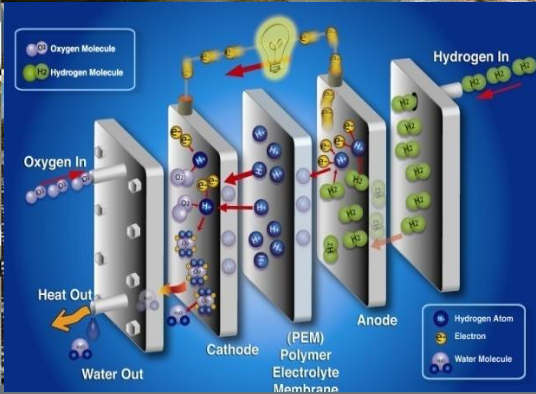
National Academy of Sciences

Committee on Transition to Alternative Vehicles and Fuels

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





Overview of Hydrogen and Fuel Cells

3/22/2011

Dr. Sunita Satyapal
Program Manager
Fuel Cell Technologies Program
U.S. Department of Energy

Global Market Overview

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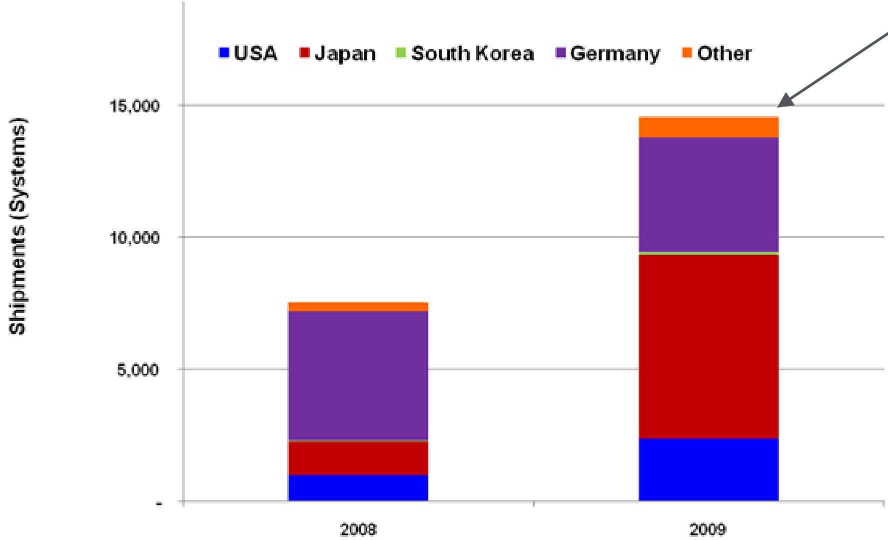
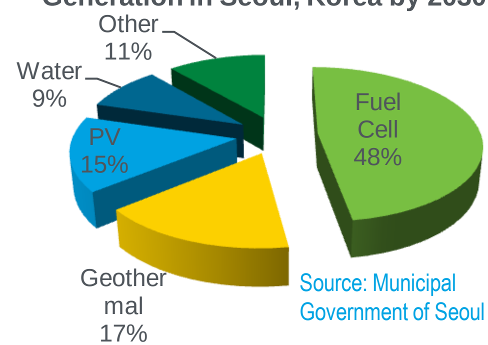
Global Shipments of Fuel Cell Systems, by US Companies and Non-US Companies



Significant increase in units shipped by non-US companies
>40% market growth in just one year

Example: Seoul's renewable energy generation plan includes **~ 48% fuel cells**

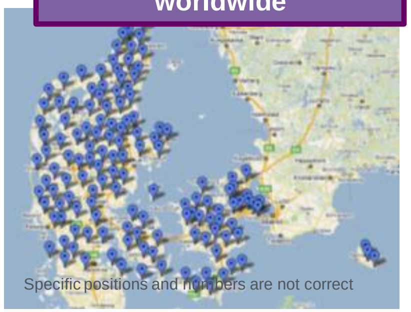
Anticipated Renewable Energy Generation in Seoul, Korea by 2030



Source: Municipal Government of Seoul

Example: Denmark Backup Power Deployments

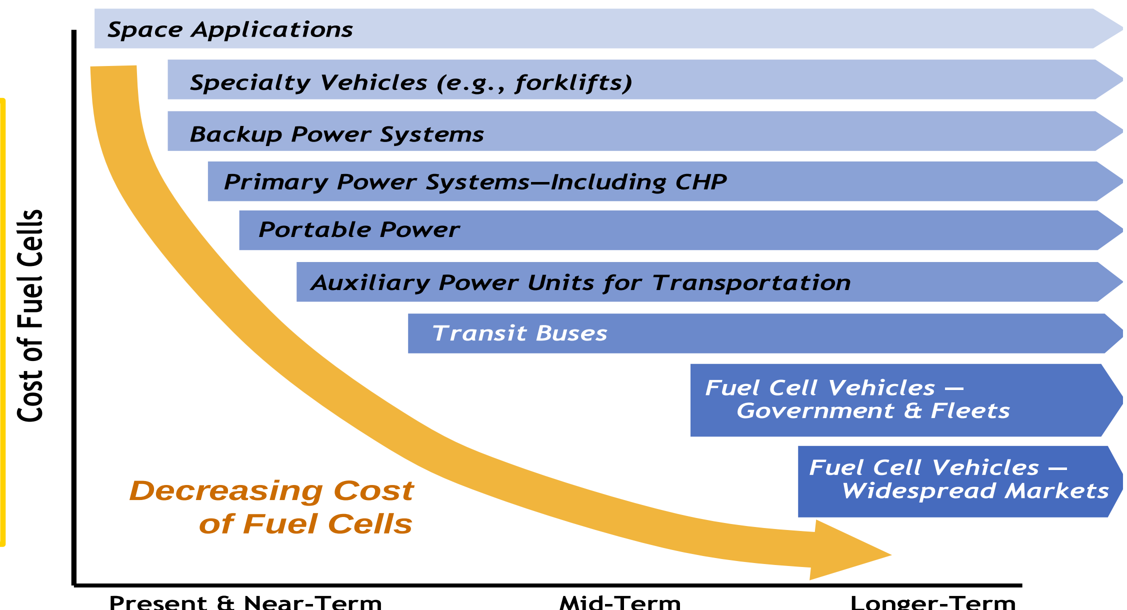
50,000 potential sites
>500 deployments worldwide



Preliminary market analysis

International Landscape favors H_2 & Fuel Cells

- Germany (>$1.2B; 1,000 H_2 stations)
- European Commission (>$1.2B, 2008-2013)
- Japan (2M vehicles, 1,000 H_2 stations by 2025)
- South Korea (plans to produce 20% of world shipments & create 560,000 jobs in Korea)
- China (thousands of small units; 70 FCVs, buses, 100 shuttles at World Expo, Olympics)
- Subsidies for jobs, manufacturing, deployments



A Portfolio of Technologies

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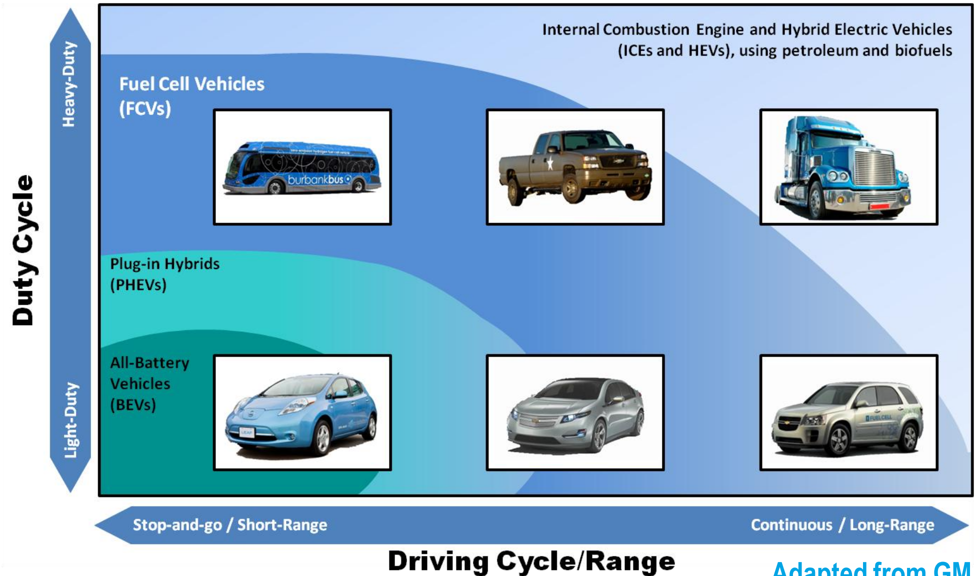
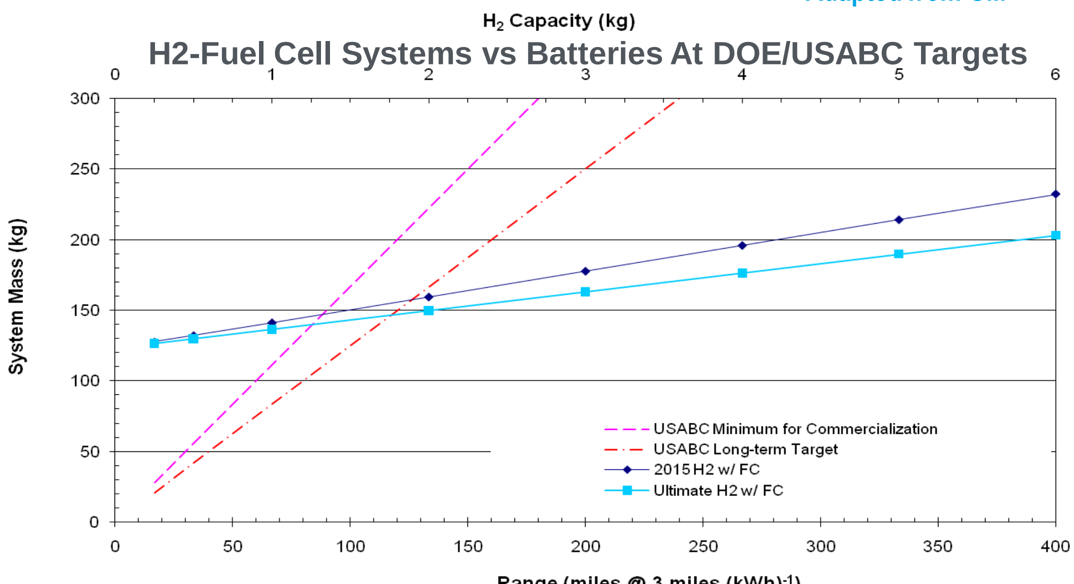


Adapted from GM

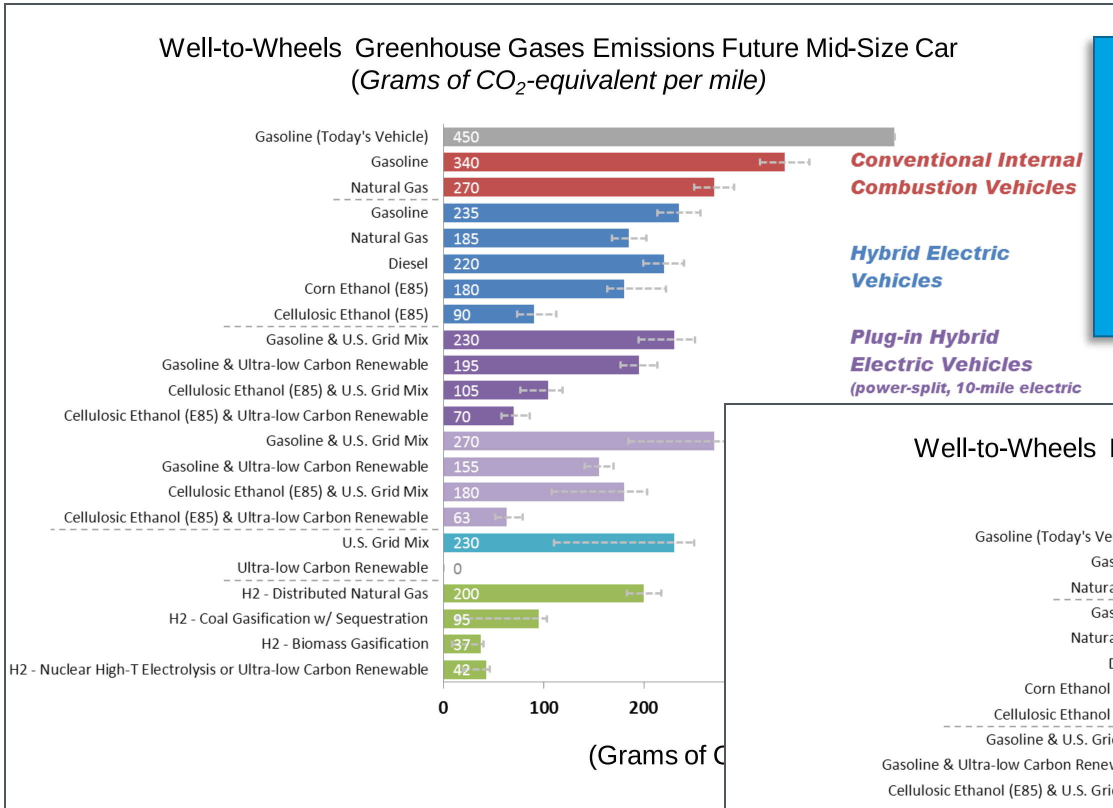
- A variety of technologies are under development with a focus on near term options such as PHEVs, hybrids, biofuels.
- The most appropriate technology depends on the drive cycle and duty cycle of the application.



