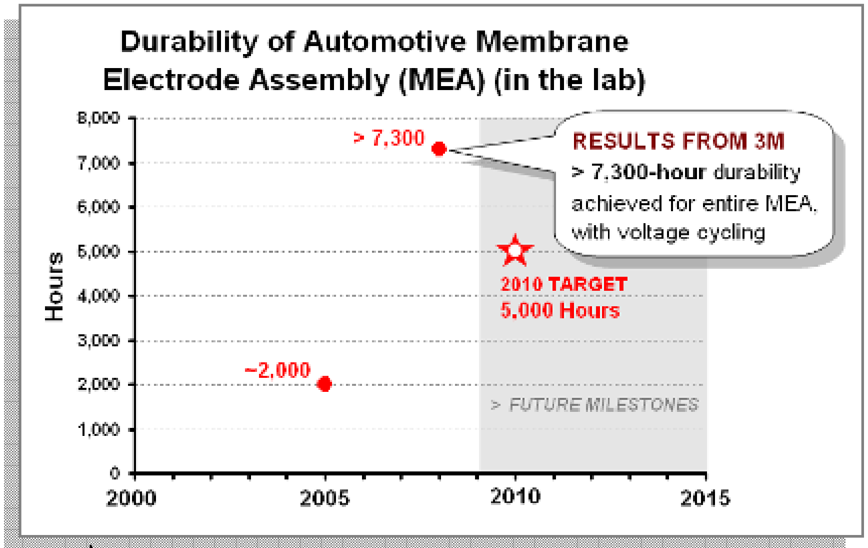


**Based on projection to high-volume manufacturing (500,000 units/year).*

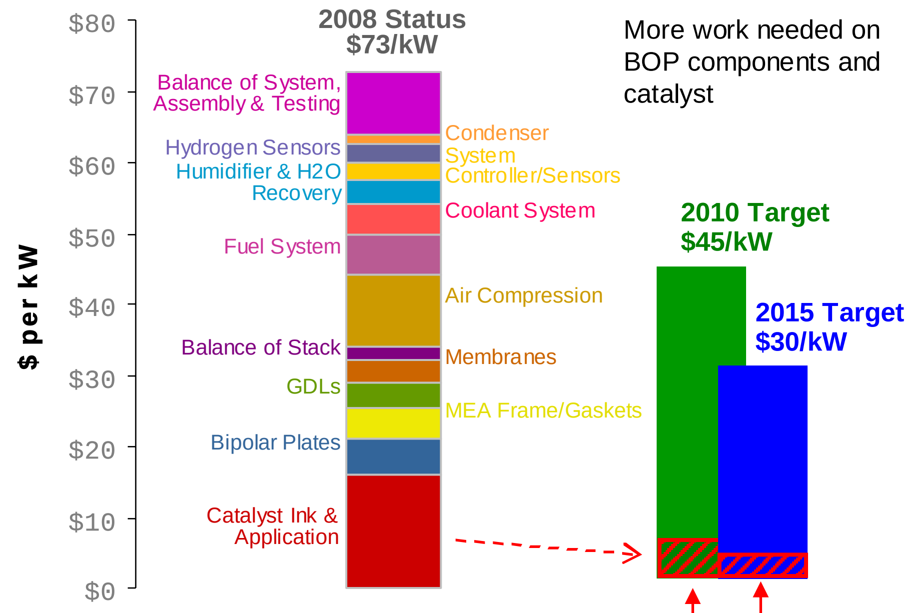
***Panel found $60 – $80/kW to be a "valid estimate": http://hydrogendoedev.nrel.gov/peer_reviews.html*

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.



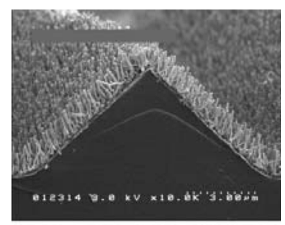
Breakdown of 2008 Cost Estimate

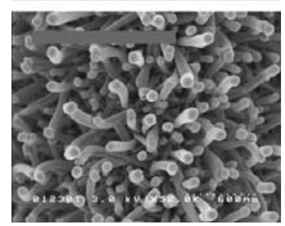
From 2007 to 2008, key cost reductions were made by:

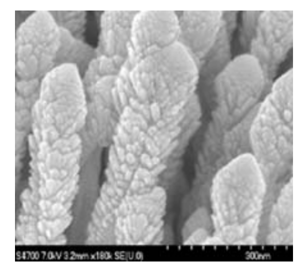
- ***Reducing platinum group metal content from 0.6 to 0.35 g/kW***
- ***Increasing power density from 583 to 715 mW/cm^2***

→ These advances resulted in a $12.40/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

- *2008 cost projection validated by an independent panel, which found $60 – 80/kW to be a "valid estimate"*
- *Cost estimates are based on projection to high-volume manufacturing (500,000 units/year); 80-kW PEM fuel cell. Breakdown by DTI, Inc.*

Hydrogen Production & Delivery R&D

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

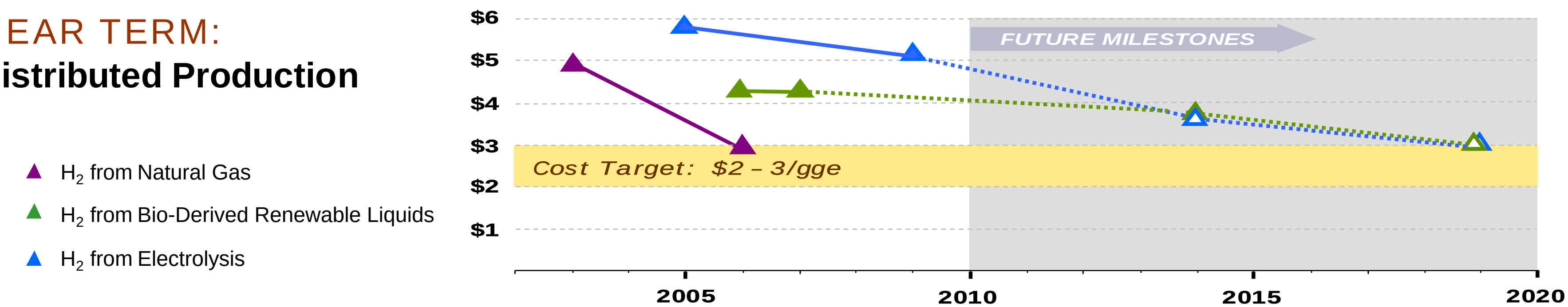
The Program is developing technologies to produce hydrogen from clean, domestic resources at reduced cost.

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

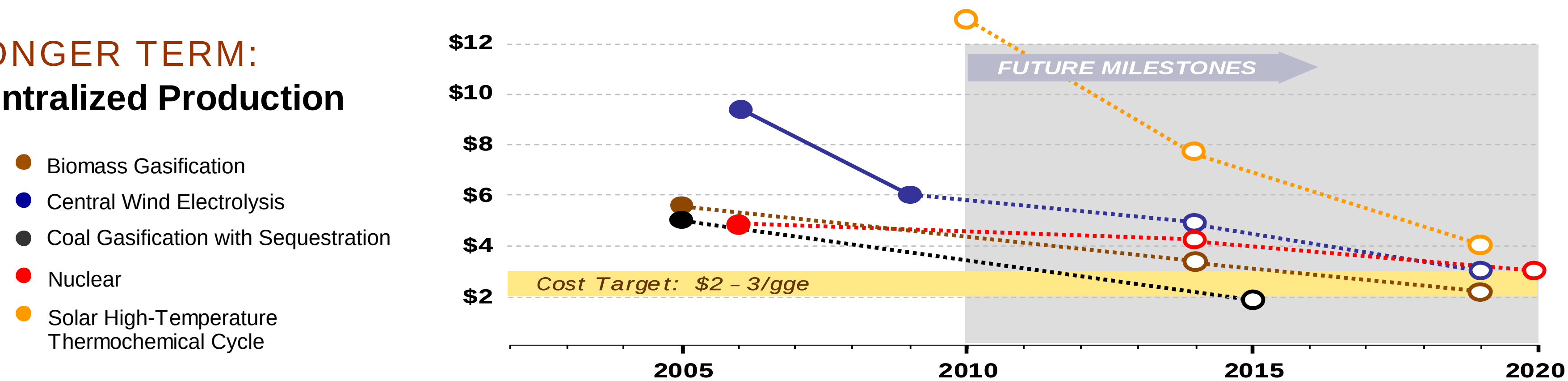
Projected* High-Volume Cost of Hydrogen (Delivered) — Status & Targets

