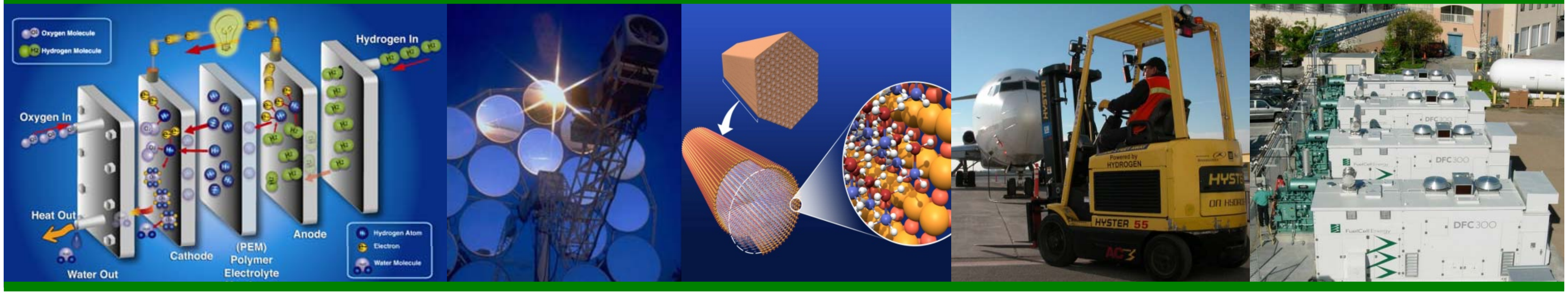
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



DOE Hydrogen Production and Delivery Research & Development Progress

Fred Joseck

Systems Analysis/International Team Leader

United States Department of Energy

Fuel Cell Technologies Program

IPHE Meeting: Shanghai, China

September 21, 2010

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, (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.

Source: US DOE 09/2010

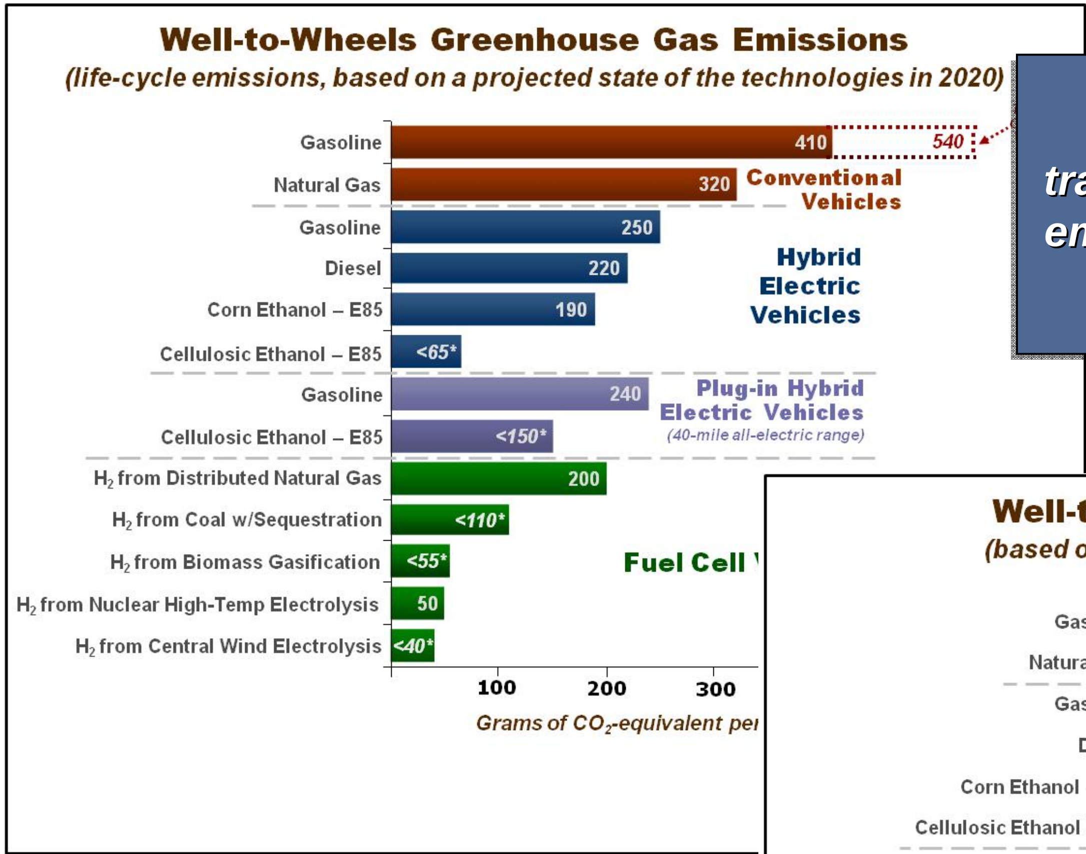
*** Targets and Metrics are being updated in 2010 .**

Administration's Clean Energy Goals

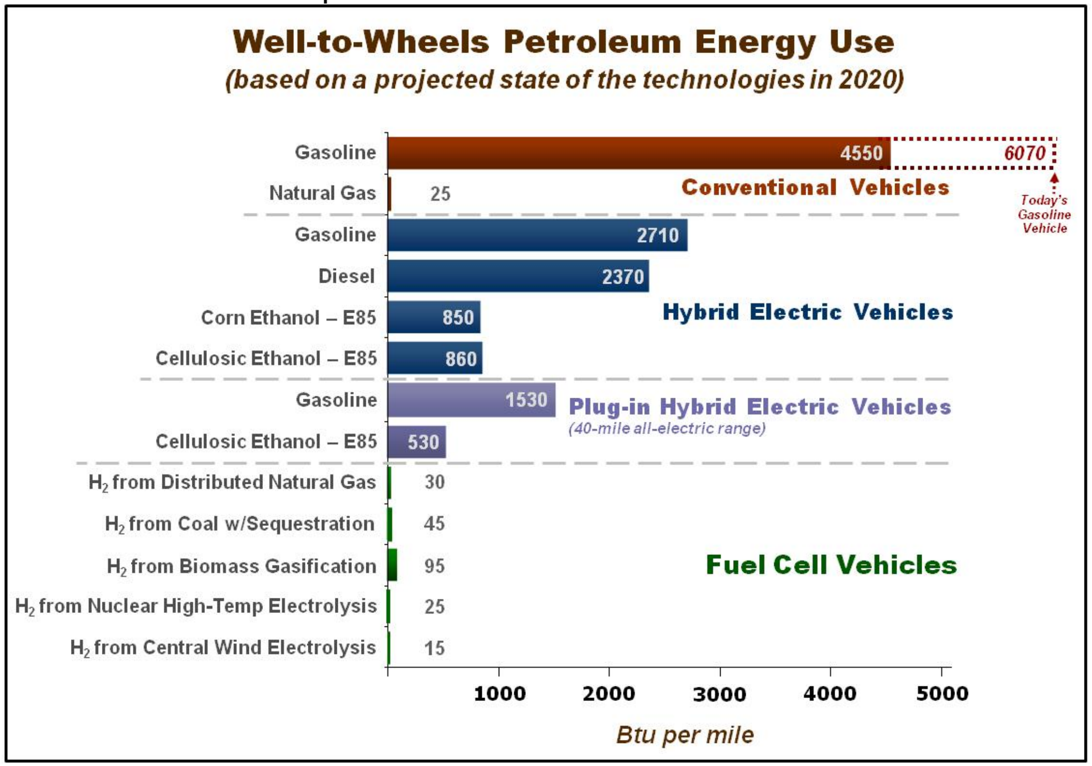
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- ✓ Double Renewable Energy Capacity by 2012
- ✓ Invest $150 billion over ten years in energy R&D to transition to a clean energy economy
- ✓ Reduce GHG emissions and petroleum use 50% by 2030
- ✓ Reduce GHG emissions 83% by 2050

Source: US DOE 09/2010



Analysis shows portfolio of transportation technologies will reduce emissions of greenhouse gases and oil consumption