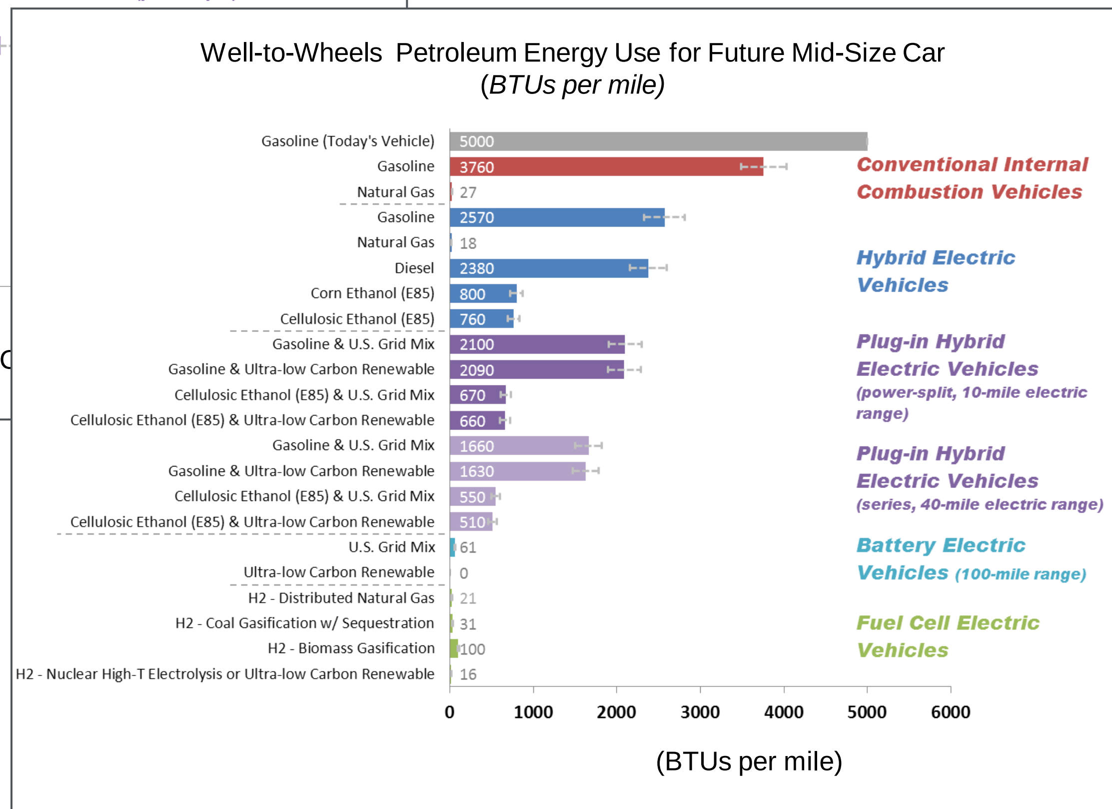
FC targets: http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/pdfs/fuel_cells.pdf ; H_2 Storage targets: http://www1.eere.energy.gov/hydrogenandfuelcells/storage/pdfs/targets_onboard_hydro_storage.pdf;

Battery targets: http://www.uscar.org/commands/files_download.php?files_id=27

At extended driving ranges, the differences between BEVs and FCEVs become more pronounced.



Analysis includes portfolio of transportation technologies and latest models and updates to well-to-wheels assumptions



Analysis & Assumptions at:
http://hydrogen.energy.gov/pdfs/10001_well_to_wheels_gge_petroleum_use.pdf

Notes:
For a projected state of technologies in 2035-2045.
Ultra-low carbon renewable electricity includes wind, solar, etc.
Does not include the life-cycle effects of vehicle manufacturing and infrastructure construction/decommissioning.
Global warming potential of primary fuels excluded.

Key Challenges

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The Program has been addressing the key challenges facing the widespread commercialization of fuel cells.

Technology Barriers*

Fuel Cell Cost & Durability

Targets*:

Stationary Systems: **$1,000-1,500 per kW, 60,000-80,000 hr durability**

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

Hydrogen Cost

Target*: $2 – 4 /gge, (dispensed and untaxed)

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

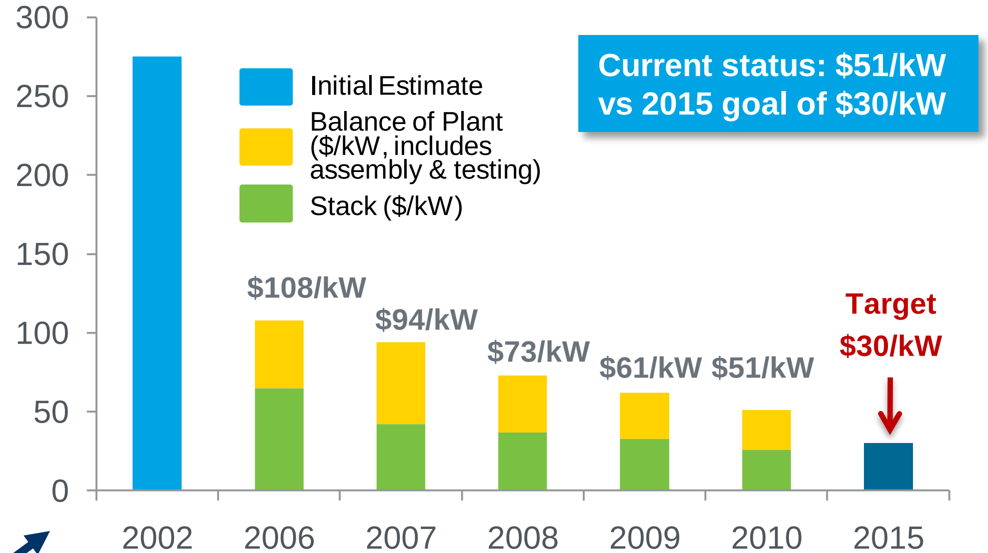
Assisting the growth of early markets will help to overcome many barriers, including achieving significant cost reductions through economies of scale.

*** Targets and Metrics are being updated in 2011 .**

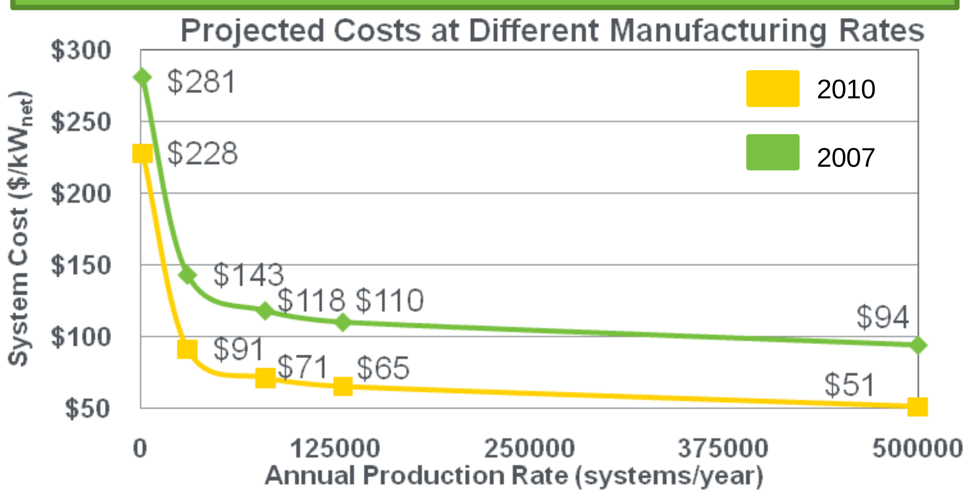
Projected high-volume cost of fuel cells has been reduced to $51/kW (2010)*

- ***More than 30% reduction since 2008***
- ***More than 80% 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.



More than 80% cost reduction since 2002.



**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, increased power density, and simplified balance of plant, resulting in a decrease in system cost.

From 2008 to 2010, key cost reductions were made by:

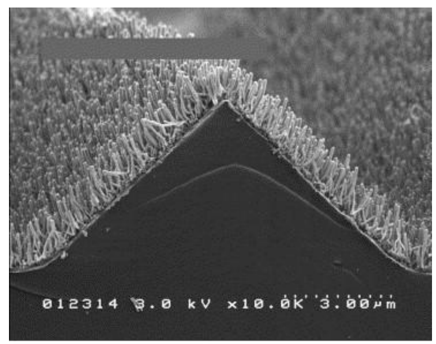
- **Reducing platinum group metal content from 0.35 to 0.18 g/kW**
- **Increasing power density from 715 to 833 mW/cm²**
- **Simplifying balance of plant**

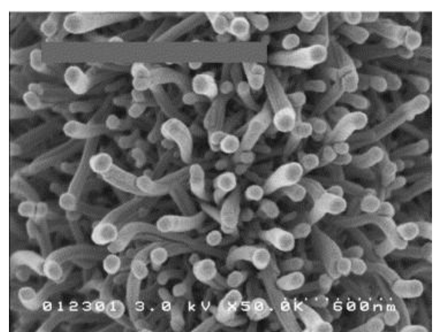
→ These advances contributed to a $22/kW cost reduction.

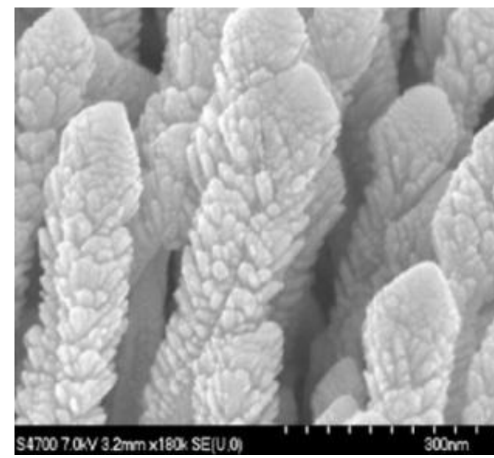
Key improvements enabled by using novel organic crystalline whisker catalyst supports and Pt-alloy whiskerettes.

There are ~ 5 billion whiskers/cm^2.

Whiskers are ~ 25 X 50 X 1000 nm.



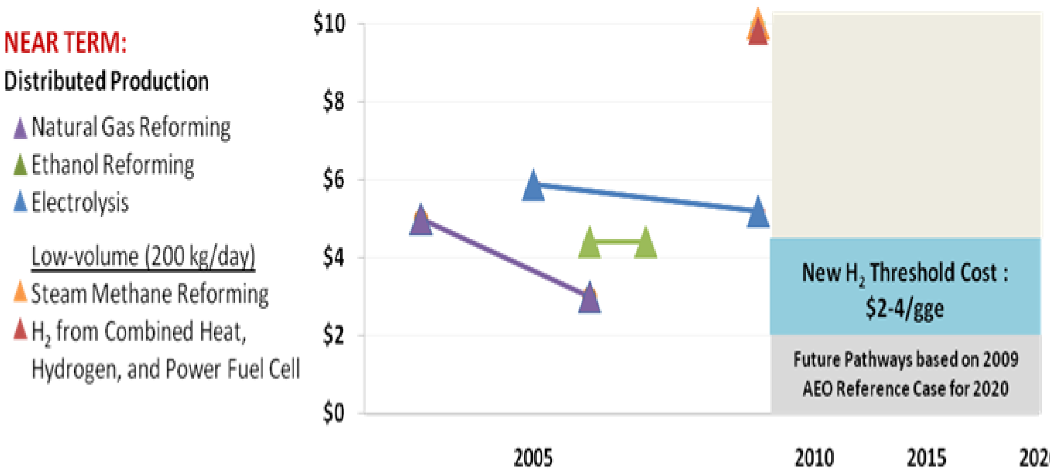


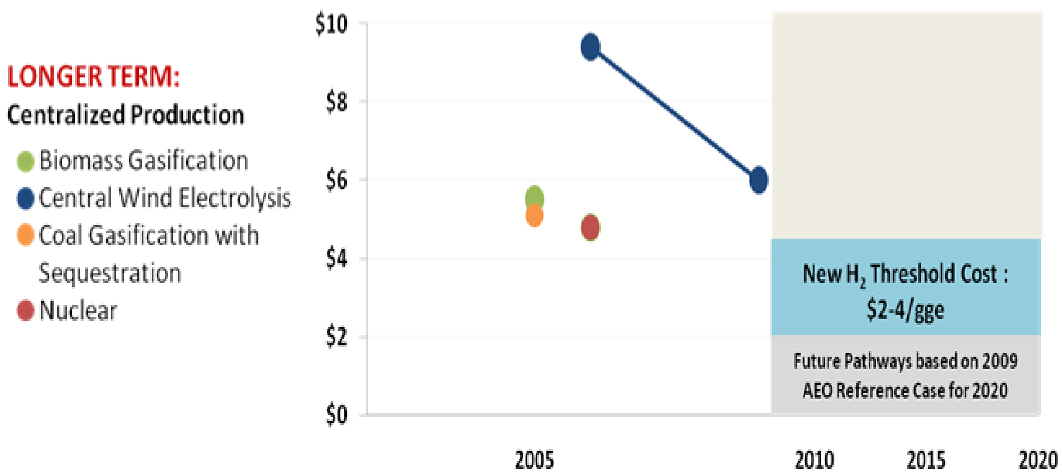


Whiskerettes:
6 nm x 20 nm

Source: 3M

Projections of high-volume / n^{th} plant production and delivery of hydrogen meet the targets for most technologies.