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

NEAR TERM:
Distributed Production

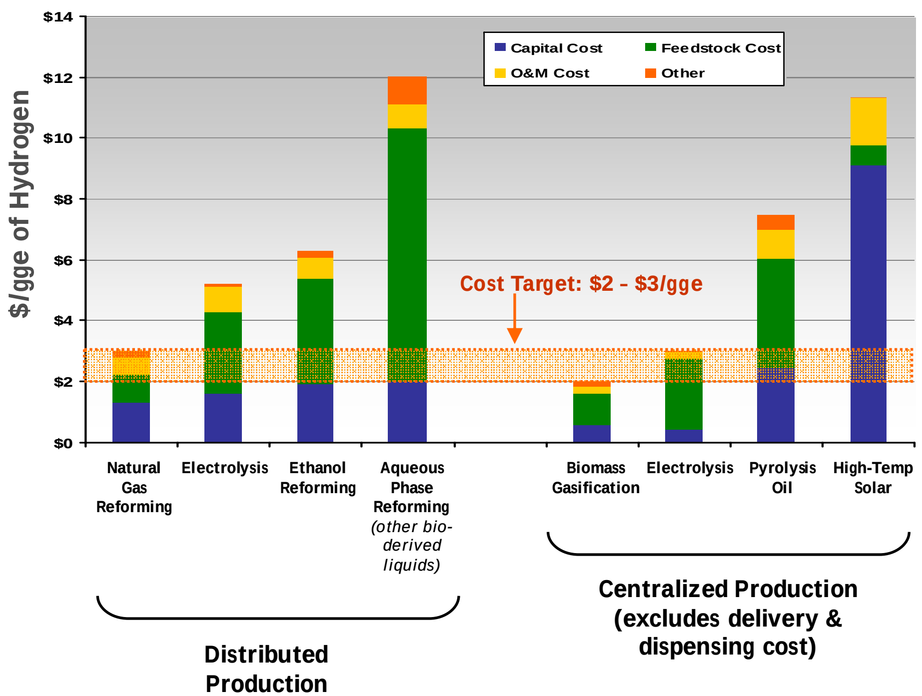


LONGER TERM:
Centralized Production



* 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.

Modeled High-volume Cost of Major Hydrogen Production Pathways

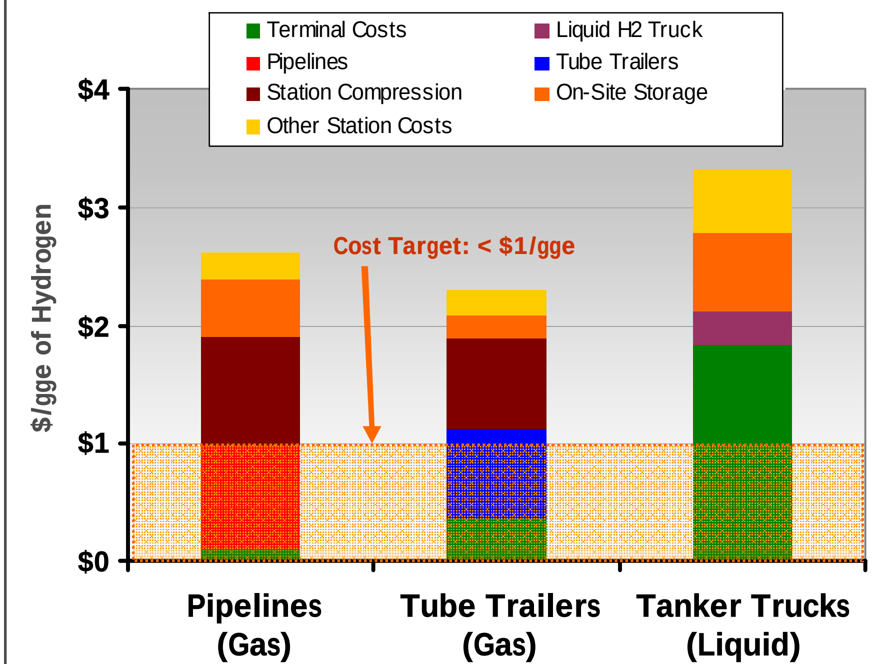


Key Assumptions:

- 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

Modeled High-volume Cost of Major Hydrogen Delivery Pathways



Key Assumptions:

- Scenarios assume current technology with potential 2030 market penetration of 25%
- H_2 is delivered 62 miles, from production plant to Los Angeles
- Stations dispense 1000 kg/day at 350 bar

Hydrogen Delivery R&D

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

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

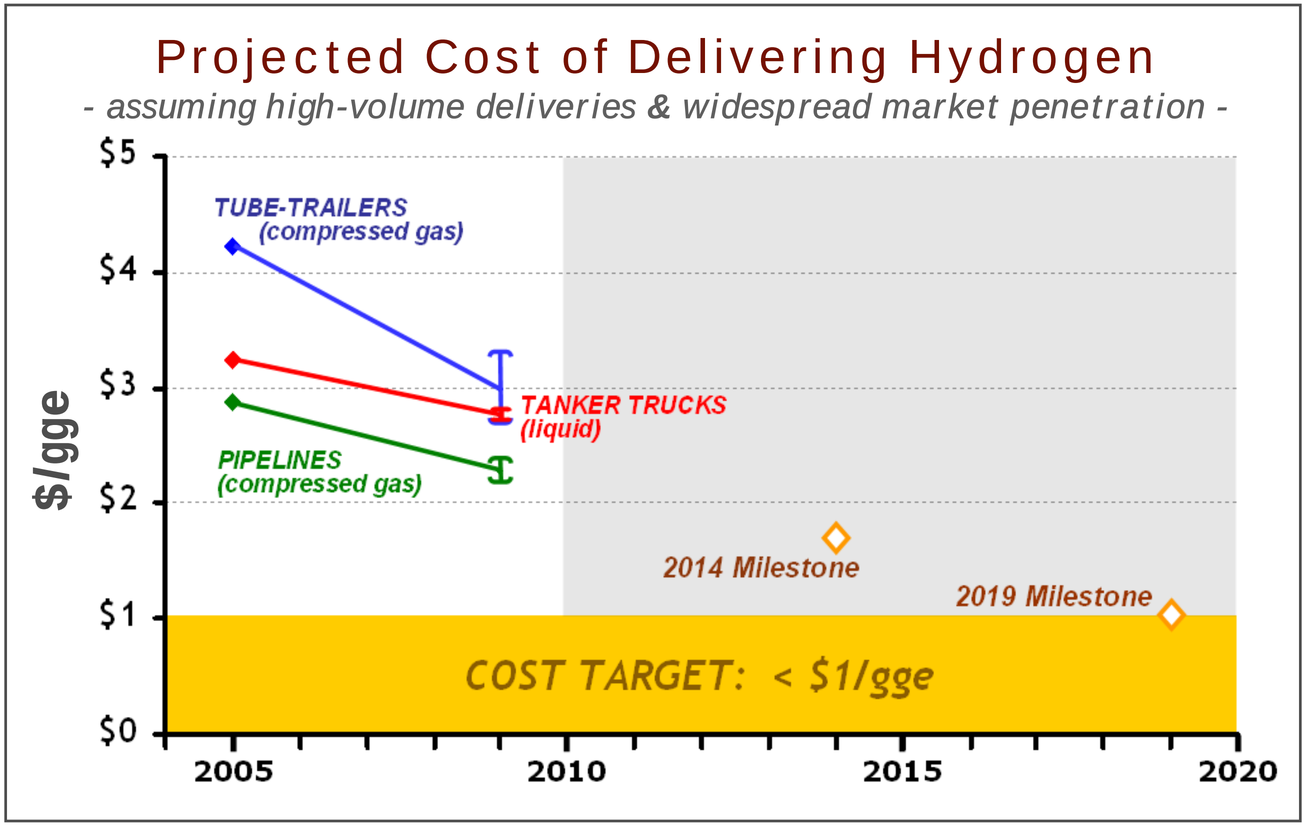
KEY OBJECTIVE

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 in liquid hydrogen delivery costs***