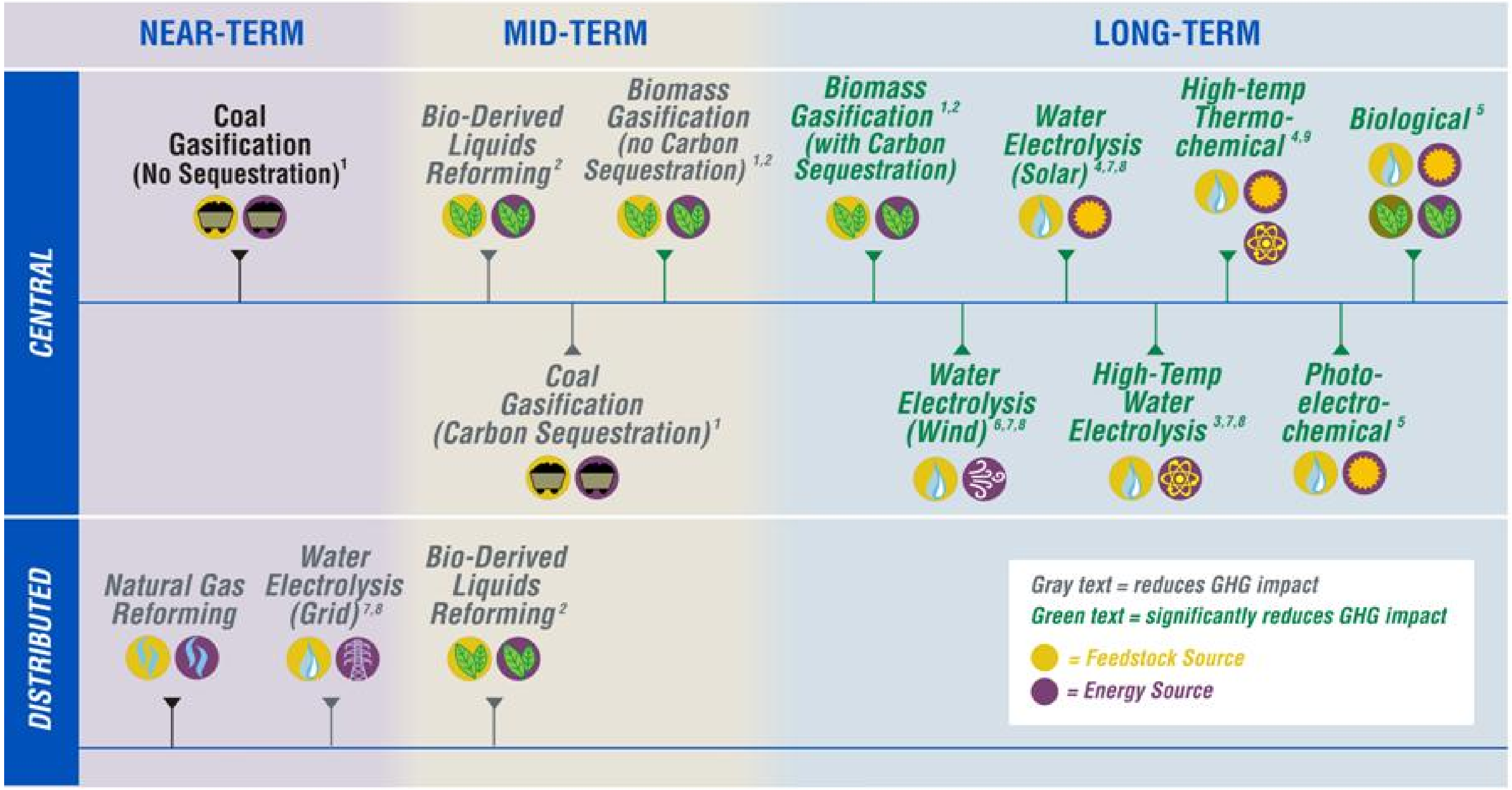
DOE Program Record #9002,
www.hydrogen.energy.gov/program_records.html.

Source: US DOE 09/2010

Pathways for Hydrogen Production

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

Near-term, mid-term, and long-term solutions



Enabling technologies under development by

1. The Office of Fossil Energy
2. The Biomass Program
3. The Nuclear Hydrogen Initiative
4. The Solar Energy Technologies Program
5. The Office of Basic Energy Sciences
6. The Wind Program
7. The Geothermal Technologies Program
8. The Hydrogen Utility Group
9. The International Partnership for a Hydrogen Economy

Source: US DOE 09/2010

Critical Challenges for H_2 Production

U.S. DEPARTMENT OF ENERGY

Key R&D Gaps

Distributed Natural Gas Reforming
- High capital costs
- High operation and maintenance costs
- Design for manufacturing

Bio-Derived Liquids Reforming
- High capital costs
- High operation and maintenance costs
- Design for manufacturing
- Feedstock quantity and quality

Coal and Biomass Gasification
- High reactor costs
- System efficiency
- Feedstock impurities
- Carbon capture and storage

Thermochemical
- Cost-effective reactor
- Effective and durable materials of construction
- Longer-term technology

Water Electrolysis
- Low system efficiency and high capital costs
- Integration with renewable energy sources
- Design for manufacturing

Photoelectrochemical
- Effective photocatalyst material
- Low system efficiency
- Cost-effective reactor
- Longer-term technology

Biological
- Efficient microorganisms for sustainable production
- Optimal microorganism functionality in a single organism
- Reactor materials
- Longer-term technology

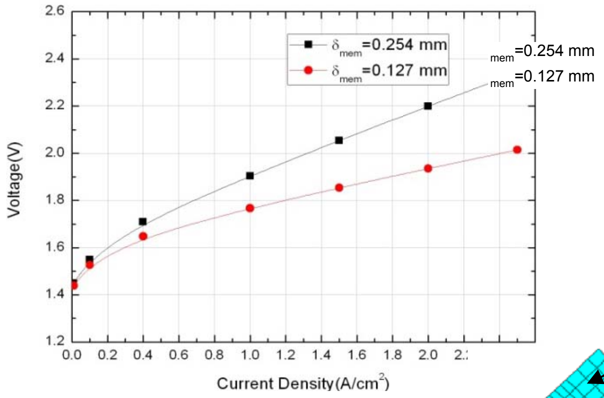
Source: US DOE 09/2010

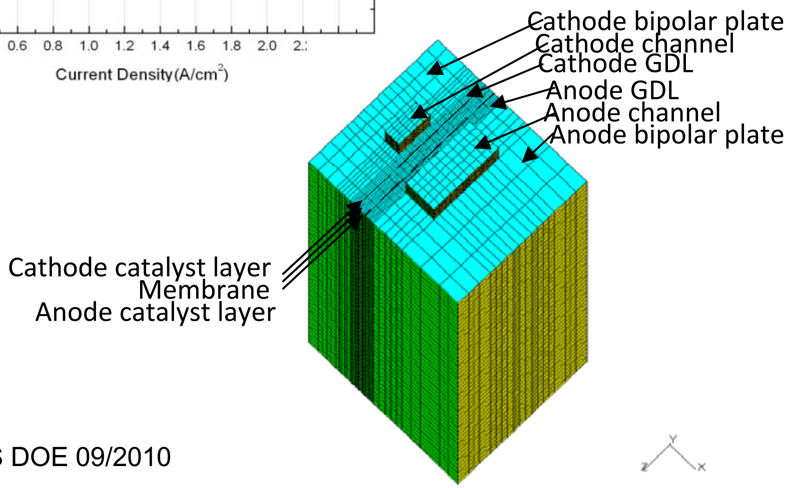
Hydrogen Production R&D
2010 Progress & Accomplishments - Examples

The key objective is to reduce cost of H_2 (delivered, dispensed & untaxed)

Electrolysis

> 20% reduction cost of electrolyzer cell via a 55% reduction in catalyst loading from new process techniques (Proton Energy)