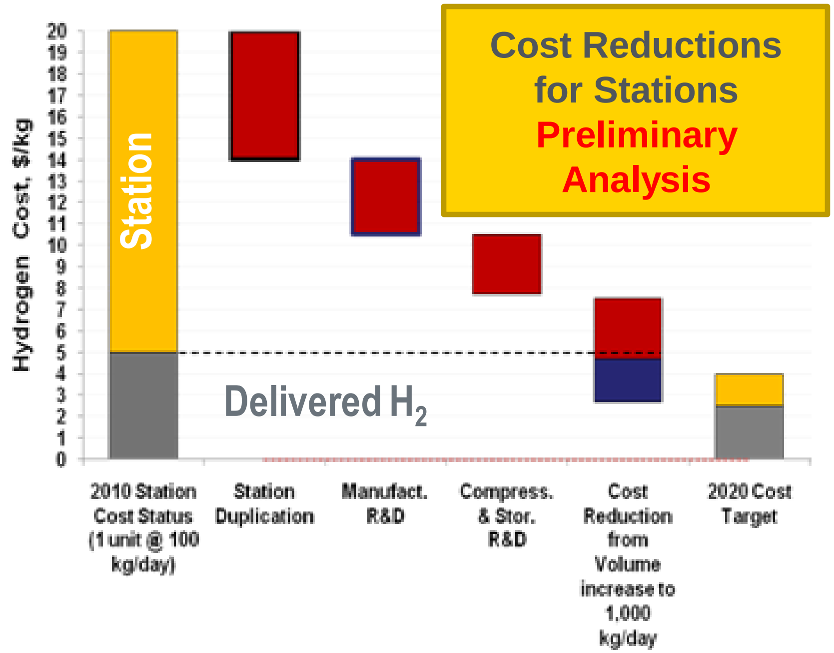


Notes: Data points are being updated to the 2009 AEO reference case. The 2010 Technology Validation results show a cost range of $8-$10/gge for a 1,500 kg/day distributed natural gas and $10-$13/gge for a 1,500 kg/day distributed electrolysis hydrogen station.

We've reduced the cost of H2 delivery*

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

****Projected cost, based on analysis of state-of-the-art technology***

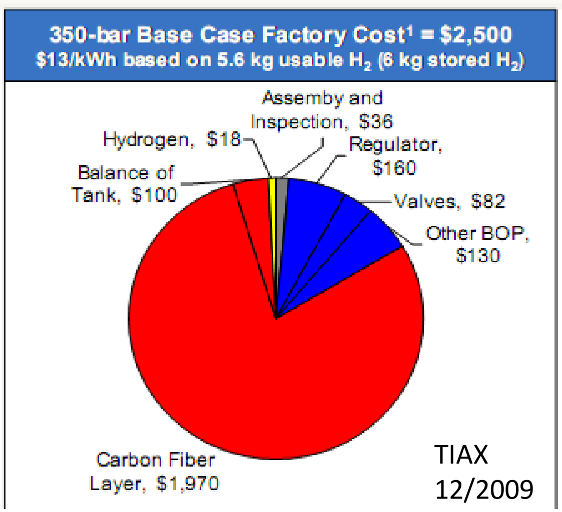


1. Cost reduction from station duplication will required ~120 stations and was based on 3% reduction for a doubling of capacity. Reference: "A portfolio of power-trains for Europe: a fact-based analysis" by McKinsey & Co.
2. Cost of hydrogen delivered to station is ~$5/kg based on TTC Hydrogen Market Study 2009.
3. Station cost reductions based on ANL Hydrogen Delivery Systems Analysis Model (HDSAM). 4. The Current station cost is based on costs from the current California state funded stations. The capital cost for the station is $2.5 million.. 5. The starting station capacity is 100 kg/day.

Significant progress has been made but meeting all weight, volume, performance and cost requirements is still challenging.

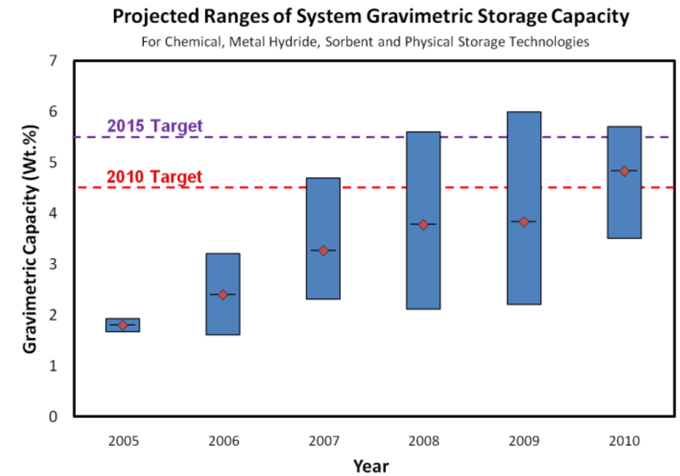
Compressed gas storage offers a near-term option for initial vehicle commercialization and early markets

- Validated driving range of up to ~ 430 mi
- Cost of composite tanks is challenging
  - carbon fiber layer estimated to be >75% of cost
- Advanced materials R&D under way for the long term

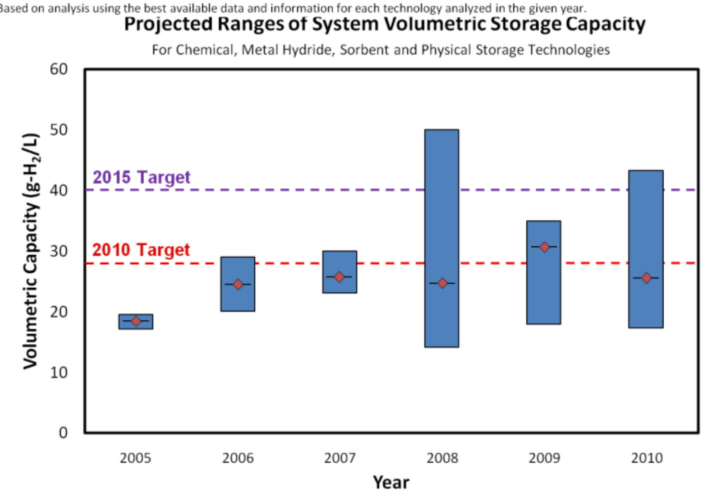


[1] Cost estimate in 2005 USD. Includes processing costs.

Projected Capacities for Complete 5.6-kg H_2 Storage Systems



Based on analysis using the best available data and information for each technology analyzed in the given year.



Based on analysis using the best available data and information for each technology analyzed in the given year.

Safety, Codes & Standards R&D

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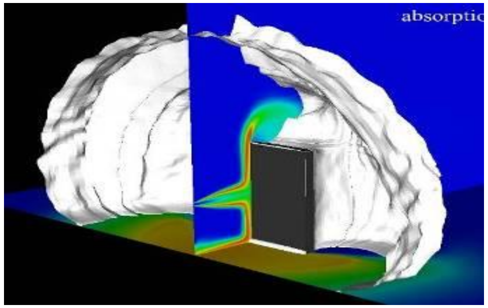
Separation Distances

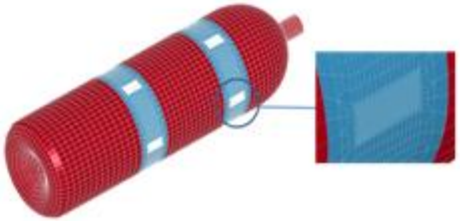
Provided technical data and incorporated risk-informed approach that enabled NFPA2 to update bulk gas storage separation distances in the 2010 edition of NFPA55

Barrier walls reduce separation distances – simulated position of allowable heat flux iso-surface for 3-minute employee exposure (2009 IFC).



Materials and Components Compatibility

- Performed testing of forklift tank materials to enable design qualification
- Added two additional Nickel alloy chapters to the Technical Reference



Fuel Quality Specification

- Draft International Standard (DIS) was submitted to ISO TC197 Nov 2010
- Technical Specification (TS) published and harmonized with SAE J2719, Committee Draft (CD) prepared
- Developing standardized sampling and analytical methodologies with ASTM

Safety Sensor Development

- Completed extensive life testing - 4,000 hrs and 10,000 thermal cycles - of a robust, ceramic, electrochemical Hydrogen safety sensor with exceptional baseline stability and resistance to H2 signal degradation

Technical Performance Requirements	
Sensitivity: 1 vol% H_2 in air	Temperature: -40°C to 60°C
Accuracy: 0.04-4% ±1% of full scale	Durability: 5 yrs without calibration
Response time: <1 min at 1% And <1 sec at 4% Recovery <1 min	Low cross-sensitivity to humidity, H_2S, CH_4, CO, and VOCs

Technology Validation

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

RECENT PROGRESS

Vehicles & Infrastructure

- 152 fuel cell vehicles and 24 hydrogen fueling stations
- Over 2.8 million miles traveled
- Over 114 thousand total vehicle hours driven
- 2,500 hours (nearly 75K miles) durability
- Fuel cell efficiency 53-59%
- Vehicle Range: ~196 – 254 miles (independently also validated 430 mile range)

Buses

- DOE is evaluating real-world bus fleet data (DOT collaboration)
- H_2 fuel cell buses have a 41% to 132% better fuel economy when compared to diesel & CNG buses

Forklifts

- Over 18,000 refuelings at Defense Logistics Agency site

Recovery Act

- DOE (NREL) is collecting operating data from deployments for an industry-wide report

Combined Heat, Hydrogen & Power (CHHP)

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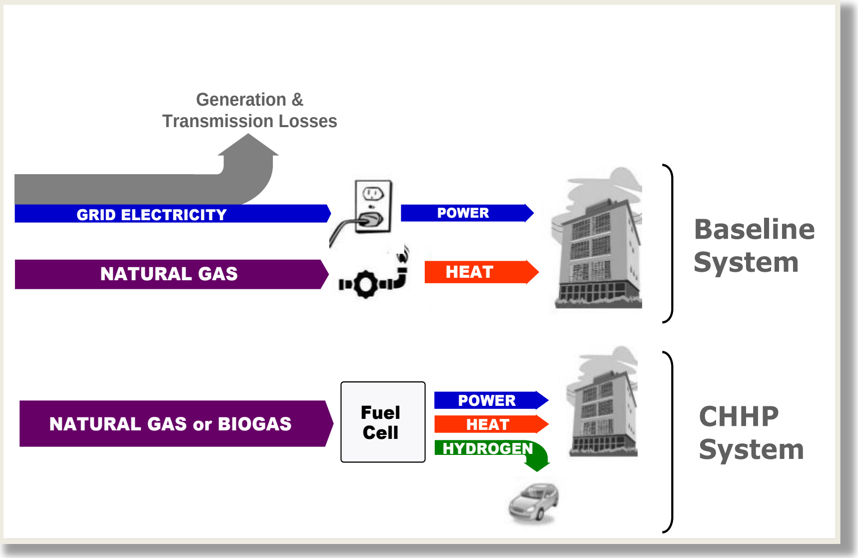
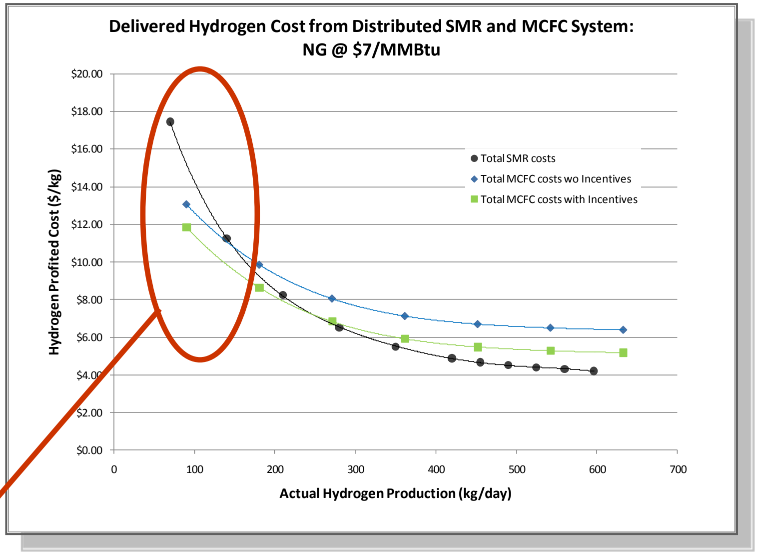
The cost of hydrogen production from CHHP can be comparable to distributed SMR at low volumes.