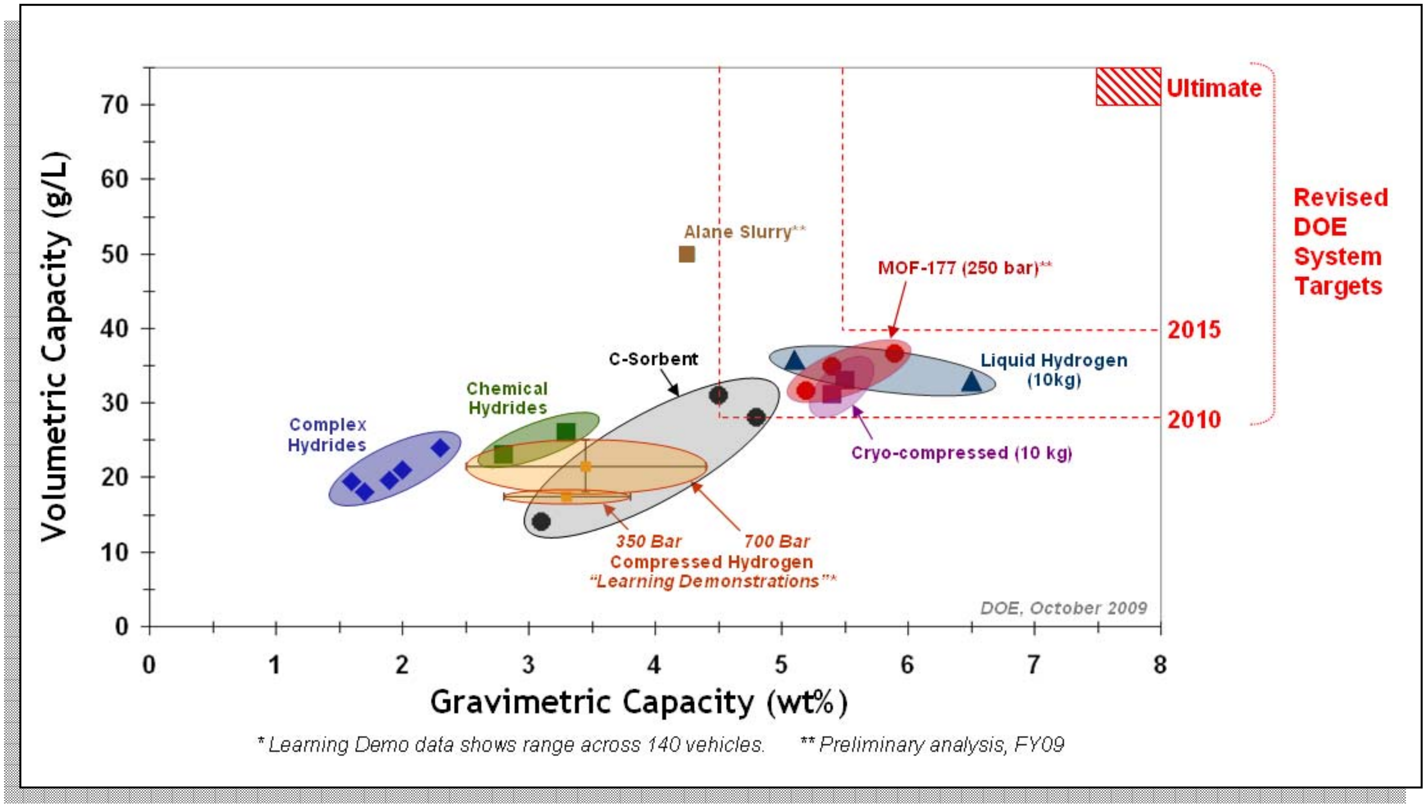
NOTE: This slide updates the original shown at the November 2009 HTAC meeting; this revised version reflects the example of the Sacramento market, with 20% market penetration.

Updated Storage Targets

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

High pressure tanks can already enable > 400 mile range on some vehicles. Costs must be reduced from $13-$20/kWh to $2-$4/kWh and storage capacity must be increased for all vehicles.

Storage System Capacities (weight vs. volume)



- 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

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 & 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.

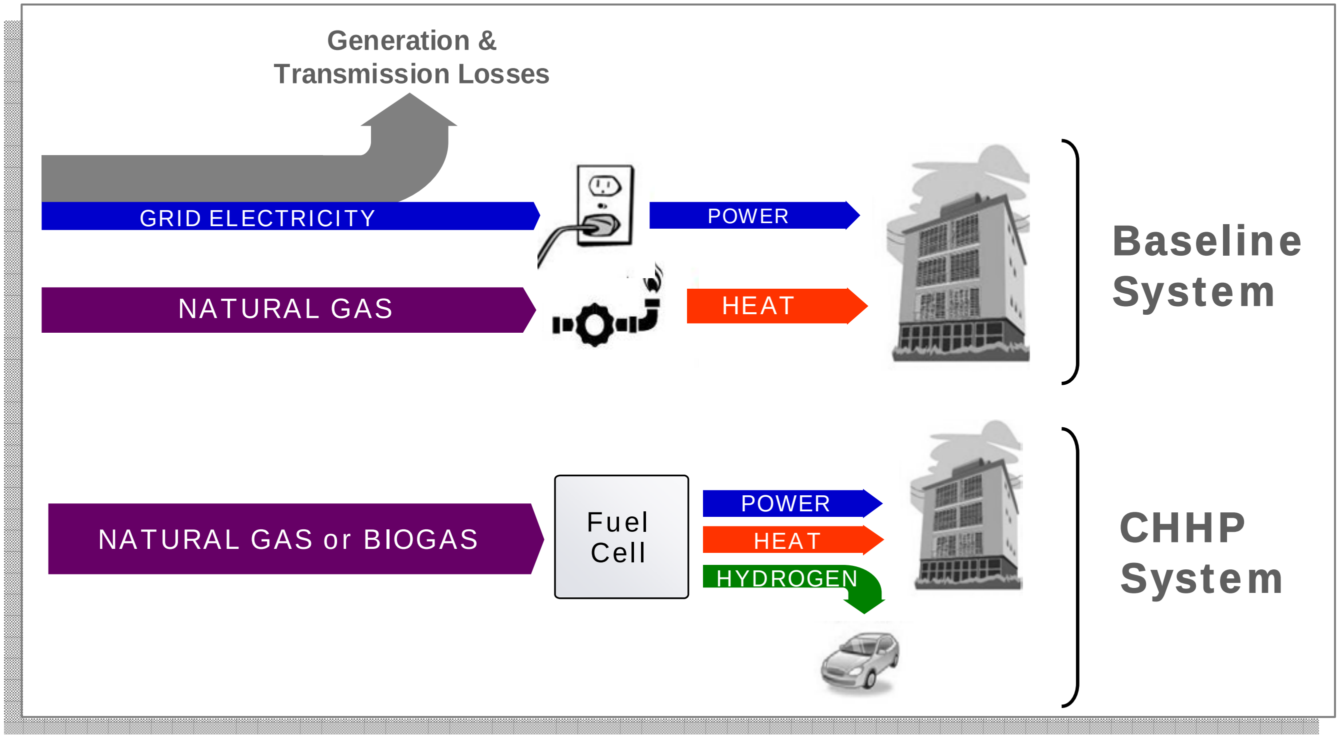
Other Demonstrations: *DOE is also evaluating real-world bus fleet data (DOD and DOT collaboration) and demonstrating stationary fuel cells — e.g., tri-generation (combined heat, hydrogen & power with biogas).*

Technology Validation – *Tri-Gen Highlight*

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

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.**
- **On-site operation and data-collection planned to begin in FY10.**