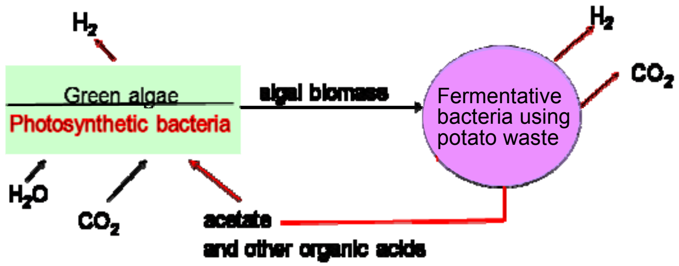


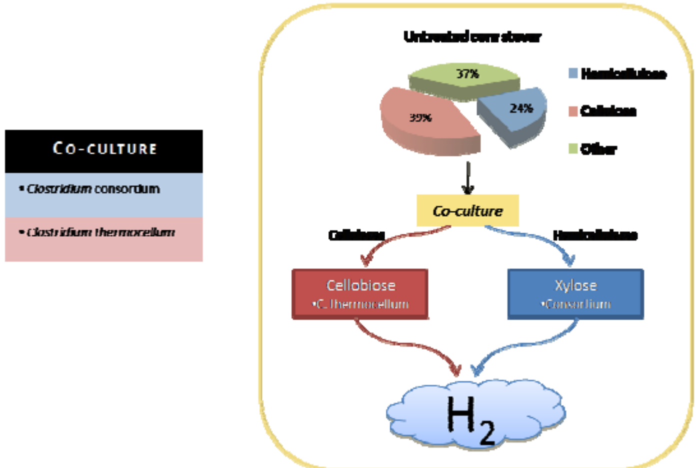


Source: US DOE 09/2010

Biological

Continuous fermentative / photobiological H_2 production from potato waste achieved a maximum molar yield of 5.6 H_2 / glucose (NREL)





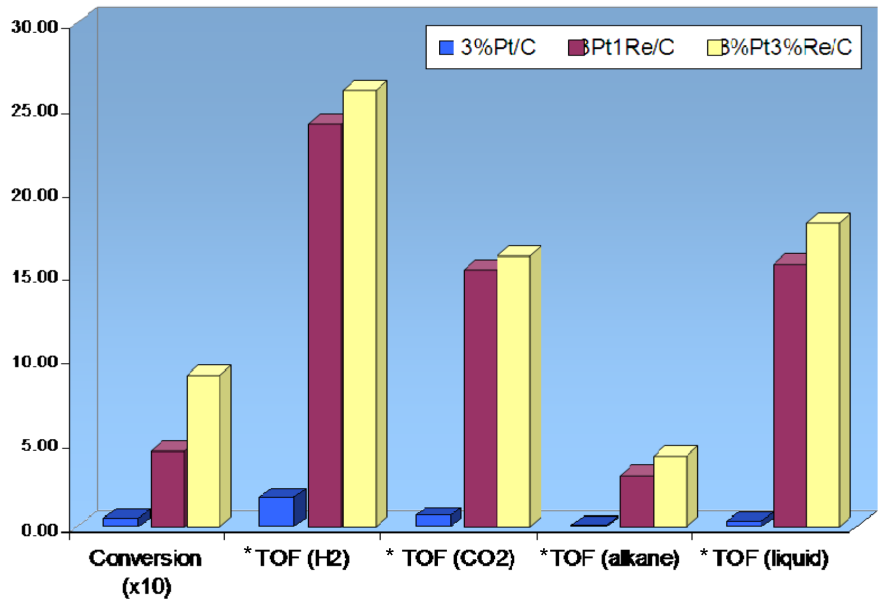
Hydrogen Production R&D
2010 Progress & Accomplishments - Examples

U.S. DEPARTMENT OF ENERGY

The key objective is to reduce cost of H_2 (delivered, dispensed & untaxed)

Reforming & Separation Processes

Minimized the acid sites for undesired reaction pathways for aqueous phase reforming of bio-derived liquids (BDL) using Pt-Re/C catalysts, resulting in H2 yields well above 60%. (PNNL)



PNNL

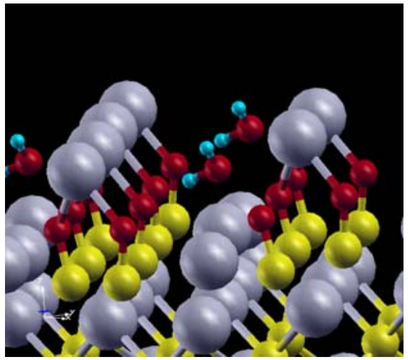
* TOF means Time of Flight in mass spectrometer.

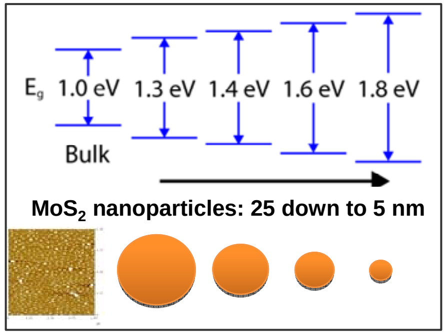
Source: US DOE 09/2010

Photoelectrochemical

Established important correlations between surface morphology and interaction with interfacial water molecules (LLNL)

Successfully demonstrated band gap tailoring in photoactive MoS_2 nanoparticles.

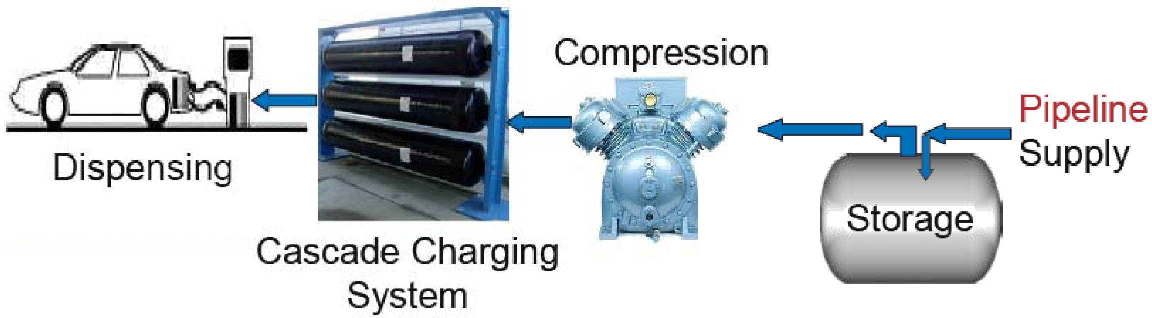


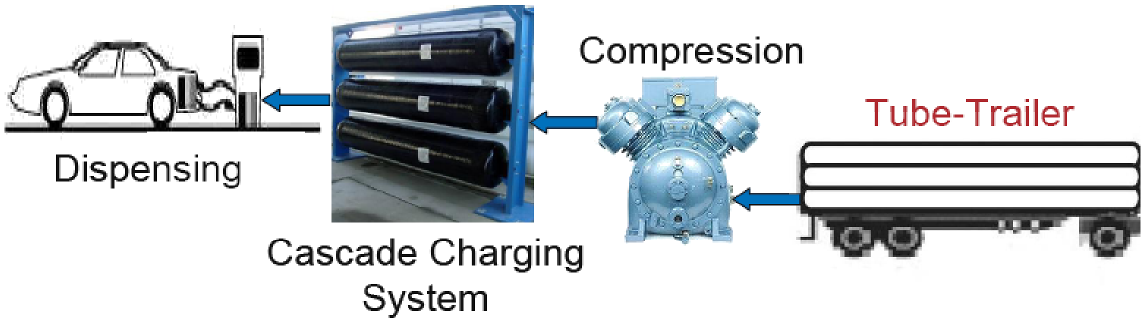


Hydrogen Delivery

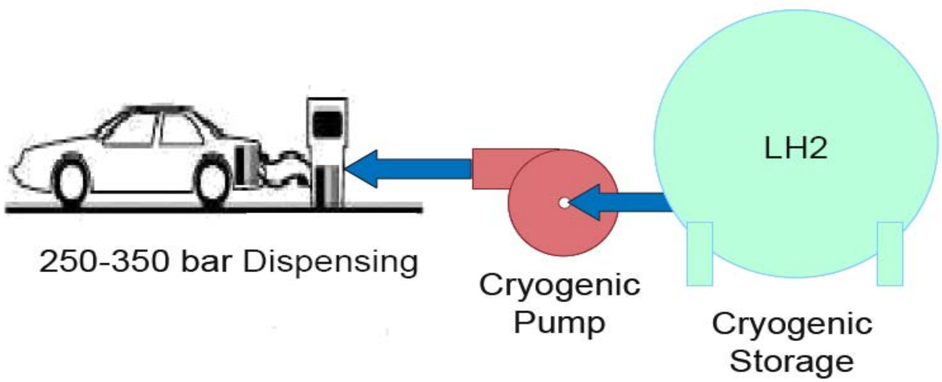
Delivery Technologies

Stations Using 350-bar Gaseous Hydrogen





Stations Using Cryo-compressed Hydrogen *(from liquid hydrogen delivery)*



Source: US DOE 09/2010

Critical Challenges for H_2 Delivery

U.S. DEPARTMENT OF ENERGY

Key R&D Gaps

Compression Technologies

Required for pipelines, terminals & retail stations

- Reliability
- Efficiency
- Cost
- Materials Compatibility

Bulk Storage

Required at the plant gate production, terminals, and retail stations

- Hydrogen Quality
- Cost (fluctuating raw materials cost)
- Materials Compatibility