Combined Heat, Hydrogen, and Power (CHHP)



- CHHP is an innovative approach that can :
  - Help establish an initial infrastructure for fueling vehicles, *with minimal investment risk*
  - Produce clean power and fuel for multiple applications
- The Program is demonstrating a CHHP system using biogas.



In cases where there is a low demand for hydrogen in early years of FCV deployment, CHHP may have cost advantages over on-site SMR production.

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**

Biogas Resource Example: Methane from Waste Water Treatment

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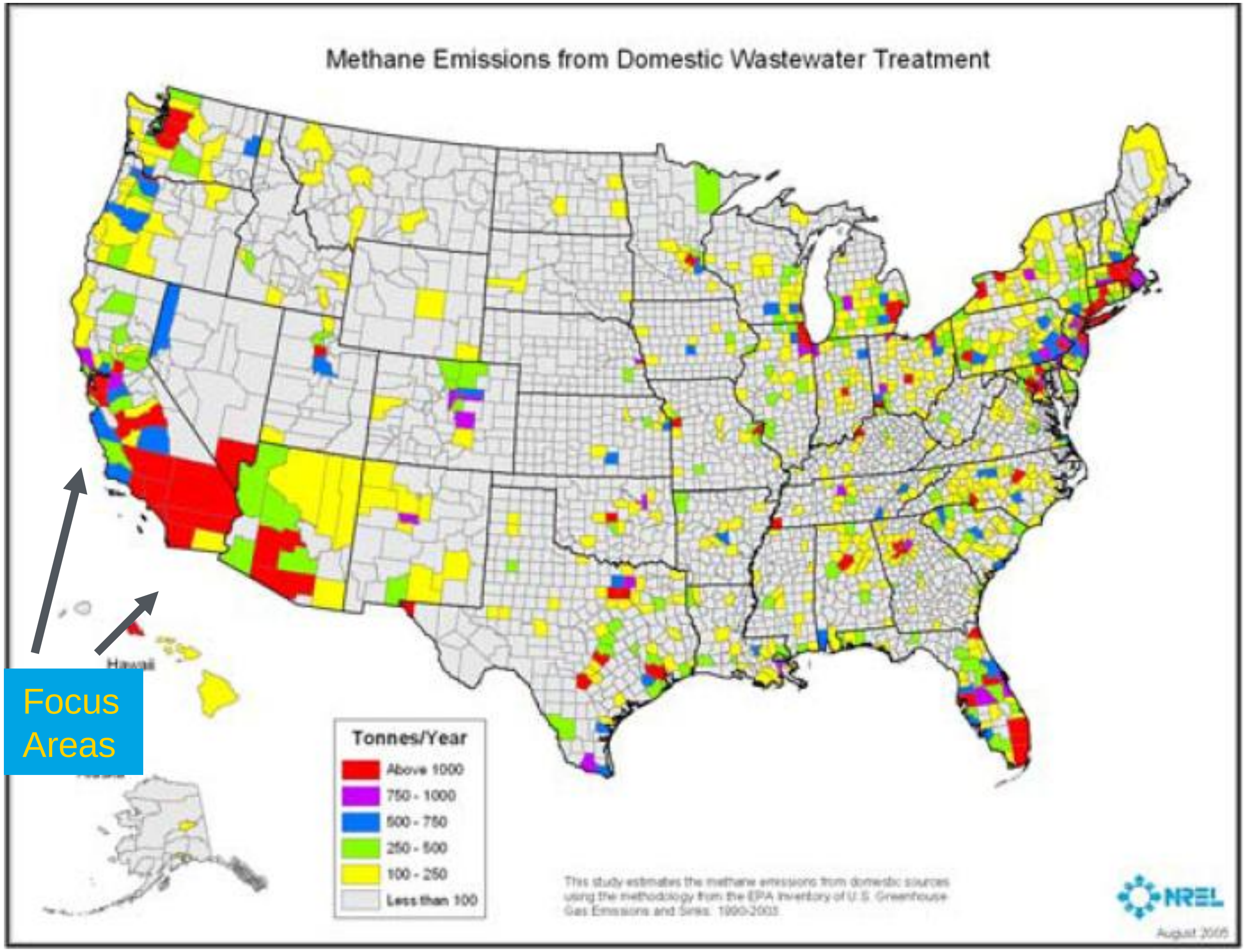
Biogas from waste water treatment plants is ideally located near urban centers to supply hydrogen for fuel cell vehicles.



Source: NREL report *A Geographic Perspective on Current Biomass Resource Availability in the United States*, 2005

- 500,000 MT per year of methane available from waste water treatment plants in U.S.
- Majority of resource located near urban centers.
- If ~50% of the bio-methane was available, ~340,000 kg/day of renewable hydrogen could be produced from steam methane reforming.
- Renewable hydrogen is enough to fuel ~340,000 fuel cell vehicles per day.

Analysis of Policies for FCEVs & Hydrogen Infrastructure

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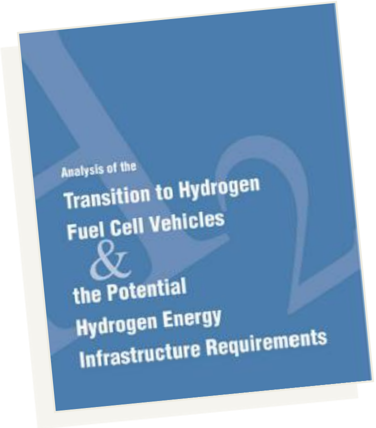
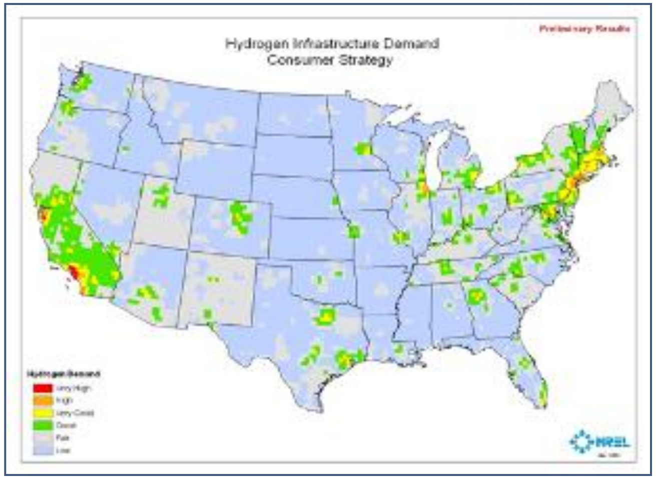
Analysis by Oak Ridge National Laboratory explores the impacts and infrastructure and policy requirements of potential market penetration scenarios for fuel cell vehicles.

Key Findings:

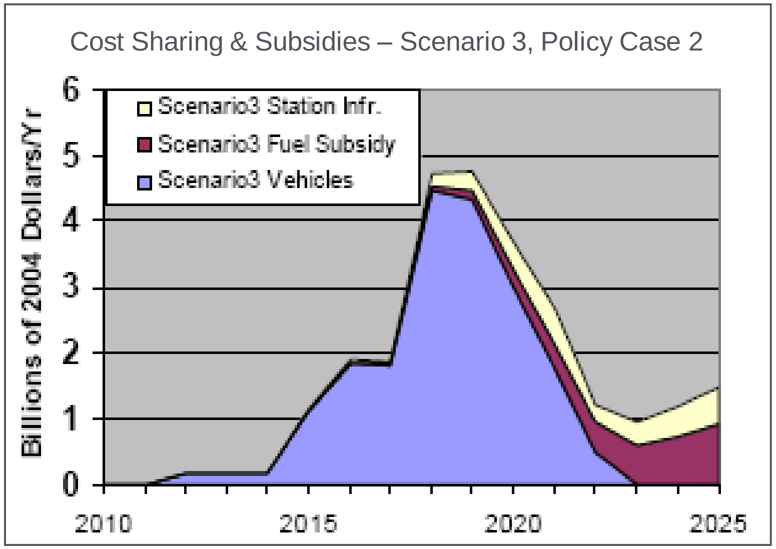
- Transition policies will be essential to overcome initial economic barriers.
- Cost-sharing & tax credits (2015 – 2025) would enable industry to be competitive in the marketplace by 2025.
- With targeted deployment policies from 2012 to 2025, FCV market share could grow to 50% by 2030, and 90% by 2050.
- Cost of these policies is not out of line with other policies that support national goals.
  - The annual cost would not exceed $6 billion—*federal incentives for ethanol are expected to cost more than $5 billion/year by 2010.*
  - Cumulative costs would range from $10 billion to $45 billion, from 2010 to 2025—*federal incentives for ethanol have already cost more than $28 billion, and these cumulative costs are projected to exceed $40 billion by 2010.*



http://cta.ornl.gov/cta/Publications/Reports/ORNL_TM_2008_30.pdf



Areas of projected fuel cell vehicle use—and fuel demand



Projected cost of policies to sustain a transition to fuel cell vehicles and H_2 infrastructure, based on the most aggressive scenario

Analysis of Policies for FCEVs & Hydrogen Infrastructure

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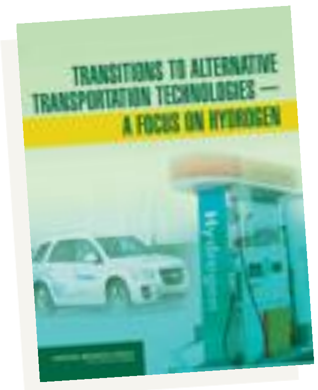
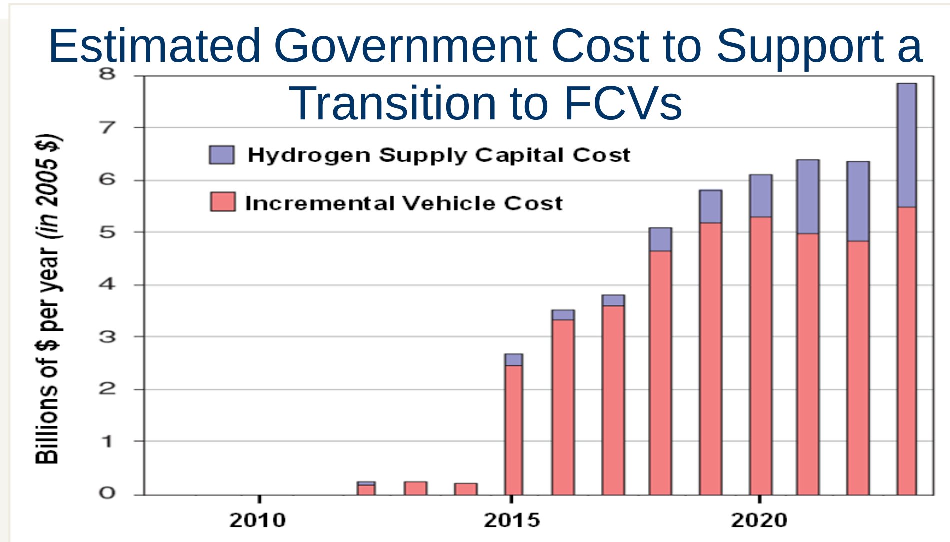
NAS study, "Transitions to Alternative Transportation Technologies: A Focus on Hydrogen," shows positive outlook for fuel cell technologies—results are similar to ORNL's "Transition Scenario Analysis."



The study was required by EPACT section 1825 and the report was released in 2008, by the Committee on Assessment of Resource Needs for Fuel Cell and Hydrogen Technologies.

www.nap.edu/catalog.php?record_id=12222



Key Findings Include:

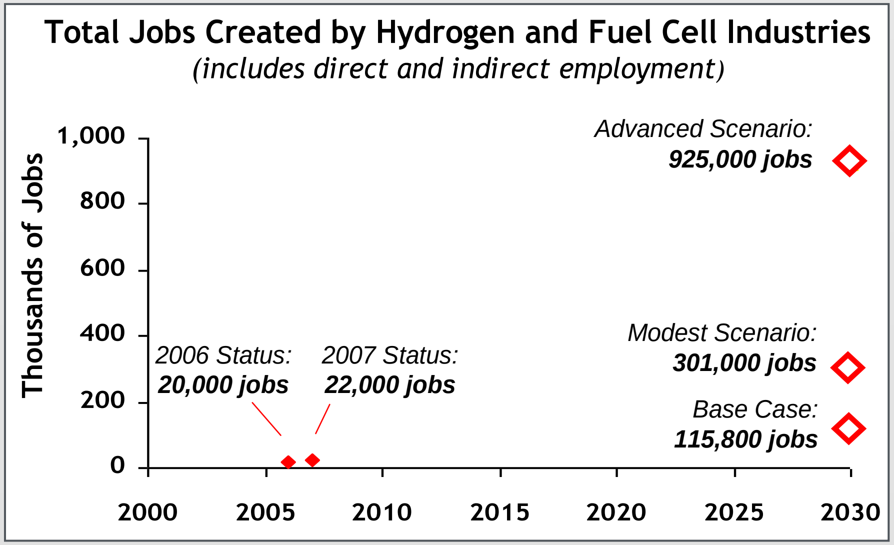
- By 2020, there could be 2 million FCVs on the road. This number could grow rapidly to about 60 million by 2035 and 200 million by 2050.
- Government cost to support a transition to FCVs (for 2008 – 2023) estimated to be $55 billion—about $3.5 billion/year.
- The introduction of FCVs into the light-duty vehicle fleet is much closer to reality than when the NRC last examined the technology in 2004—due to concentrated efforts by private companies, together with the U.S. FreedomCAR & Fuel Partnership and other government-supported programs around the world.
- A portfolio of technologies has the potential to eliminate petroleum use in the light-duty vehicle sector and to reduce greenhouse gas emissions from light-duty vehicles to 20 percent of current levels—by 2050.