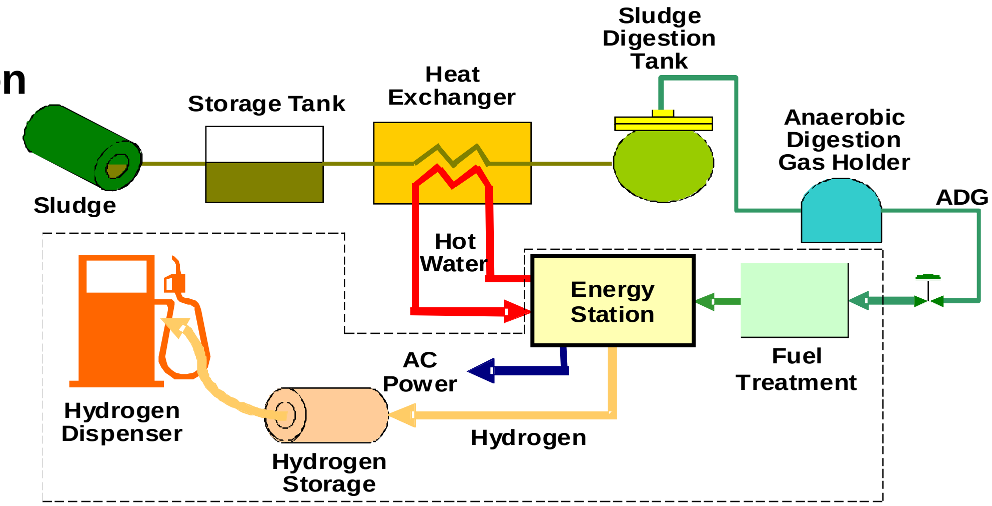


Combined heat, hydrogen, and power systems (CHHP) can:

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

Preliminary Test Results

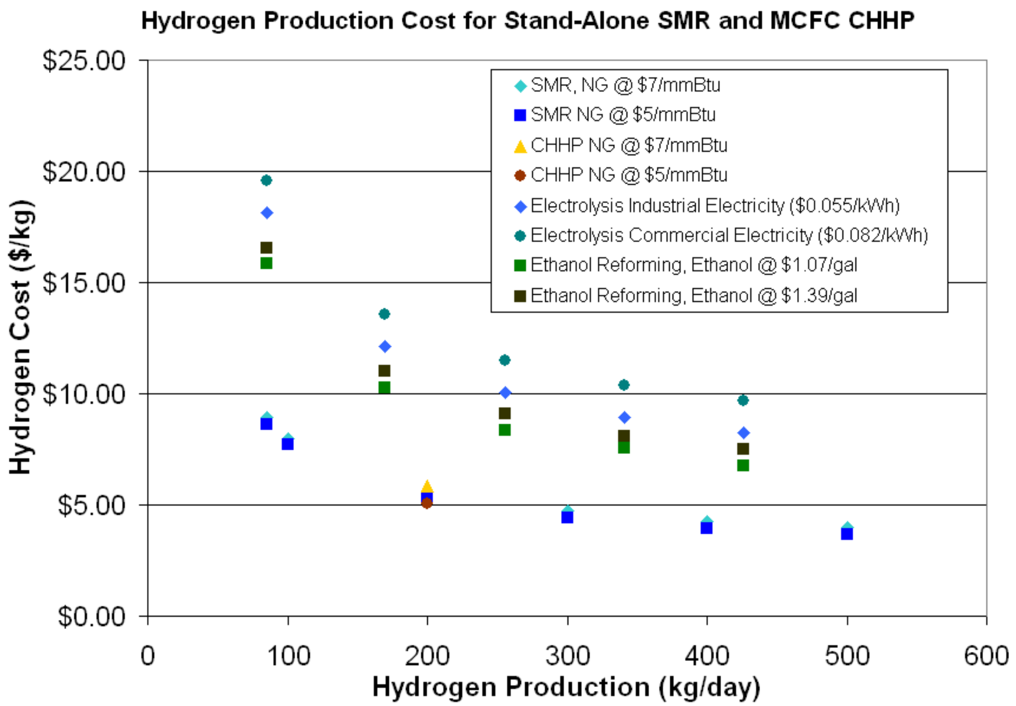
- **Fuel cell with water-gas shift in operation > 6,000 hours**
- **Tri-generation results:**
  - **Coproduced 5 to 10 lb/hr hydrogen with > 200 kW electricity**
  - **Estimated hydrogen recovery at 80 to 85%**
  - **Product purity <0.2 ppm CO; <2 ppm CO_2**
  - **Operation with simulated digester gas feed**
  - **PSA operating map developed (cycle time vs. feed rate)**
  - **Implemented automated system to switch to CHP mode when hydrogen tanks are filled.**



Anode Exhaust Processing and H_2 PSA

The cost of hydrogen production from CHHP can be comparable to distributed SMR at low volumes.

Preliminary Cost Comparison for Production of Hydrogen in a CHHP Application v. at a Stand-Alone Station



Model Calculation of Energy Cost

- Calculated cost of energy (electricity, heat, and hydrogen)
- Electricity assumed to have the same value as purchased electricity
- Heat valued at 1/2 value of electricity
- Hydrogen value calculated by difference

New Project Kick Offs

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

Recovery Act Projects Kick-Off Aug 21, 2009

- 13 projects initiated
- $42 M in funding
- Refueling ceremony celebrated 7,000 fuelings in seven months of the 40 hydrogen fuel cell powered forklifts operating at Defense Distribution Depot Susquehanna, PA

Fuel Cell Projects Kick Off Sept 30 – Oct 1, 2009

- 28 projects
- Topics included catalysts, transport, durability, innovative concepts, and portable power.
- Details at http://www1.eere.energy.gov/hydrogenandfuelcells/2009_projects_meeting.html

SBIR Projects Kick Off and Review Oct 13-15, 2009

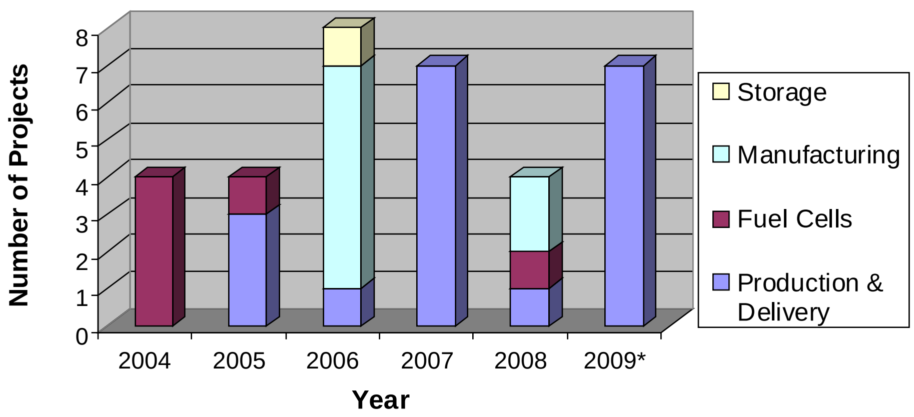
- Phase 1 Topics included: Production & Delivery (6 projects)
- Phase 2 Topics included: Manufacturing and Fuel Cells (4 projects) and Production & Delivery (6 projects)

FCT Phase 1 SBIR Projects 2004 – 2009*

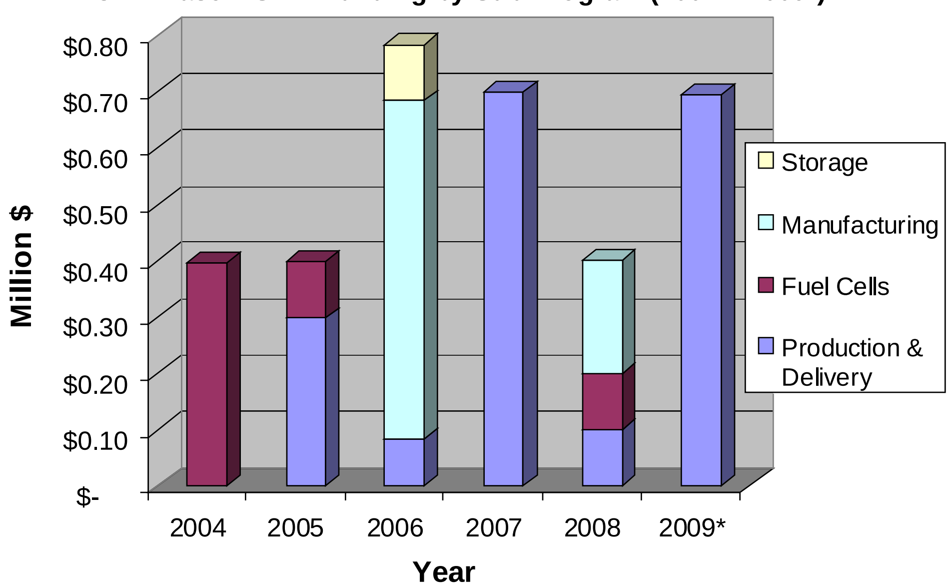
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Total of 34 Projects & $3.4 Million in funding

HFCIT Phase 1 SBIR Projects by Sub-Program (2004 - 2009*)