Source: US DOE 09/2010

H_2 Delivery R&D

2010 Progress & Accomplishments

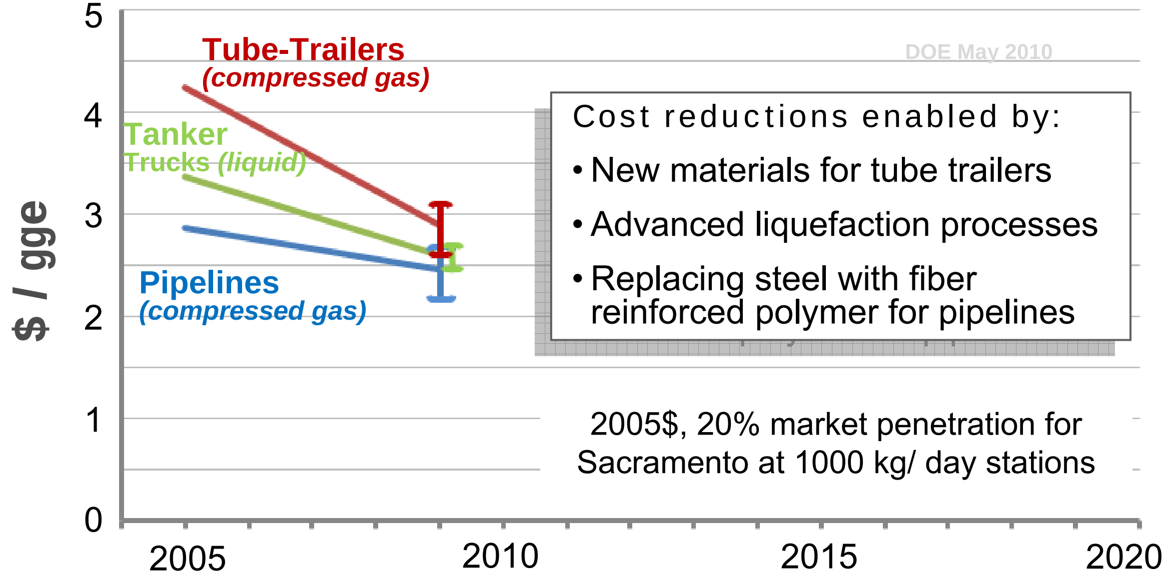
U.S. DEPARTMENT OF ENERGY

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

Projected Cost of Delivering Hydrogen



RECENT ACCOMPLISHMENTS

- Testing demonstrated Cryopump flow rates up to 2 kg / min exceeding targets (BMW, Linde, LLNL)
  - Provides lowest cost compression option for a station and meets the challenges of sequential vehicle refueling
- Demonstrated manufacturability and scalability of glass fiber wrapped tanks through sequential prototypes (3 to 24 to 144 inches in length) (LLNL)
- Completed design criteria and specifications for centrifugal compression of hydrogen which are projected to meet or exceed DOE targets. Compressor designed using off-the-shelf parts is in testing (Concepts NREC)

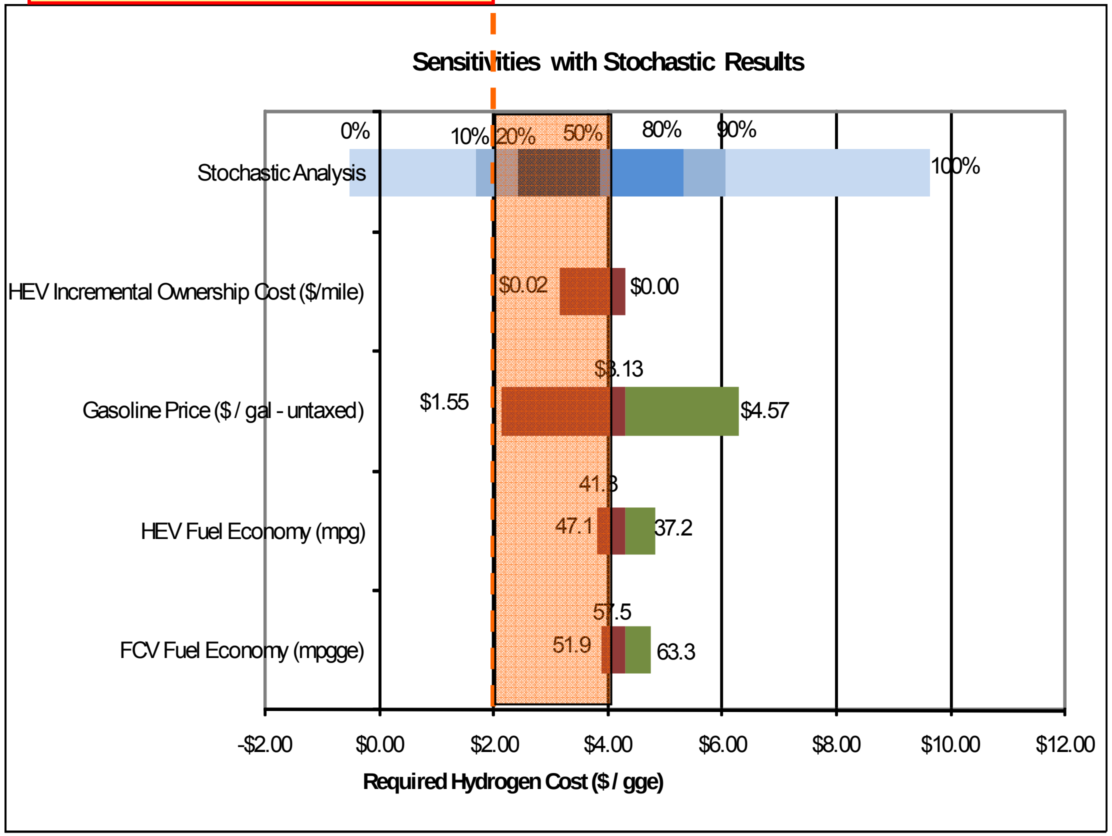
Source: US DOE 09/2010

Hydrogen Competitive Threshold Cost Analysis *DRAFT*

U.S. DEPARTMENT OF ENERGY

New H_2 Cost Target Range = $2.00-$4.00/gge

- **The cost necessary for hydrogen to be competitive depends upon the gasoline cost, electricity cost, and vehicle fuel economies and incremental cost.**