Fuel Cells - *The Economic Potential*

The fuel cell and hydrogen industries could generate substantial revenues and job growth.

Renewable Energy Industry Study*

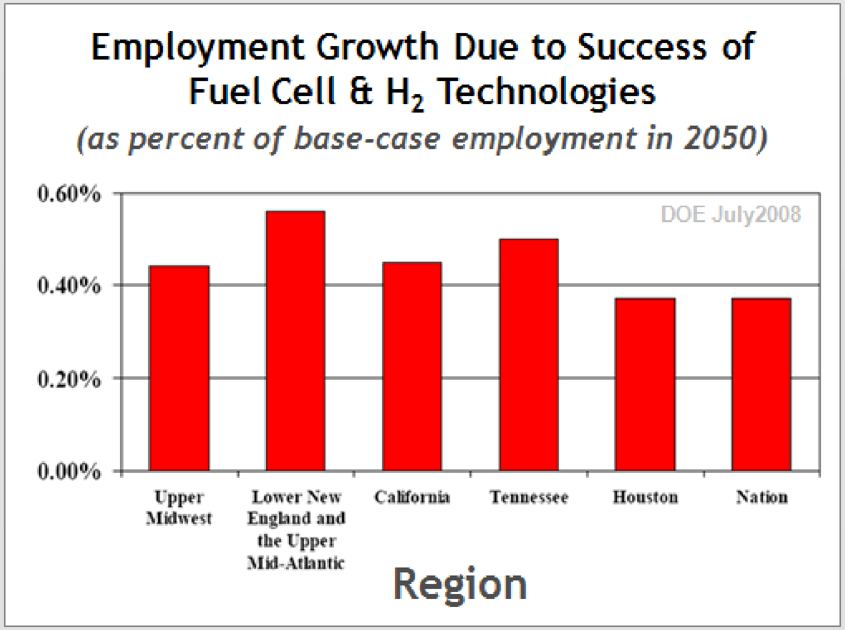
- **Fuel cells are the third-fastest growing renewable energy industry** (after biomass & solar).
- Potential U.S. employment from fuel cell and hydrogen industries of **up to 925,000 jobs** (by 2030).
- Potential gross revenues up to **$81 Billion/year** (by 2030).



***Study Conducted by the American Solar Energy Society**
www.ases.org/images/stories/ASES/pdfs/CO_Jobs_Final_Report_December2008.pdf

DOE Employment Study

- Projects net increase of **360,000 – 675,000** jobs.
- Job gains would be distributed across up to 41 industries.
- Workforce skills would be mainly in the vehicle manufacturing and service sectors.

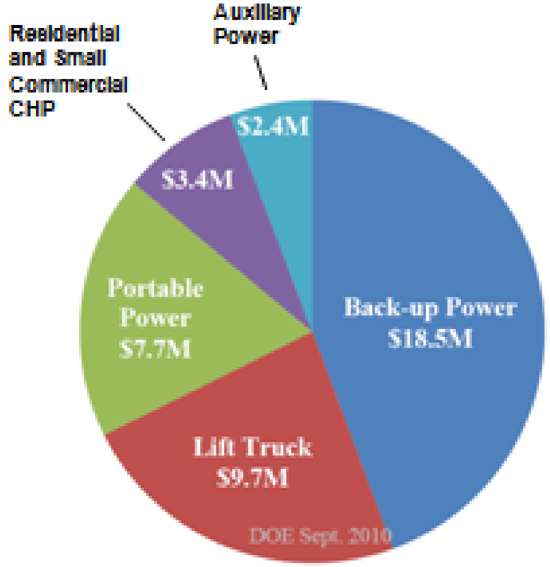


www.hydrogen.energy.gov/pdfs/epact1820_employment_study.pdf

$42 million from the 2009 American Recovery and Reinvestment Act to fund 12 projects to deploy up to 1,000 fuel cells

Exceeded 2010 target for Recovery Act fuel cell installations by more than 90% at 230 fuel cells installed:

- 206 lift trucks (35 with FedEx, 14 with Nuvera, 98 with Sysco, and 59 with GENCO)
- 24 telecommunication backup power units provided by ReliOn for AT&T.

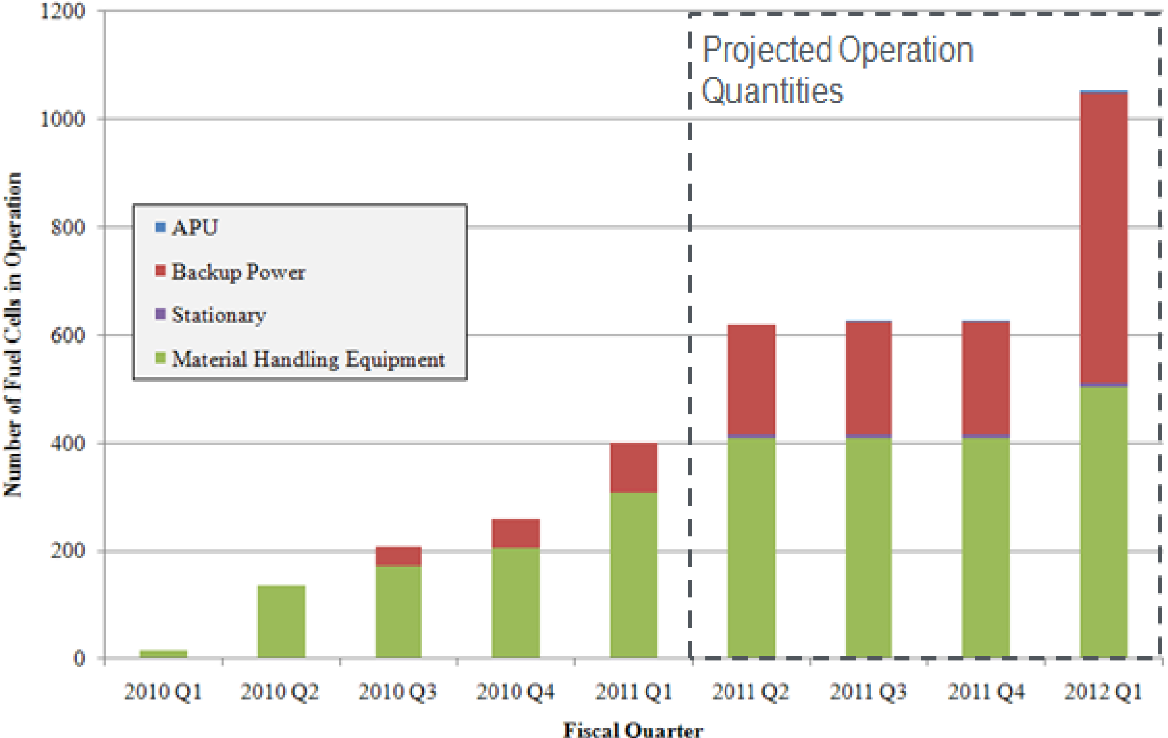


Approximately $54 million in cost-share funding from industry participants—for a total of about $96 million.

Major companies such as FedEx, Coca Cola, Whole Foods, Sprint, AT&T, Sysco and Wegmans are installing fuel cells

Federal Agencies: DOD-DLA: ~120 fuel cell life trucks to four distribution centers, FAA :~26 back-up power fuel cells ; CERL: >200 kW in fuel cell backup power across nine federal installations.

ARRA Fuel Cell Units in Operation - Current and Projected Quantities

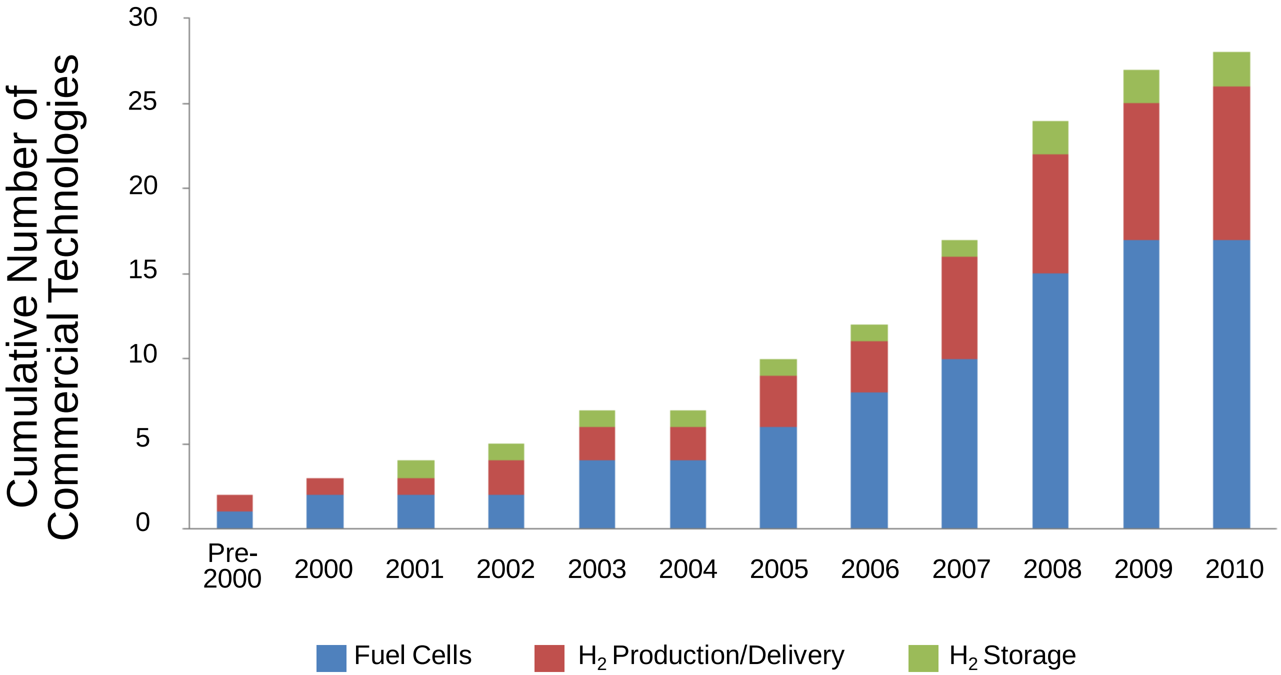


*Compiled using data from National Renewable Energy Laboratory (NREL).

Close to 30 hydrogen and fuel cell technologies developed by the Program entered the market.