HFCIT Phase 1 SBIR Funding by Sub-Program (2004 – 2009*)



*Only one round of 2009 SBIR project selection has been completed
Funding is estimated for 2009 projects

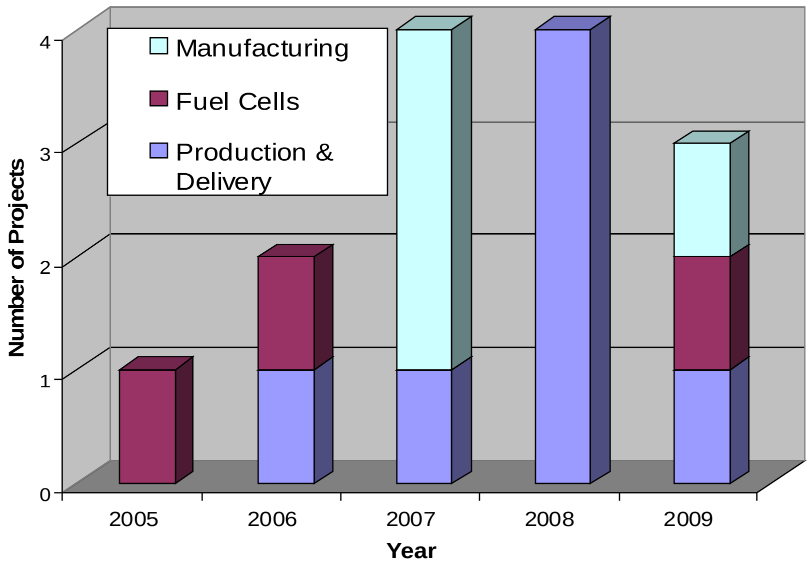
Sub-Topics

- **Storage:**
  - Advanced Materials for Hydrogen Storage (1 project)
- **Manufacturing:**
  - Hydrogen Production Equipment (2 projects)
  - Hydrogen Storage Containers (2 projects)
  - Proton Exchange Membrane (PEM) Fuel Cells (2 projects)
  - Bipolar Plates (2 projects)
- **Fuel Cells Sub-Topics:**
  - Fuel Cell Systems Coolants and Membranes (2 projects)
  - Innovative Fuel Cell Concepts (2 projects)
  - Dimensionally Stable High Performance Membrane (1 project)
  - Bio-Fueled Solid Oxide Fuel Cell (1 project)
- **Production & Delivery:**
  - Hydrogen Compression (4 projects)
  - Hydrogen from Waste (1 project)
  - Novel Carrier Technologies (1 project)
  - Hydrogen Production (4 projects)
  - Hydrogen Liquefaction (1 project)
  - Off-Board Hydrogen Bulk Storage (1 project)
  - Hydrogen Home Fueling Analysis (5 projects)
  - Hydrogen Production Process Intensification Technology (1 project)
  - Modeling of Hydrogen-Dispensing Options for Advanced Storage (1 project)

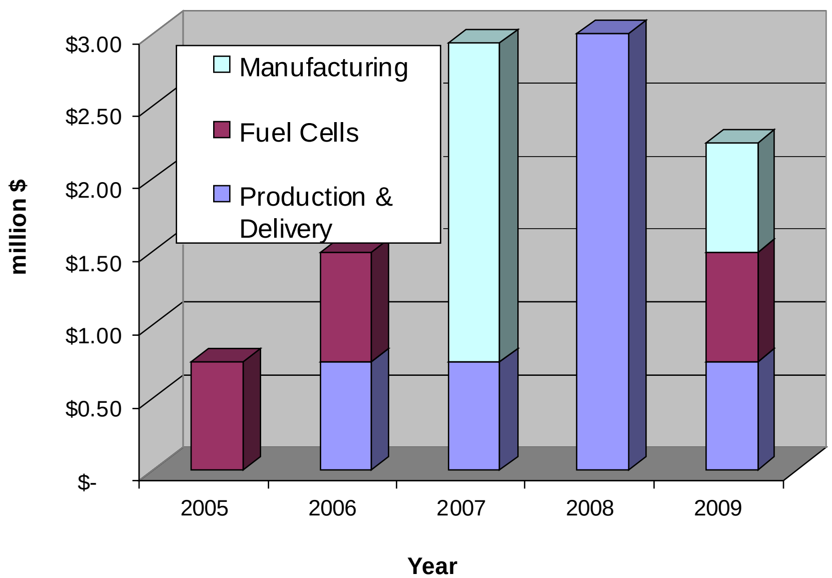
FCT Phase 2 SBIR Projects 2005 – 2009

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

HFCIT Phase 2 SBIR Projects by Sub-Program (2005 - 2009)



HFCIT Phase 2 SBIR Funding by Sub-Program (2005 - 2009)



Total of 14 Projects & $10.4 Million in funding

- **Manufacturing Sub-Topics:**
  - Manufacturing of Hydrogen Storage Containers
    - Innosense, Loc
  - Manufacturing of Proton Exchange Membrane (PEM) Fuel Cells
    - Nanotek Instruments, Inc.
    - Scribner Associates Incorporated
  - Manufacturing of Bipolar Plates
    - Faraday Technology, Inc.
- **Fuel Cells Sub-Topics:**
  - Fuel Cell Systems Coolants and Membranes
    - Advanced Fluid Tech Inc., Dab Dynalene Heat Trans
  - Dimensionally Stable High Performance Membrane
    - Giner Electrochemical Systems, Loc
  - Bio-Fueled Solid Oxide Fuel Cell
    - Innovatek, Inc
- **Production & Delivery Sub-Topics:**
  - Hydrogen Compression Technology
    - Mohawk Innovative Technology (2 projects)
    - Fuelcell Energy
  - Hydrogen Production
    - Genesis Fueltech
    - Physical Optics Corporation
    - Synkera Technologies Inc.
  - Hydrogen from Waste
    - Directed Technologies, Inc.

- SBIR FOA is currently open
- Topics include:
  a. Energy Storage for Intermittent Renewable Resources
  b. Fuel Cell Balance-of-Plant
  c. Advanced Hydrogen Storage for Early Market Applications
  d. Low-Cost Dispensing for Material Handling and Specialty Vehicles

Closes November 20, 2009

http://www.science.doe.gov/sbir/solicitations/FY%202010/C30_Notice.htm

Upcoming Workshops

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

- **Production & Delivery**
  - Low temperature delivery working group: May 2010 at NHA conference (tentative)
- **Storage**
  - Workshop on early markets: Nov 16, 2009 at the Fuel Cell Seminar, Palm Springs
  - LANL-AIST-NEDO storage workshop: Dec 2009 at the MRS conference, Boston
- **Fuel Cells**
  - Workshop on high temperature fuel cell gaps: Nov 16, Fuel Cell Seminar, Palm Springs
  - Workshop on bus targets and gaps: TBD
  - Pre-solicitation meeting (BOP, stationary); Jan/Feb 2010
- **Market Transformation**
  - Early markets & infrastructure workshop: Nov 2009, Fuel Cell Seminar, Palm Springs
- **Safety, Codes & Standards**
  - DOE-DOT workshop on CNG-H2: Dec 2010, Washington, DC
  - NHA Codes & Standards
  - Insurance workshop
  - NASA-DOE tank safety workshop

Storage RFI

- **Focus:** Performance and cost requirements of fuel storage subsystems for early-market fuel cell applications.
- **Target Audience:** Prospective fuel cell system users, fuel cell component and system suppliers and other stakeholders.
- **Objective:** To develop consumer- and user-driven requirements and targets.
- **Application Categories:** Handheld and higher power portable applications; residential and commercial CHHP; APUs for trucks, RVs, etc.; stationary power for remote applications, back-up power and residential; and material handling.