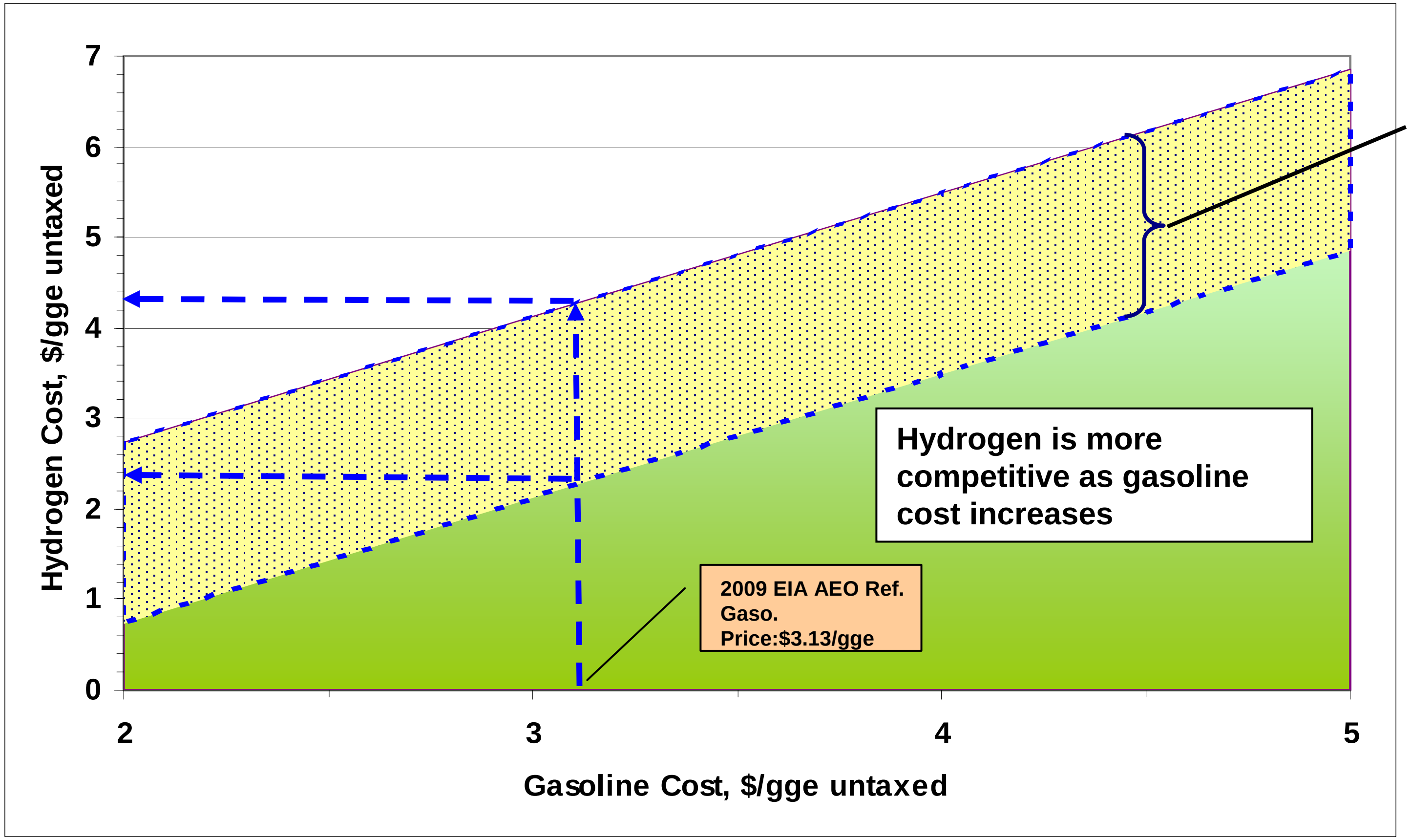
$5.00 / gal gasoline (untaxed) is approximately 10% higher than the AEO 2009 High Energy Price case
$3.00 / gal gasoline (untaxed) is the AEO 2009 Reference (including effects of ARRA) case estimate rounded down.
The HEV fuel economy sensitivity was set at the base +/-10%
The FCV fuel economy sensitivity was set at the base +/-20%
Electricity price range includes low and high residential electricity rates in the contiguous United States.
Time in CD mode depends upon vehicle's individual miles traveled between charges.

Source: US DOE 09/2010

Hydrogen Competitive Threshold Cost Analysis *DRAFT*

U.S. DEPARTMENT OF ENERGY

Hydrogen will be competitive at \$2.00 to \$4.00 per gge.



Range includes diverse technologies, fuel economies and incremental vehicle cost assumptions.

Competitive cost for H_2 — against gasoline HEV: ~\$2.00 -\$4.00/gge

- Goal is pathway independent
- Consumer fueling costs are equivalent or less on a cents per mile basis
- Gasoline-electric hybrids is benchmark
- R&D guidance provided in two forms:
  - Gasoline HEV defines a threshold H_2 cost range used to screen or eliminate options that can't show ability to meet target and to prioritize projects for resource allocation

Source: US DOE 09/2010

Hydrogen Competitive Threshold Cost Analysis *DRAFT*

Status vs. Targets

U.S. DEPARTMENT OF ENERGY

Revising the hydrogen cost target will result in an assessment of Hydrogen Production and Delivery R&D priorities. Projections of high-volume / n^{th} plant production and delivery of hydrogen meet the targets for most technologies.

Projected High-Volume Cost of Hydrogen (Dispensed) — Status

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

NEAR TERM:

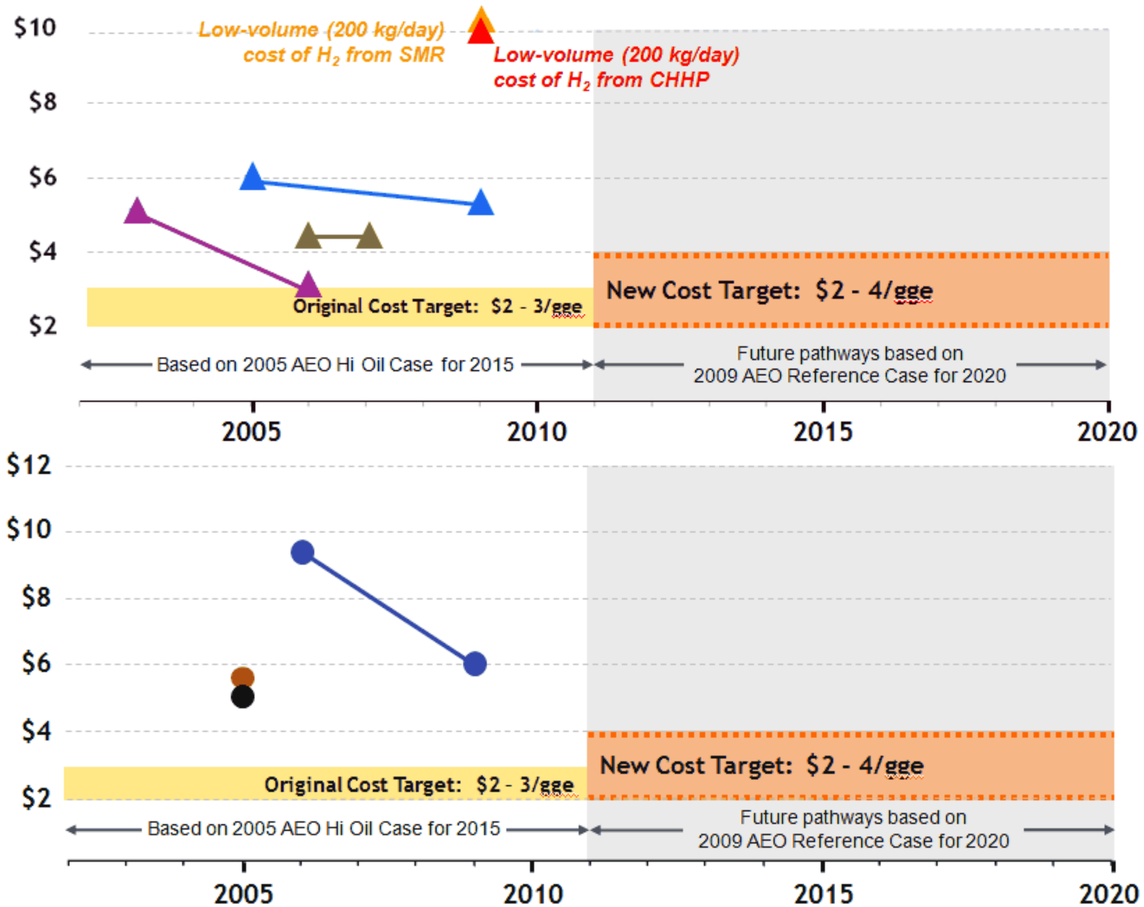
Distributed Production

- ▲ H_2 from Natural Gas
- ▲ H_2 from Ethanol Reforming
- ▲ H_2 from Electrolysis

LONGER TERM:

Centralized Production

- ● Biomass Gasification
- ● Central Wind Electrolysis
- ● Coal Gasification with Sequestration
- ● Solar Thermochemical Cycle



Source: US DOE 09/2010

Summary

U.S. DEPARTMENT OF ENERGY

- ***The DOE Fuel Cell Technologies Program is developing technologies to produce fuels from clean, diverse domestic sources—including renewable, nuclear, and fossil resources as part of the portfolio of pathways to reduce greenhouse gas emissions and petroleum use.***

- ***Renewable hydrogen production faces key challenges which require R&D to overcome.***

- ***Cost of distributed production pathways has been reduced for unit production at production levels of 500+ units.***