Accelerating Commercialization

EERE-funded Fuel Cell Technologies that are Commercially Available



Source: Pacific Northwest National Laboratory
http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/pathways_success_hfcit.pdf

198 PATENTS resulting from EERE-funded R&D:

- 99 fuel cell
- 74 H_2 production and delivery
- 25 H_2 storage

60% are actively used in:

1) Commercial products
2) Emerging technologies
3) Research

Completed Fuel Cell Market Report provides an overview of market trends and profiles for select fuel cell companies

EERE H_2 & Fuel Cells Budgets

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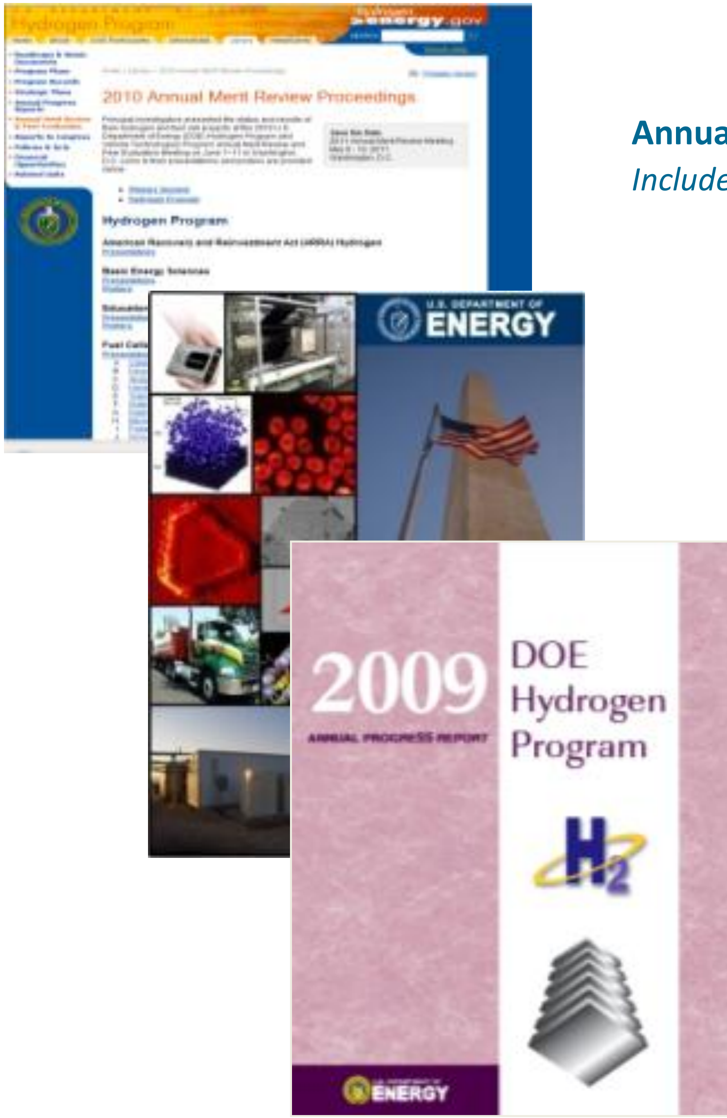
Funding (*$ in thousands*)			
Key Activity	**FY 2009[4]**	**FY 2010 Current Appropriation**	**FY 2012 Request**
Fuel Cell Systems R&D[1]	-	75,609	45,450
Fuel Cell Stack Component R&D	61,133		
Transportation Systems R&D	6,435		-
Distributed Energy Systems R&D	9,750		-
Fuel Processor R&D	2,750		-
Hydrogen Fuel R&D[2]	-	45,750	35,000
Hydrogen Production & Delivery R&D	10,000		-
Hydrogen Storage R&D	57,823		-
Technology Validation	14,789[5]	13,005	8,000
Market Transformation[3]	4,747	15,005	-
Early Markets	4,747	15,005	-
Safety, Codes & Standards	12,238[5]	8,653	7,000
Education	4,200[5]	2,000	-
Systems Analysis	7,520	5,408	3,000
Manufacturing R&D	4,480	4,867	2,000
Total	$195,865	$170,297	$100,450[6]

[1] Fuel Cell Systems R &D includes Fuel Cell Stack Component R&D, Transportation Systems R&D, Distributed Energy Systems R&D, and Fuel Processor R&D [2] Hydrogen Fuel R&D includes Hydrogen Production & Delivery R&D and Hydrogen Storage R&D [3] No Market Transformation in FY 2012. [4] FY 2009 Recovery Act funding of $42.967M not shown in table [5] Under Vehicle Technologies Budget in FY 2009 [6] Includes SBIR/STTR funds to be transferred to the Science Appropriation; all prior years shown exclude this funding

Key Program Documents

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



Annual Merit Review & Peer Evaluation Proceedings

Includes downloadable versions of all presentations at the Annual Merit Review

- **Latest edition released June 2010**

  www.hydrogen.energy.gov/annual_review10_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

- **Released January 2011**

  http://www.hydrogen.energy.gov/annual_review10_report.html

Annual Progress Report

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

- **Released February 2011**

  www.hydrogen.energy.gov/annual_progress.html

Next Annual Review: May 9 – 13, 2011

Washington, D.C.

http://annualmeritreview.energy.gov/

Collaborations

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

Federal Agencies

- DOC
- DOD
- DOE
- 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 Hydrogen & Fuel Cells in the Economy – 17 countries & EC, 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
- Fuel Cell and Hydrogen Energy Association (FCHEA)
- 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, MN
Argonne A, FC, P&D, SC&S
Los Alamos S, FC, SC&S
Sandia P&D, S, SC&S
Pacific Northwest P&D, S, FC, SC&S, A
Oak Ridge P&D, S, FC, A, SC&S
Lawrence Berkeley FC, A
Lawrence Livermore P&D, S, SC&S
Savannah River S, P&D
Brookhaven S, FC
Idaho National Lab P&D

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

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

* Office of Energy Efficiency and Renewable Energy

Thank you

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Additional Information

Preliminary Analysis

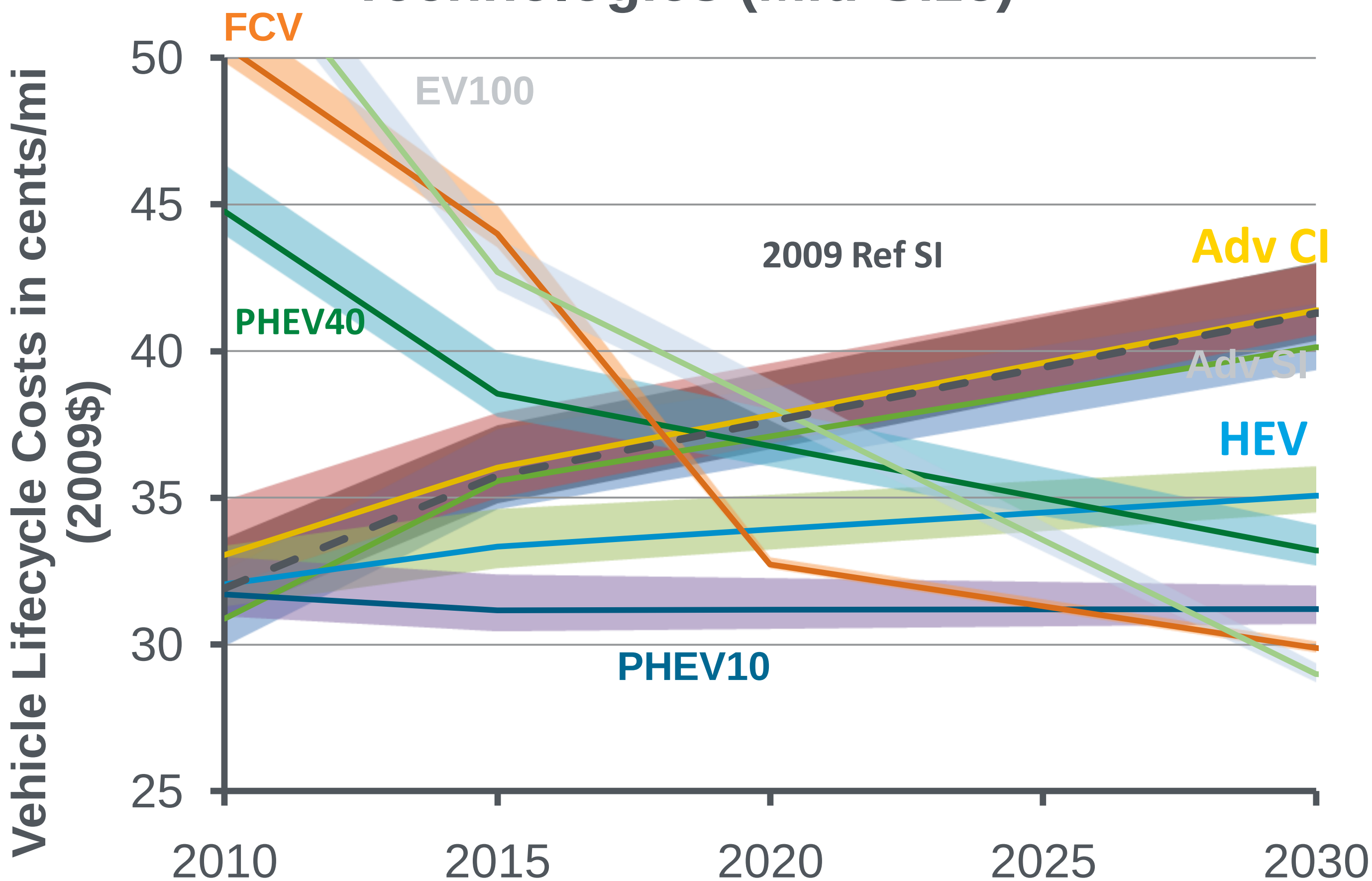
2015

- Lifetime cost of diesel ownership is roughly equivalent to an SI ICE
- HEVs and PHEV10s are competitive.
- Energy storage costs are still high for PHEV40s and EVs

2030

- Hybrid, electrified, and fuel cell vehicles are competitive
- Diesels cost is still roughly equivalent to an SI ICE

Advanced Light Duty Vehicle Technologies (Mid-Size)



* No state, local or utility incentives are included. Federal subsidy policies (e.g., Recovery Act 09 credits for PHEVs) are also excluded. Fuel prices follow AEO09 high oil projections (gases rises from $3.07 in 2010 to $5.47 in 2030; diesel increases from $3.02 in 2010 to $5.57 in 2030); fuel taxes are included in EIA estimates. The vehicle cost range represents a range of potential carbon prices, from $0 to $56 (the centerline is plotted at a carbon price of $20). Technology costs are estimated based on a 50% ("average") likelihood of achieving program goals.

Source: Presentation to ERAC, November 30, 2010

EERE Budget: *FY09 – FY12*

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Funding *($ in thousands)*			
Activity	**FY 2009**	**FY 2010 Current Approp.**	**FY 2012 *Request***
Biomass and Biorefinery Systems	214,245	216,225	340,500
Building Technologies	138,113	219,046	470,700
Federal Energy Management Program	22,000	32,000	33,072
Geothermal Technology	43,322	43,120	101,535
Hydrogen Technology	164,638	0	0
Hydrogen and Fuel Cell Technologies	0	170,297	100,450
Water Power	39,082	48,669	38,500
Industrial Technologies	88,196	94,270	319,784
Solar Energy	172,414	243,396	457,000
Vehicle Technologies	267,143	304,223	588,003
Weatherization & Intergovernmental Activities	516,000**	270,000	393,798
Wind Energy	54,370	79,011	126,859
Facilities & Infrastructure	76,000	19,000	26,407
Strategic Programs	18,157	45,000	53,204
Program Direction	127,620	140,000	176,605
Congressionally Directed Activities	228,803	292,135	0
RE-ENERGYSE	0	0	0
Adjustments	-13,238	0	-26,364
Total	**$2,156,865**	**2,216,392**	**3,200,053**

* SBIR/STTR funding transferred in FY 2009 was $19,327,840 for the SBIR program and $2,347,160 for the STTR program.
** Includes $250.0 million in emergency funding for the Weatherization Assistance Grants program provided by P.L. 111-6, "The Continuing Appropriations Resolution, 2009."

Hydrogen Delivery R&D

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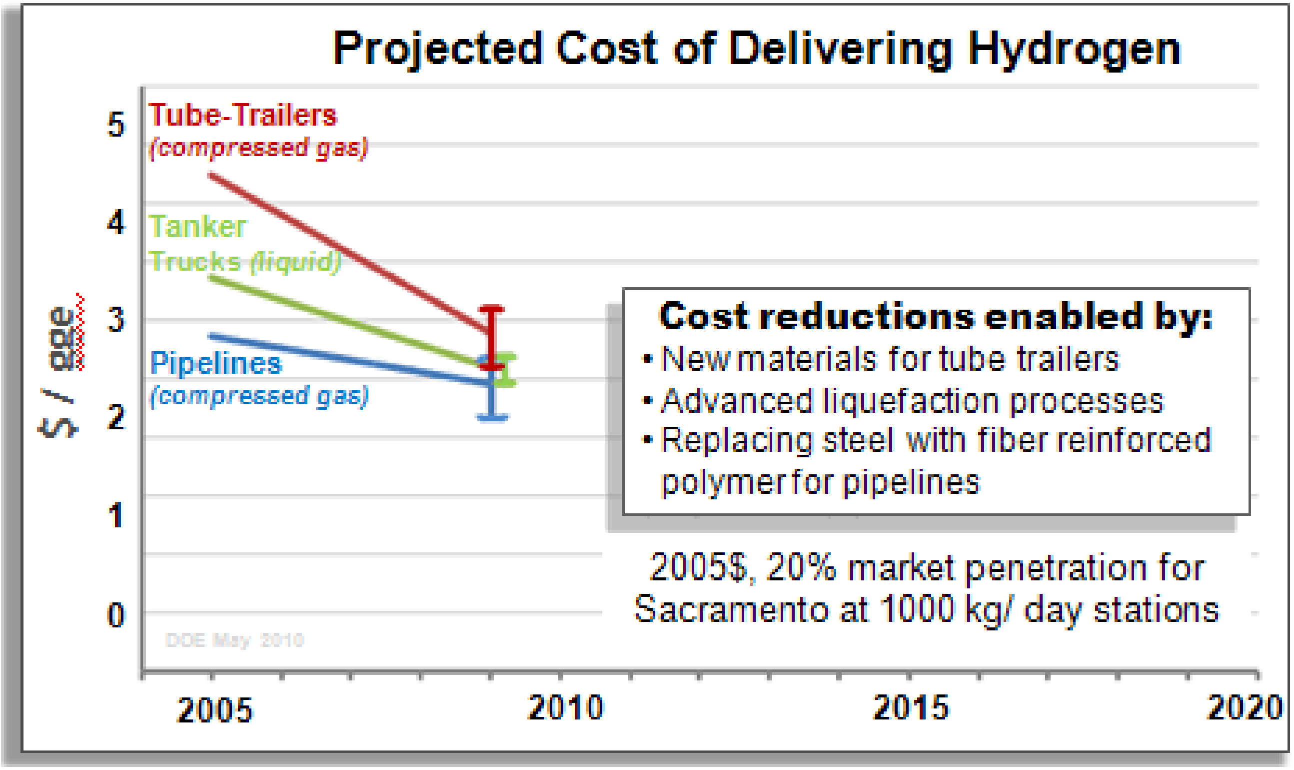
The Program is developing technologies to deliver hydrogen from centralized production facilities, efficiently and at low cost.