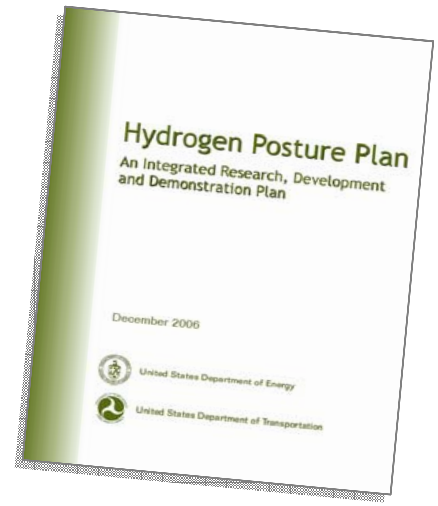
Closes December 15, 2009

http://www1.eere.energy.gov/hydrogenandfuelcells/news_detail.html?news_id=15569

- 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

Program Priorities and Next Steps



- **Publications**
  - **Fuel Cell Program Plan (replacement of current Posture Plan)**
  - **Publication of Interagency Action Plan, detailing interagency coordination**
  - **2008 Market Report**
- **NAS study entitled "Assessment of Resource Needs for Development of Fuel Cell and Hydrogen Technology" to be updated to include PHEVs and published in November 2009***
- **Workshop on infrastructure needs**
- **Continued market and benefits analysis**
- **Continued incorporation of feedback from stakeholders**

***http://www8.nationalacademies.org/cp/projectview.aspx?key=48717**

Key Program Documents

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

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

www.hydrogenandfuelcells.energy.gov

Thank you

Sunita.Satyapal@ee.doe.gov

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

Additional Information

Fuel Cells — *Worldwide Interest & Investment*

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

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).

European Union

RD&D Funding:

>$600 M ('08 – '13)

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

H_2 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

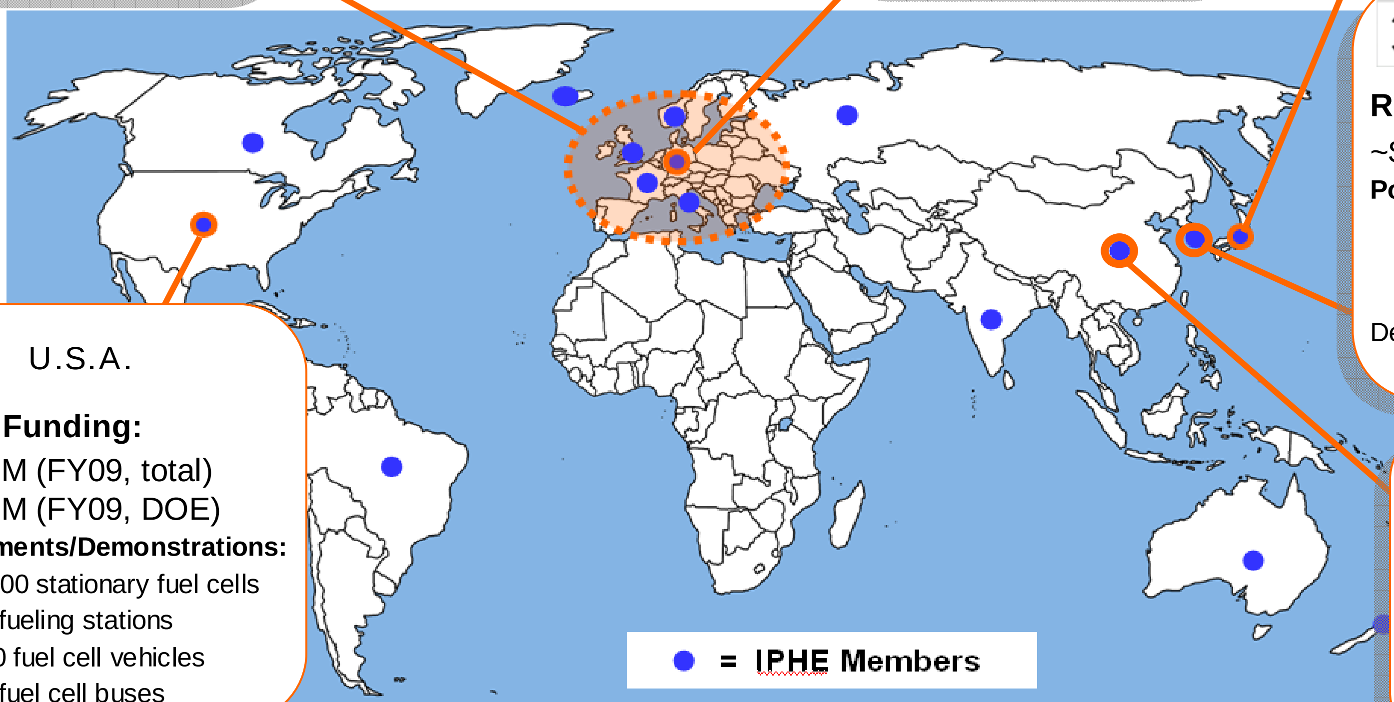
Japan

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



South Korea

RD&D Funding:

~$586 M ('04-'11)

Policy:

- 80% subsidy for residential FCs
- Feed-in tariff for stationary generation

Deployments/Demonstrations:

- 30 vehicles, 4 buses

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

China

RD&D Funding:

~$30 M ('08)

Deployments & Demonstrations:

- >3-6 buses in Shanghai for 2010 World Expo

Fuel Cell Vehicles – International Status

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

Many major automobile manufacturers have recently reaffirmed their commitment to develop fuel cell vehicles. Plans exist in Germany and Japan to expand the hydrogen infrastructure.

Daimler*
- Small-series production of FCEVs began in summer 2009
- Plans for tens of thousands of FCEVs per year in 2015 – 2017 and hundreds of thousands a few years after

Volkswagen
- Expanded demo fleet to 24 FCEVs in CA
- Recently reconfirmed commitment to FCEVs

Germany: Infrastructure
- Public/private partnership to build 1000 hydrogen stations by 2015

SAIC (China)
- Partnering with GM to build 10 fuel cell vehicles in 2010

Hyundai-Kia*
- 2020: Planned expansion of demo fleet to 500 vehicles
- 2012: 1000 FCEVs/year
- 2015: 10,000 FCEVs/year
- "Borrego" FCEV has achieved >340-mile range.

Renault*

General Motors*
- 115 vehicles in demonstration fleet
- 2012: Technology readiness goal for FC powertrain
- 2015: Target for commercialization

Ford*

Toyota*
- 2015: Target for large-scale commercialization
- "FCHV-adv" has achieved 431-mile range and 68 mpgge

Honda*
- Clarity FCX named "World Green Car of the Year"; EPA certified 72 mpgge; has begun leasing vehicles, with plans to lease 200
- 2015: Target for large-scale commercialization

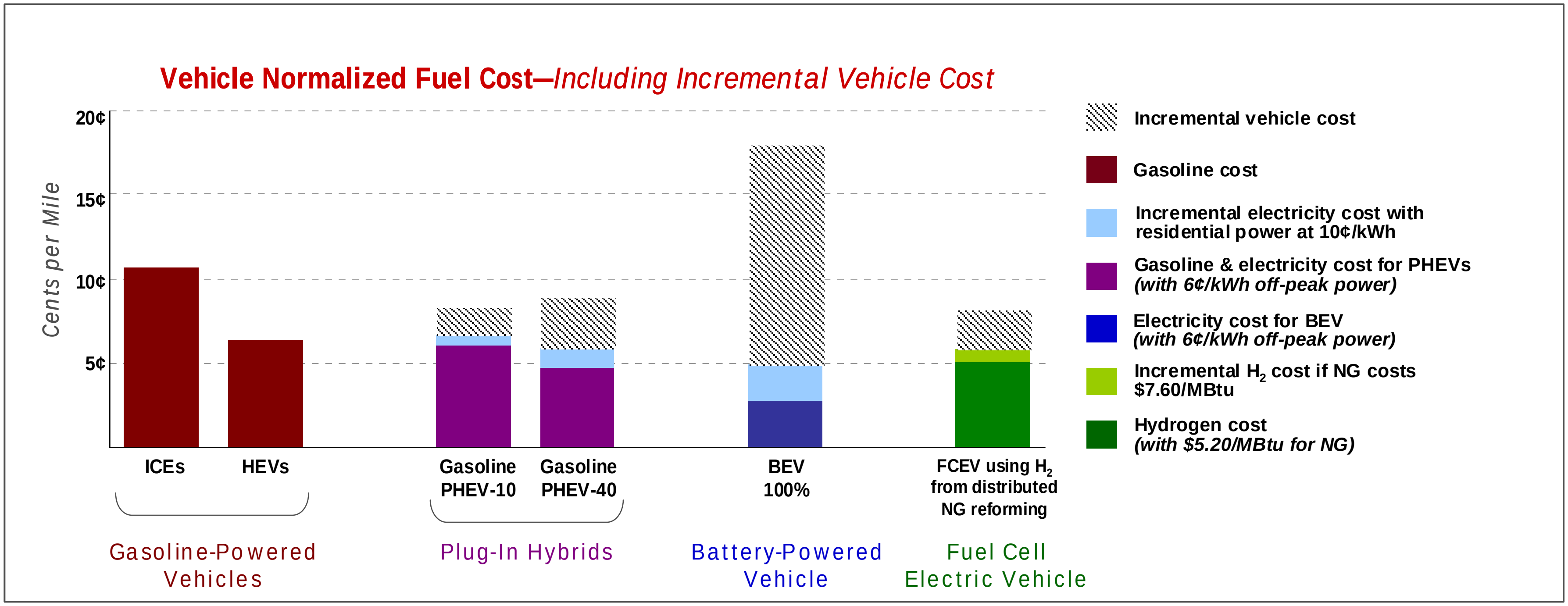
Japan: Infrastructure
- Alliance of 13 Japanese companies plans to develop commercial technologies by 2015 that will supply hydrogen for FCEVs.