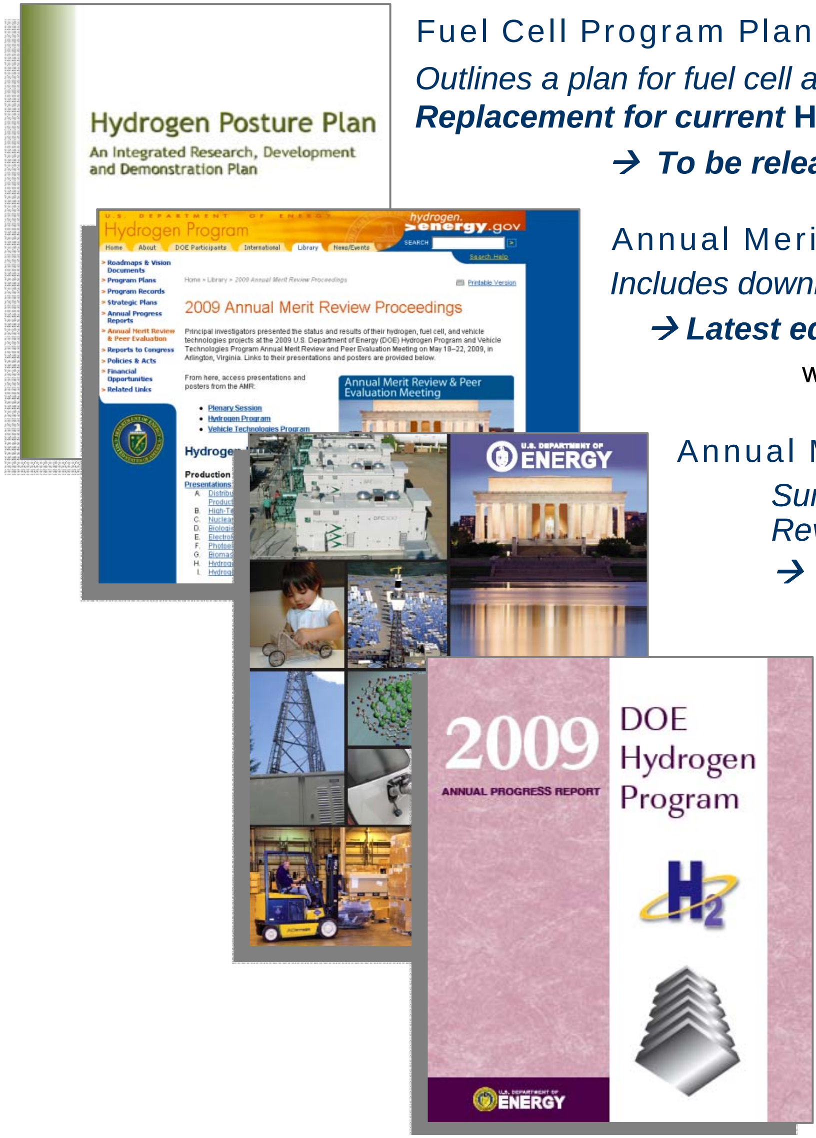
- ***Hydrogen production costs at low volumes during the early penetration of fuel cell vehicles requires development.***

- ***Hydrogen production and delivery costs will be compared with the new hydrogen competitive threshold cost.***

Source: US DOE 09/2010

For More Information

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



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

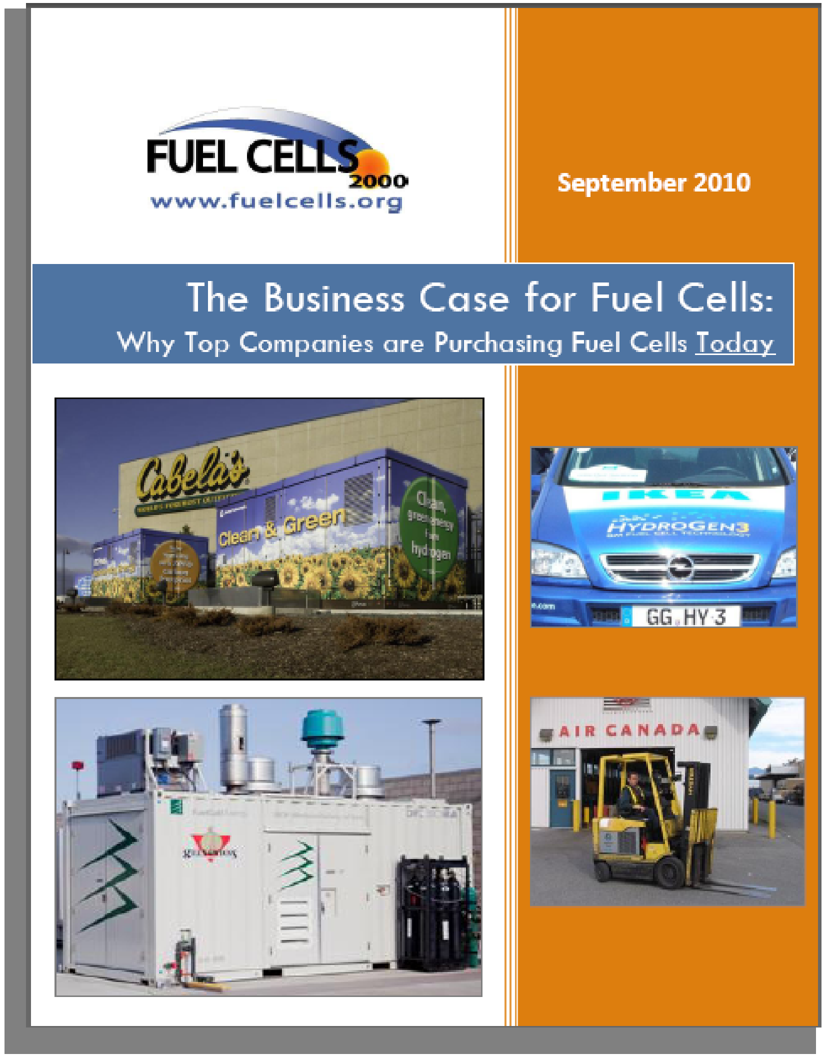
2010Annual Merit Review & Peer Evaluation Report and Annual Progress Report will be issued in November 2010

www.hydrogenandfuelcells.energy.gov* and *www.hydrogen.energy.gov

Source: US DOE 09/2010

New Report Just Released

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



The Business Case for Fuel Cells: Why Top Companies are Purchasing Fuel Cells Today

By FuelCells2000
http://www.fuelcells.org

38 companies profiled in the report, cumulatively, have ordered, installed or deployed:

- **more than 1,000 fuel cell forklifts;**
- **58 stationary fuel cell systems totaling almost 15MW of power;**
- **more than 600 fuel cell units at telecom sites.**