We've reduced the cost of hydrogen delivery* —

~30% reduction in tube trailer costs

>20% reduction in pipeline costs

~15% reduction liquid hydrogen delivery costs

Projected cost, based on analysis of state-of-the-art technology

Distributed NG

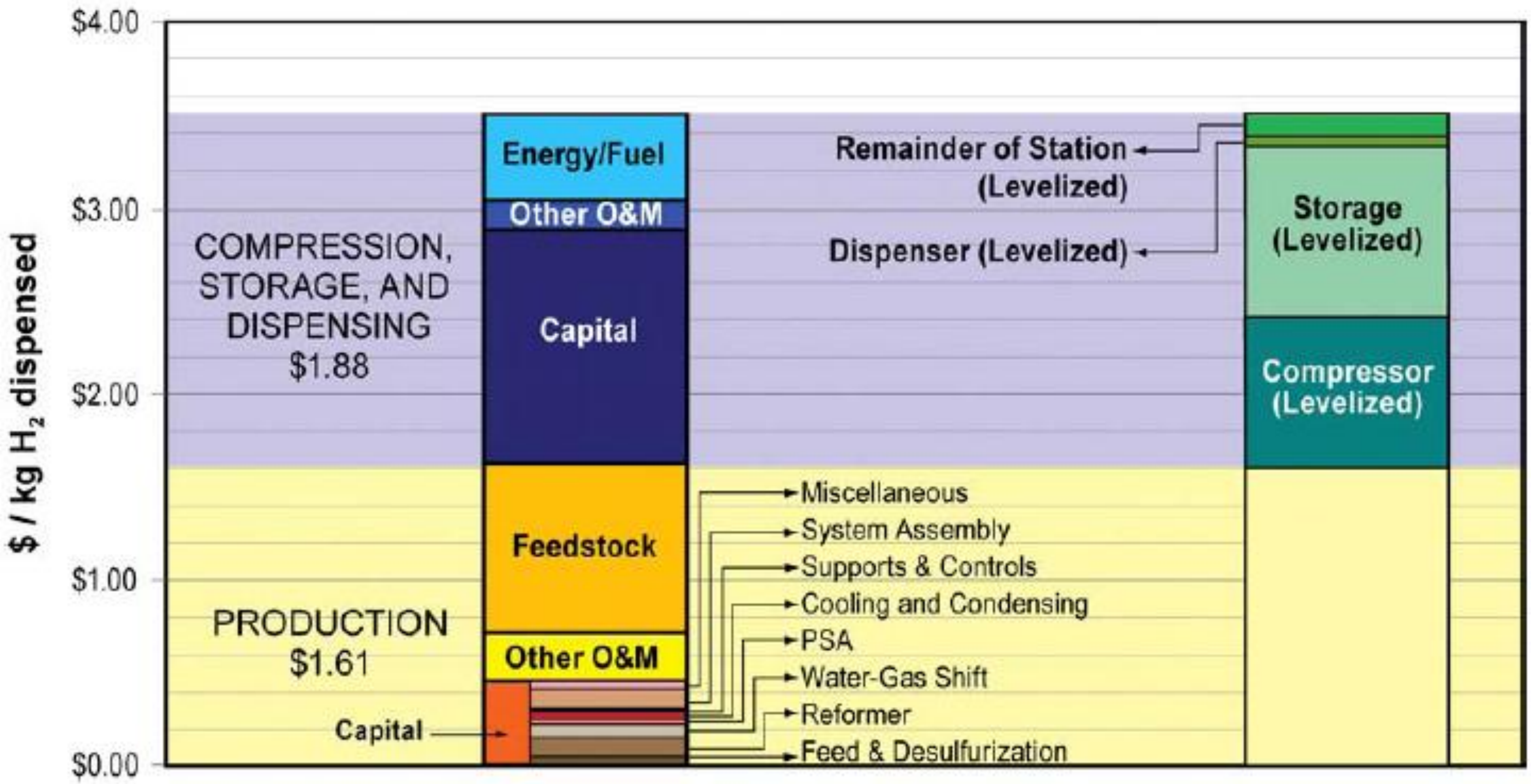


Figure 9.1.4. Breakdown of levelized costs for distributed natural gas pathway

Distributed NG

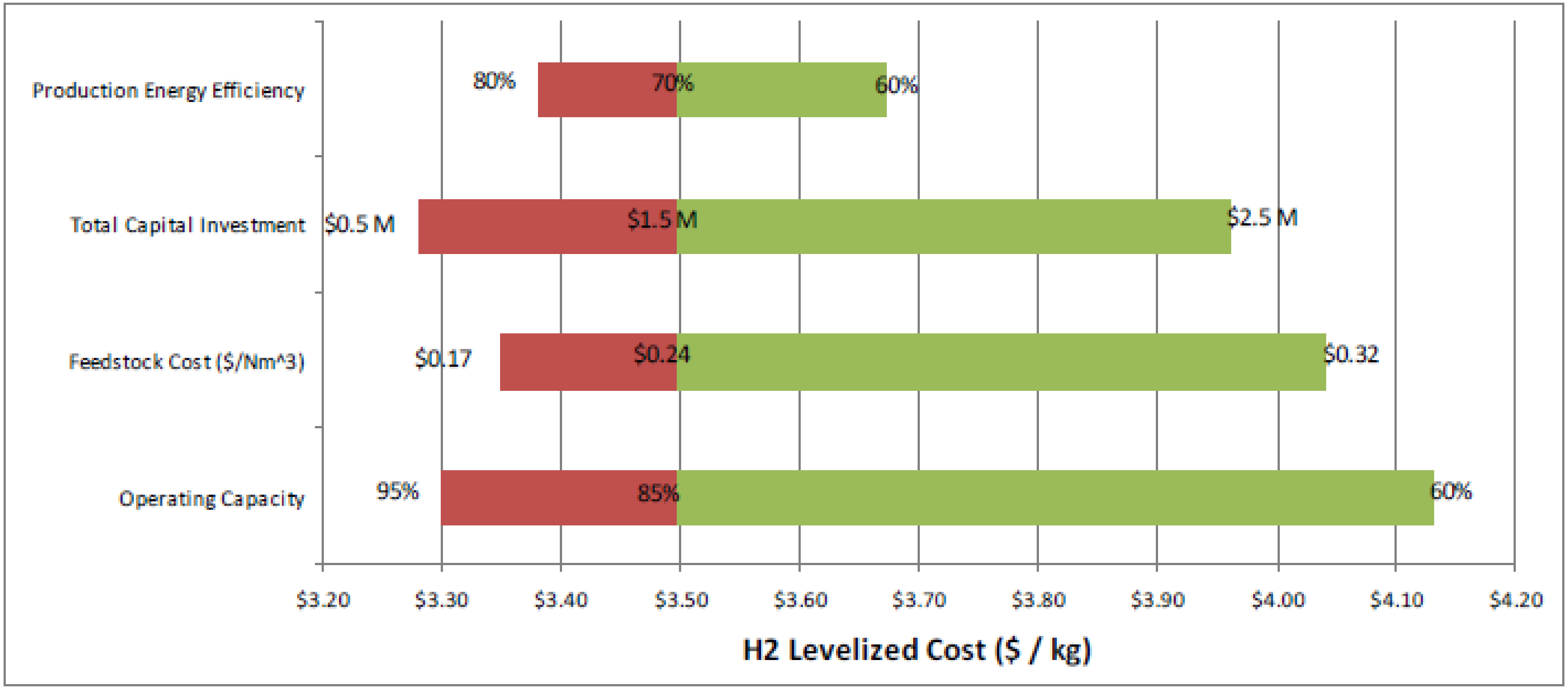
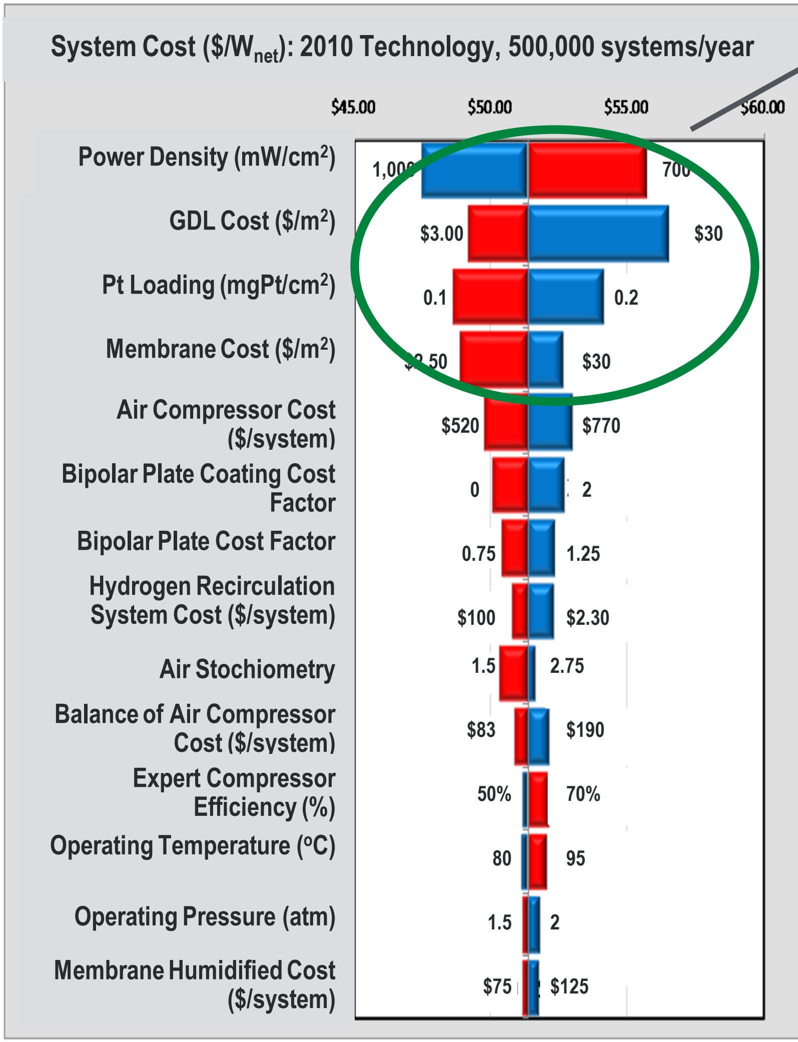


Figure 9.1.9. Production sensitivities for distributed natural gas pathway

Fuel Cells- Sensitivity Analysis Example

Challenges:

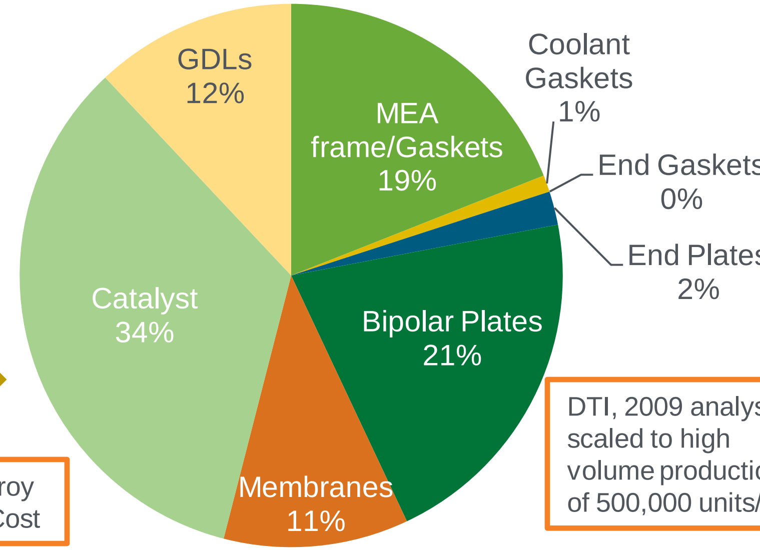
- **Platinum (Pt) cost is ~34% of total stack cost**
- **Catalyst durability needs improvement**