Nissan*

****In Sept. 2009, many of the world's major auto manufacturers signed a letter of understanding in support of fuel cell vehicles, anticipating widespread commercialization beginning in 2015 and calling for increased investment in refueling infrastructure.***

Cost-Comparison of Fuels and Vehicles

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



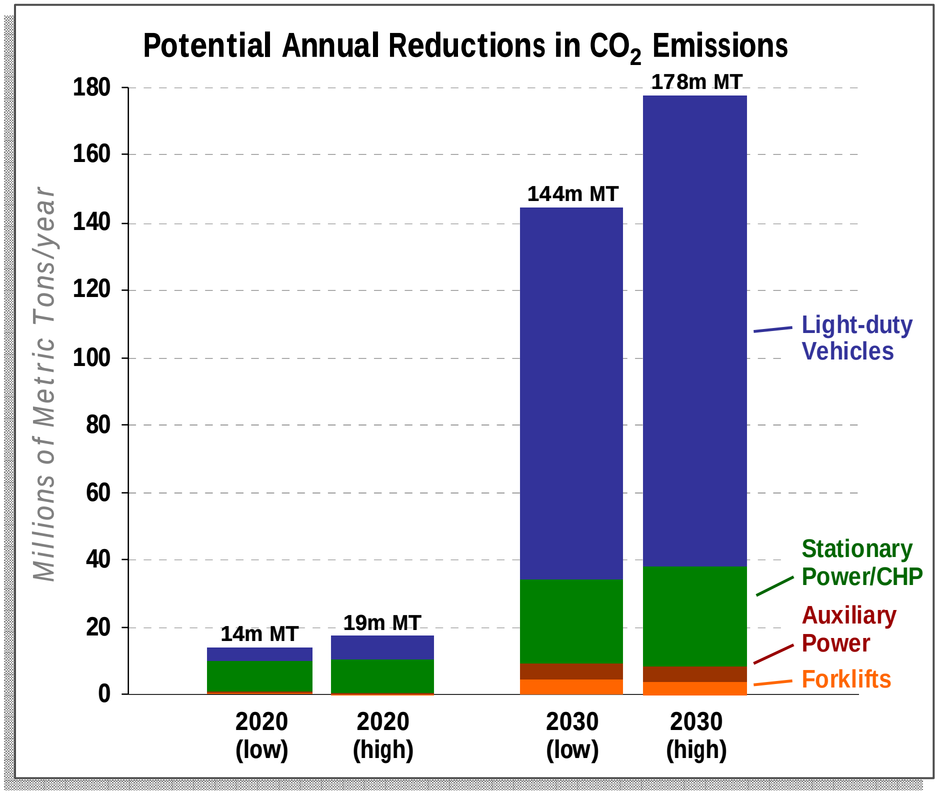
Notes and Assumptions

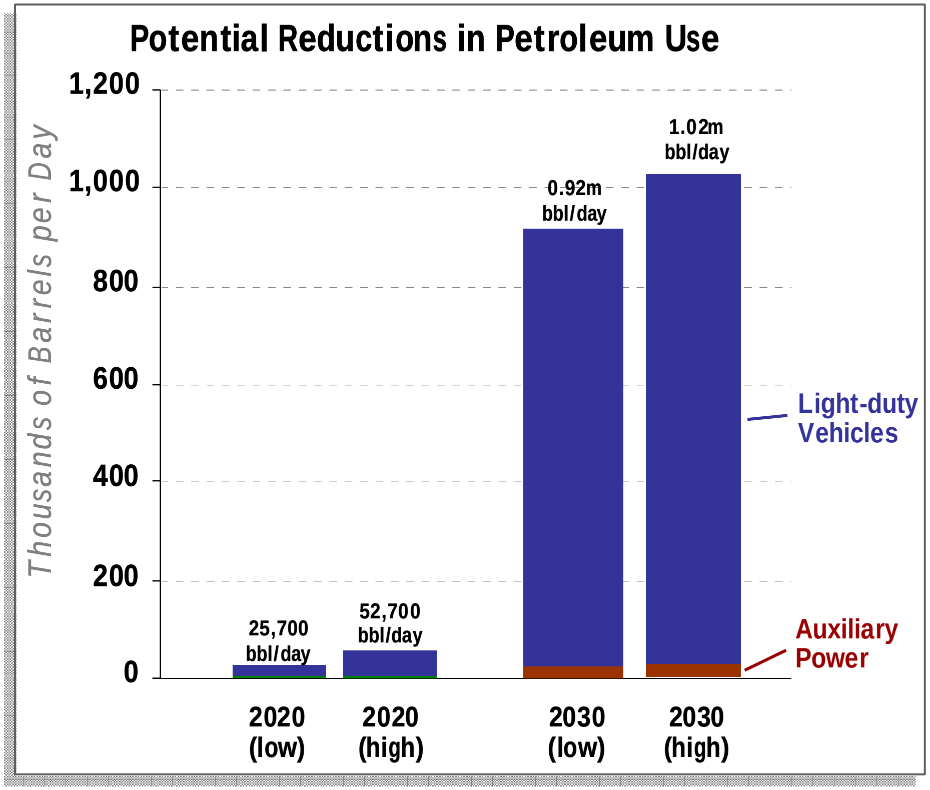
- Vehicle economies used for normalized cost for 2015 – 2020: Gasoline ICE=28mpgge; Gasoline HEV=48mpgge; H_2 FCEV=65mpgge
- Residential electrical price of 10¢/kWh used for PHEV and BEV estimates was based on 2009 EIA AEO. A lower price of 6¢/kWh was assumed for off-peak battery charging.
- Battery Electric Vehicle (BEV) fuel cost was based electric fuel economies from ANL GREET Model.
- The vehicle miles traveled allocation for the battery and gasoline engine for the PHEV were based on ANL resources.
- The natural gas cost used to calculate the hydrogen cost ranged from $5.2/M Btu to $7.6/M Btu.
- The 2009 EIA AEO 2020 untaxed gasoline cost of $3.00/gal. was used to determine the gasoline ICE and HEV normalized fuel cost.
- Incremental vehicle cost is based on delta vehicle cost above a conventional ICE from an MIT study (M. Kromer and J. Heywood, Electric Powertrains: Opportunities and Challenges in the U.S. Light-Duty Vehicle Fleet [Publication No. LFEE 2007-03 RP], MIT Laboratory for Energy and the Environment, 2007). The incremental cost was divided by a vehicle life of 150,000 miles.

Estimated Potential Impacts —
for Reducing GHG Emissions & Petroleum Use

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

As the Program continues to broaden its portfolio beyond automotive applications, market penetration and benefits analyses for diverse applications will be developed and refined.