See report:
http://www.fuelcells.org/BusinessCaseforFuelCells.pdf

Source: US DOE 09/2010

Thank you

Fred.Joseck@ee.doe.gov

hydrogenandfuelcells.energy.gov

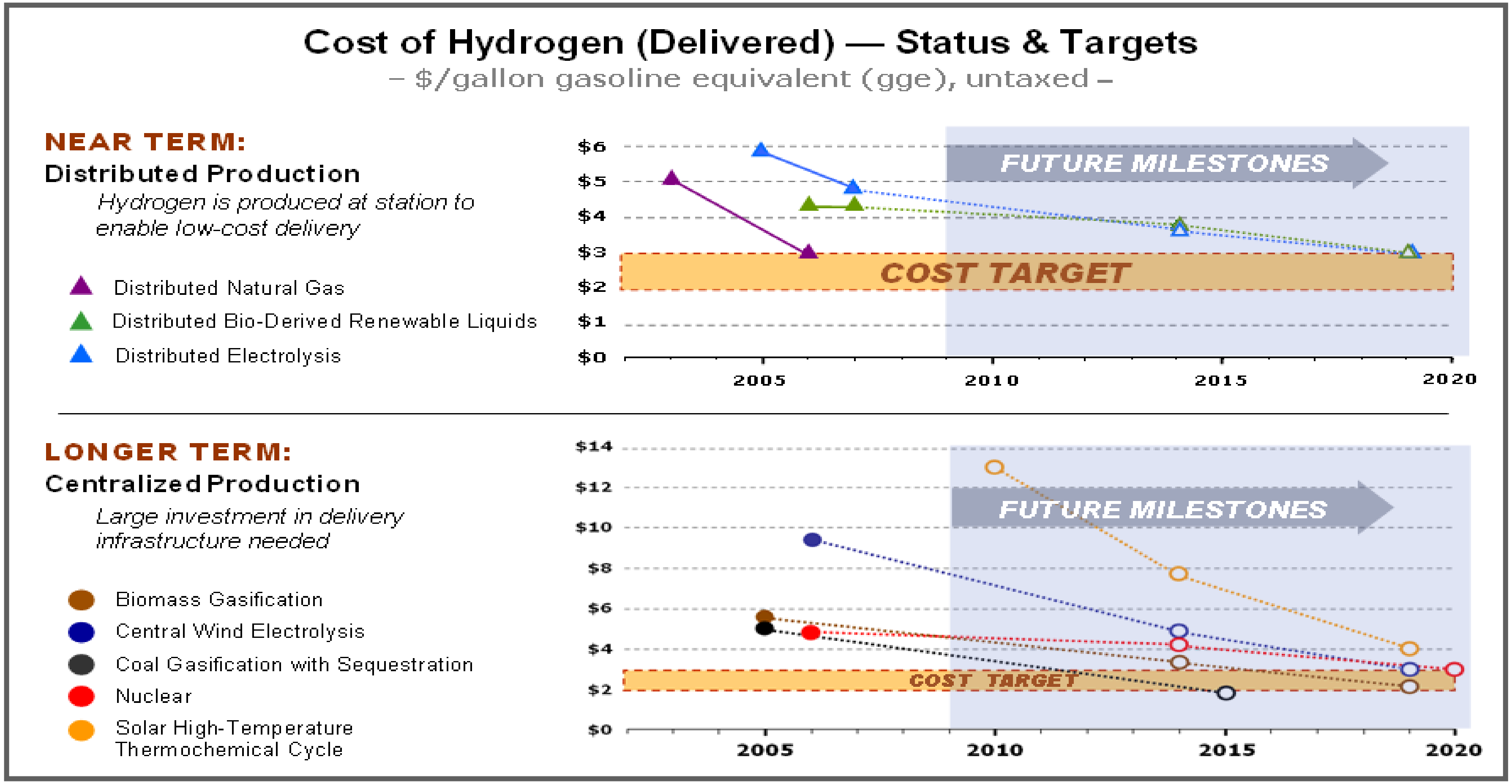
Additional Slides

Fuel Production R&D

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

The DOE Fuel Cell Program is developing technologies to produce fuels from clean, diverse domestic sources—including renewable, nuclear, and fossil resources.

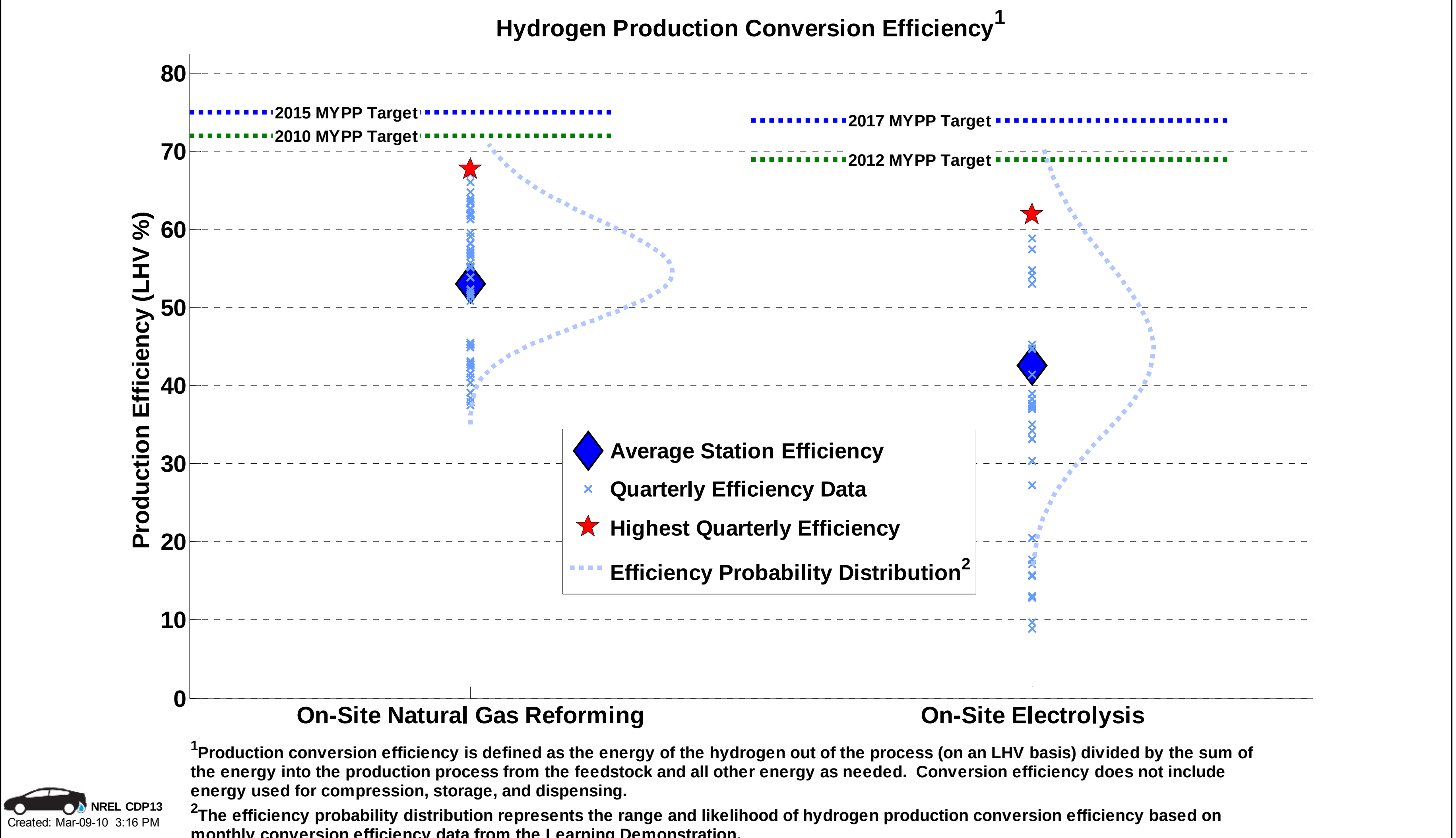
The Program's Key Production Objective: Reduce the cost of fuel (delivered & untaxed) to \$2 – \$3 per gge (gallon gasoline equivalent)



Source: US DOE 09/2010
www.hydrogen.energy.gov/pdfs/review09/program_overview_2009_amr.pdf and www.hydrogen.energy.gov/pdfs/review08/pd_0_dillich.pdf

Technology Validation
On-Site Hydrogen Production Efficiency

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



[1]Production conversion efficiency is defined as the energy of the hydrogen out of the process (on an LHV basis) divided by the sum of the energy into the production process from the feedstock and all other energy as needed. Conversion efficiency does not include energy used for compression, storage, and dispensing.

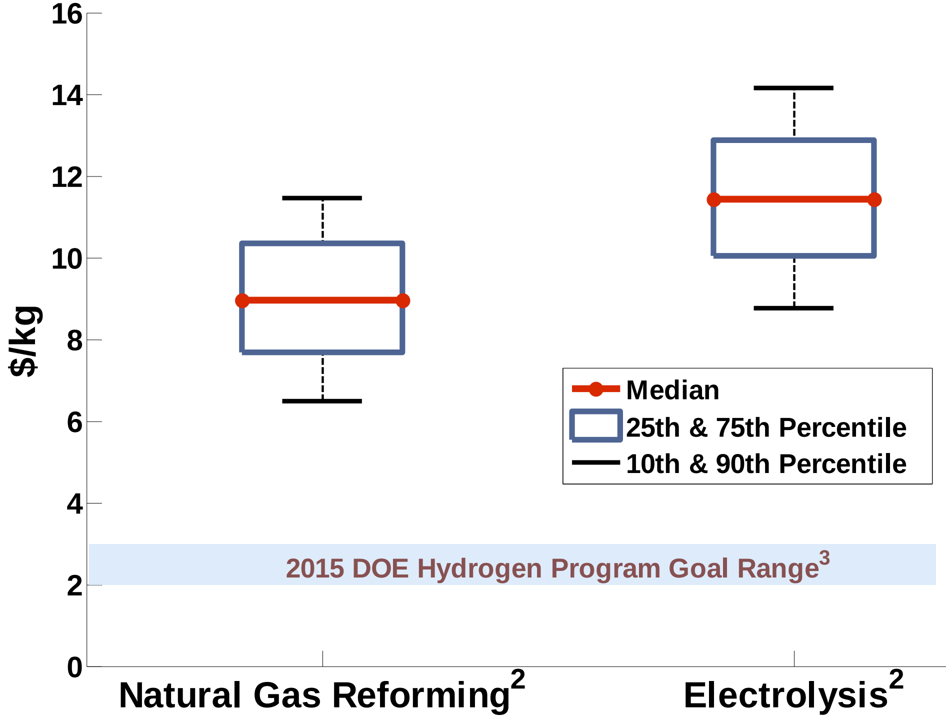
[2]The efficiency probability distribution represents the range and likelihood of hydrogen production conversion efficiency based on monthly conversion efficiency data from the Learning Demonstration.