Key Focus Areas for R&D

Used $1100/Troy Ounce for Pt Cost

Stack Cost - $26/kW



DTI, 2009 analysis, scaled to high volume production of 500,000 units/yr

Strategies to Address Challenges - Examples

- Lower PGM Content
  - Improved Pt catalyst utilization and durability
- Pt Alloys
  - Pt-based alloys with comparable performance to Pt and cost less
- Novel Support Structures
  - Non-carbon supports and alternative carbon structures
- Non-PGM catalysts
  - Non-precious metal catalysts with improved performance and durability

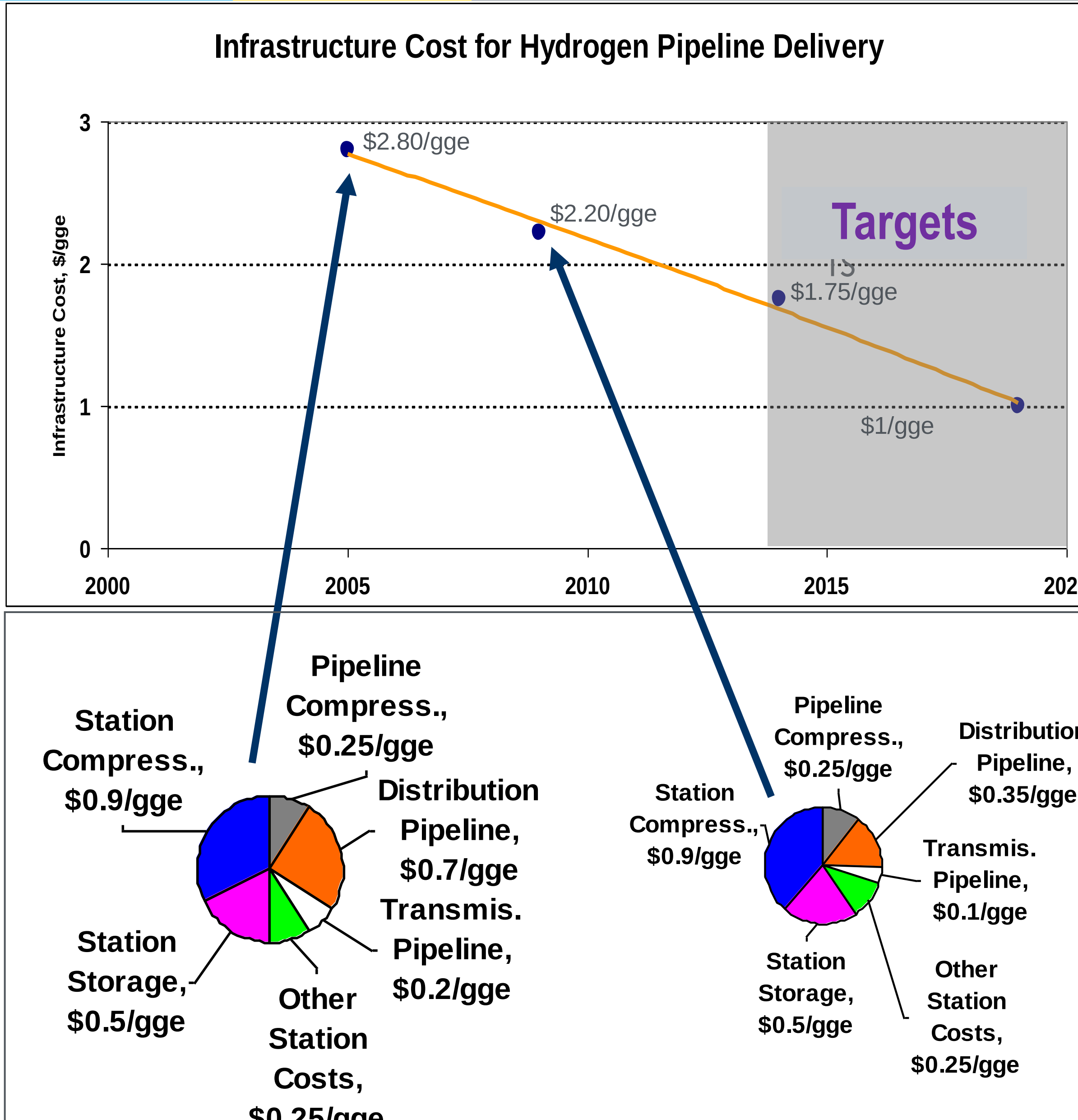
The delivered hydrogen cost at high-volume with pipeline delivery was projected to be ~$2.20/gge (2009)*

- *More than 20% reduction since 2005*
- *Majority of cost reduction from pipeline advancements*

As station and delivery costs are reduced, compressor, terminal, and storage components are responsible for a larger % of costs.

**Based on projection to high-volume hydrogen delivery.*

Source: US DOE 10/2010



Infrastructure (Station with Liquid Truck Delivery) — *Progress: Cost*

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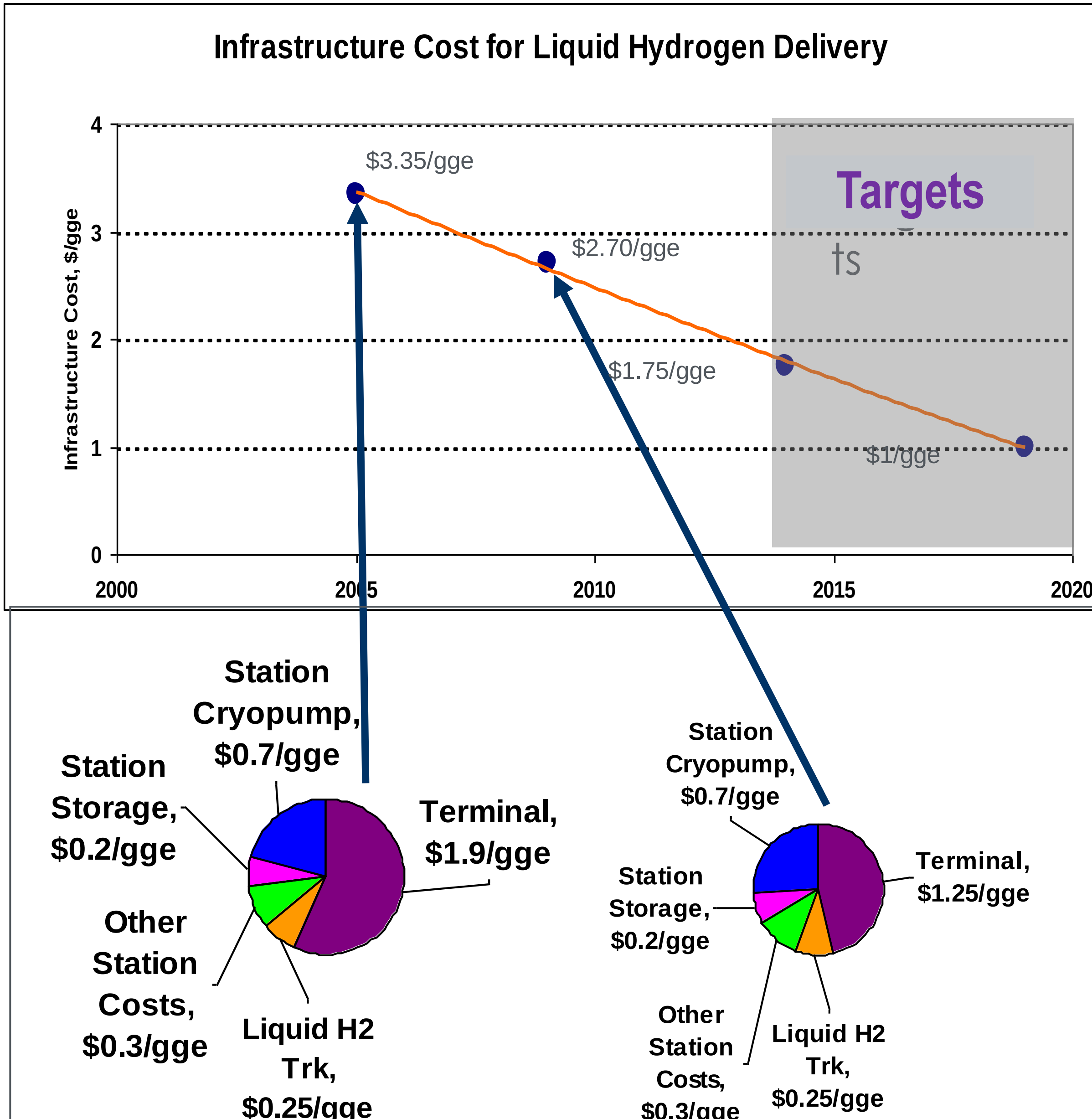
The delivered hydrogen cost at high-volume with liquid truck delivery was projected to be ~$2.70/gge (2009)*

- *~20% reduction since 2005*
- *Majority of cost reduction from terminal advancements*

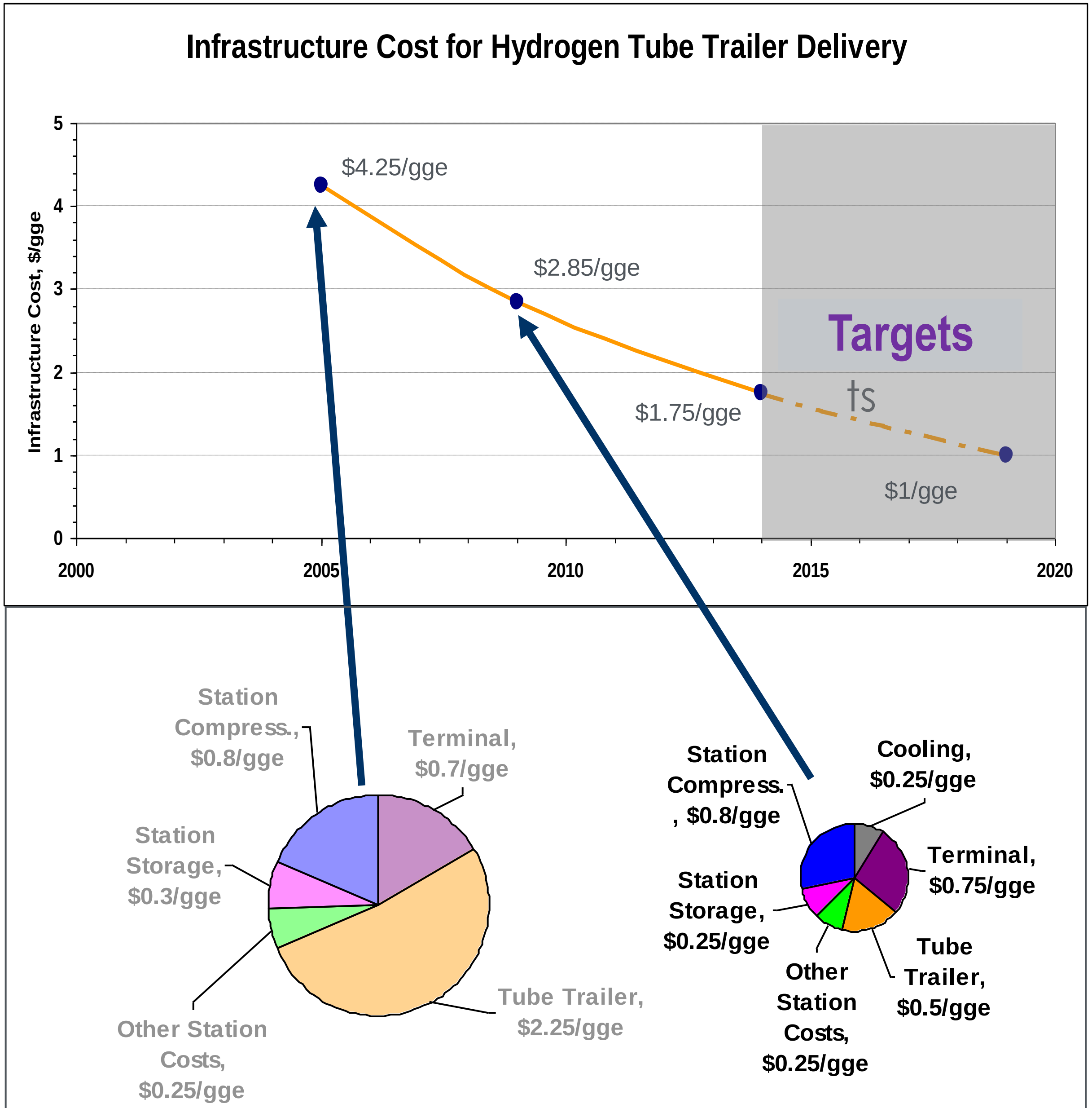
**Based on projection to high-volume hydrogen delivery.*

Source: US DOE 10/2010



The delivered hydrogen cost at high-volume with tube trailer delivery was projected to be ~$2.85/gge (2009)*

- *More than 30% reduction since 2005*
- *Majority of cost reduction from tube trailer advancements*



Based on projection to high-volume hydrogen delivery.

Source: US DOE 10/2010