Assumptions

Forklifts: 2020 Market Share = 12% or 36,000 units; 2030 Market Share = 85% or 300,000 units

Auxiliary Power: 2020 Market Share = 10% of long-haul trucks; 2030 Market Share = 100% of long-haul trucks

Stationary Power/CHP: 2020 Market Share = 0.4% of U.S. Electricity; 2030 Market Share = 0.8 – 1% of U.S. Electricity

Light-duty Vehicles: 2020 Market Share = 0.7 – 1.5 million vehicles; 2030 Market Share = 25 – 30 million vehicles. (Light-duty vehicle assumptions are derived from a scenario in the 2008 National Academies report, *Transitions to Alternative Transportation Technologies—A Focus on Hydrogen.)*

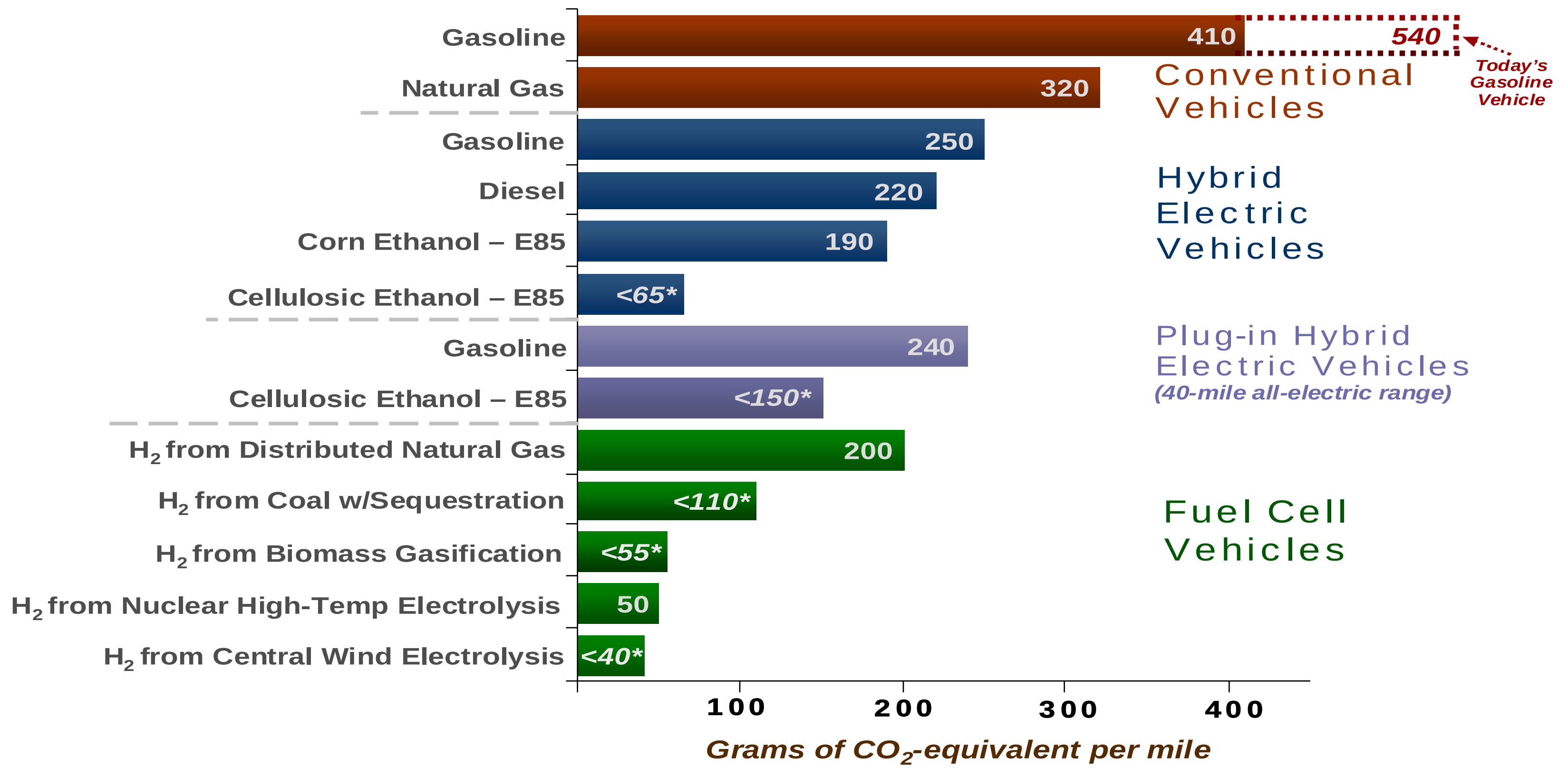
Systems Analysis — *Greenhouse Gas Emissions*

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

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

Well-to-Wheels Greenhouse Gas Emissions

(life cycle emissions, based on a projected state of the technologies in 2020)

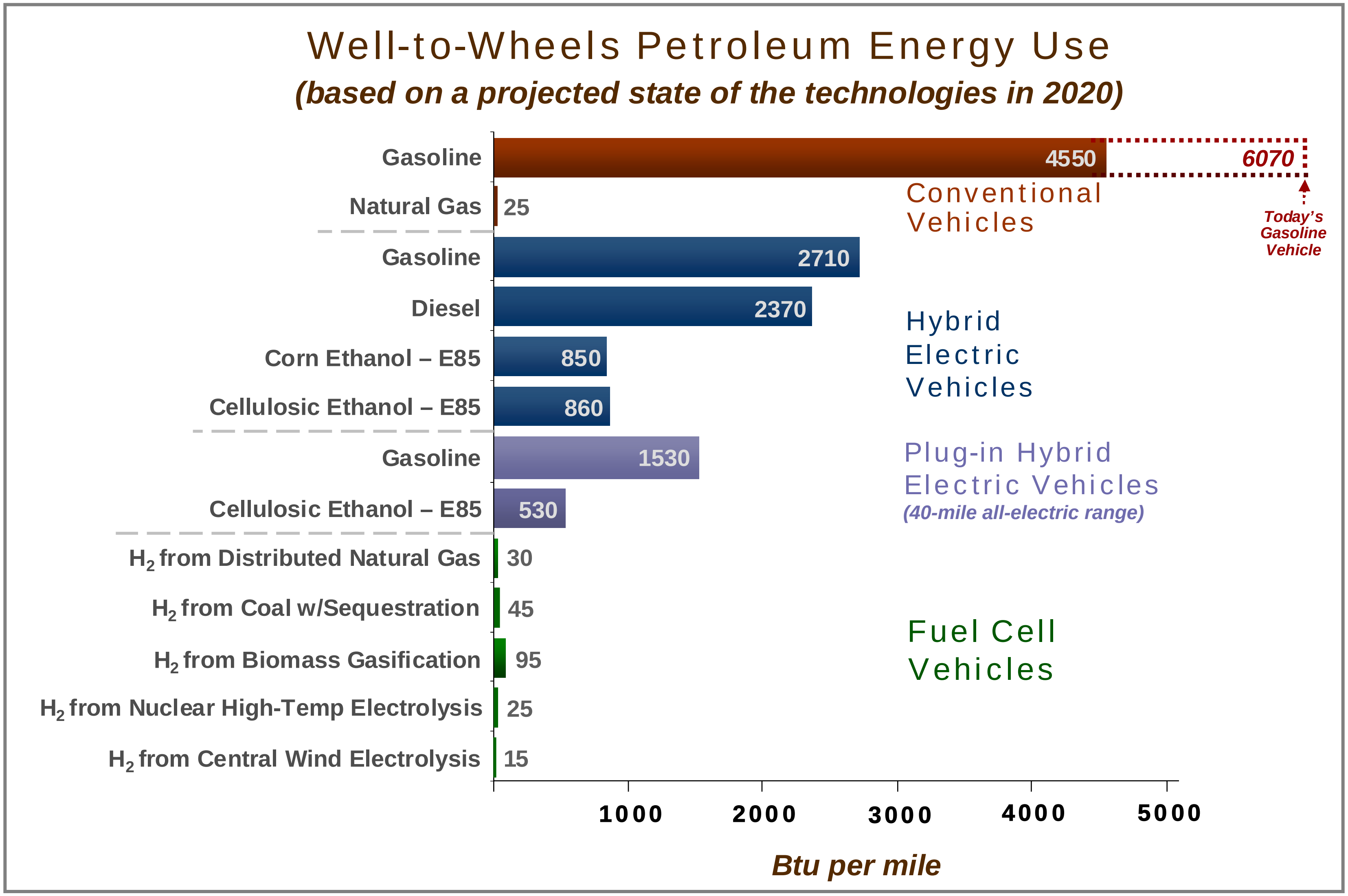


***Net emissions from these pathways will be lower if these figures are adjusted to include:**

- The displacement of emissions from grid power–generation that *will* occur when surplus electricity is co-produced with cellulosic ethanol
- The displacement of emissions from grid power–generation that *may* occur if electricity is co-produced with hydrogen in the biomass and coal pathways, and if surplus wind power is generated in the wind-to-hydrogen pathway
- Carbon dioxide sequestration in the biomass-to-hydrogen process

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

Analysis shows DOE's portfolio of transportation technologies will reduce oil consumption.



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