Source: US DOE 09/2010

Technology Validation
Hydrogen Production Cost vs. Process

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

Projected Early Market 1500 kg/day Hydrogen Cost[1]



Key H2 Cost Elements and Ranges

Input Parameter	Minimum (P10)	Maximum (P90)
Facility Direct Capital Cost	$10M	$25M
Facility Capacity Utilization	85%	95%
Annual Maintenance & Repairs	$150K	$600K
Annual Other O&M	$100K	$200K
Annual Facility Land Rent	$50K	$200K
Natural Gas Prod. Efficiency (LHV)	65%	75%
Electrolysis Prod. Efficiency (LHV)	35%	62%

(1) Reported hydrogen costs are based on estimates of key cost elements from Learning Demonstration energy company partners and represent the cost of producing hydrogen on-site at the fueling station, using either natural gas reformation or water electrolysis, dispensed to the vehicle. Costs reflect an assessment of hydrogen production technologies, not an assessment of hydrogen market demand.

(2) Hydrogen production costs for 1500 kg/day stations developed using DOE's H2A Production model, version 2.1. Cost modeling represents the lifetime cost of producing hydrogen at fueling stations installed during an early market rollout of hydrogen infrastructure and are not reflective of the costs that might be seen in a fully mature market for hydrogen installations. Modeling uses default H2A Production model inputs supplemented with feedback from Learning Demonstration energy company partners, based on their experience operating on-site hydrogen production stations. H2A-based Monte Carlo simulations (2,000 trials) were completed for both natural gas reforming and electrolysis stations using default H2A values and 10th percentile to 90th percentile estimated ranges for key cost parameters as shown in the table. Capacity utilization range is based on the capabilities of the production technologies and could be significantly lower if there is inadequate demand for hydrogen.

(3) DOE has a hydrogen cost goal of $2-$3/kg for future (2015) 1500 kg/day hydrogen production stations installed at a rate of 500 stations per year.

NREL CDP15
Created: Jan-19-10 11:08 AM

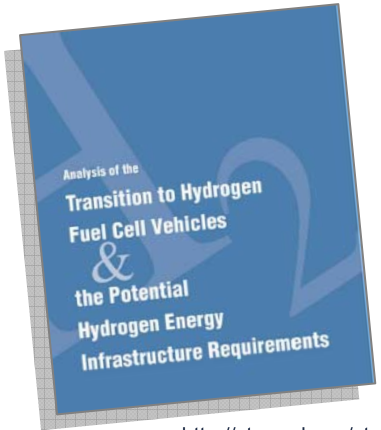
Source: US DOE 09/2010

Policies for FCEVs & Hydrogen Infrastructure

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

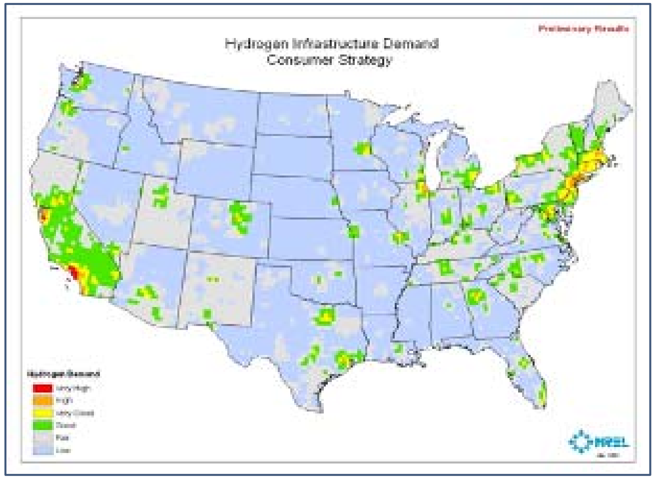
Key Findings:

- 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 were $2.6 billion in 2006 and expected to cost more than $15 billion/year by 2015.*
  - 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.*

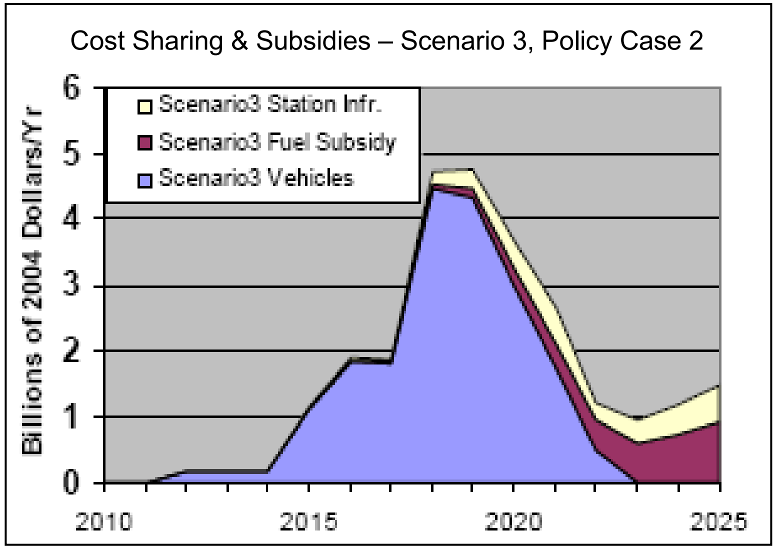


http://cta.ornl.gov/cta/Publications/Reports/ORNL_TM_2008_30.pdf

Source: US DOE 09/2010



Areas of projected fuel cell vehicle use—and fuel demand

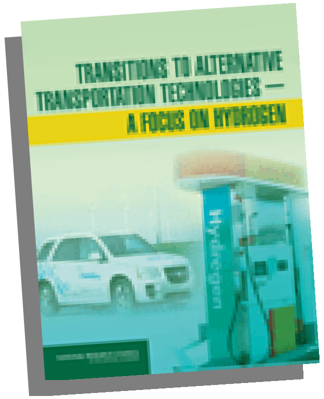


Projected cost of policies to sustain a transition to fuel cell vehicles and H_2 infrastructure, based on the most aggressive scenario

Policies for FCEVs & Hydrogen Infrastructure

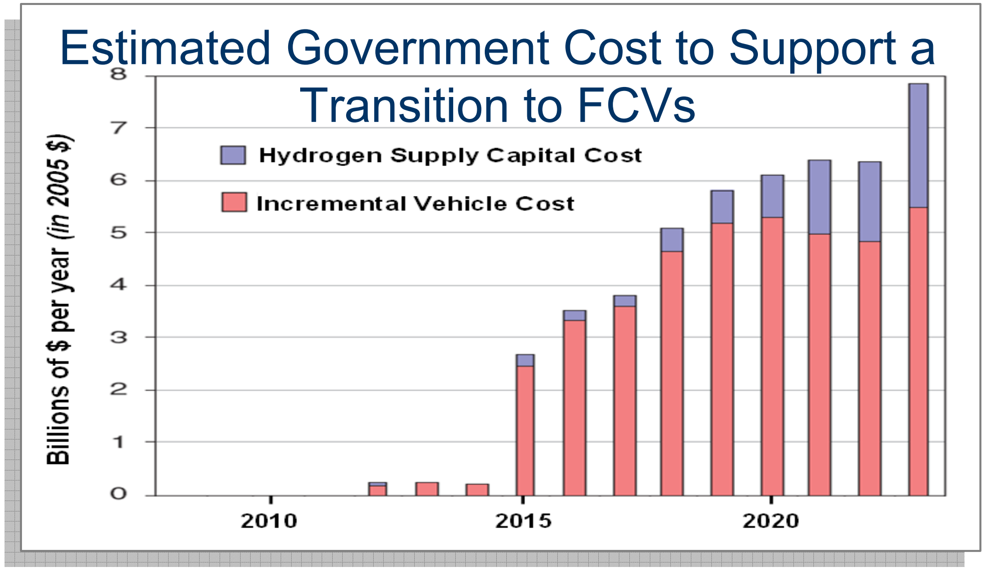
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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."



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

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.



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.

Source: US DOE 09/2010