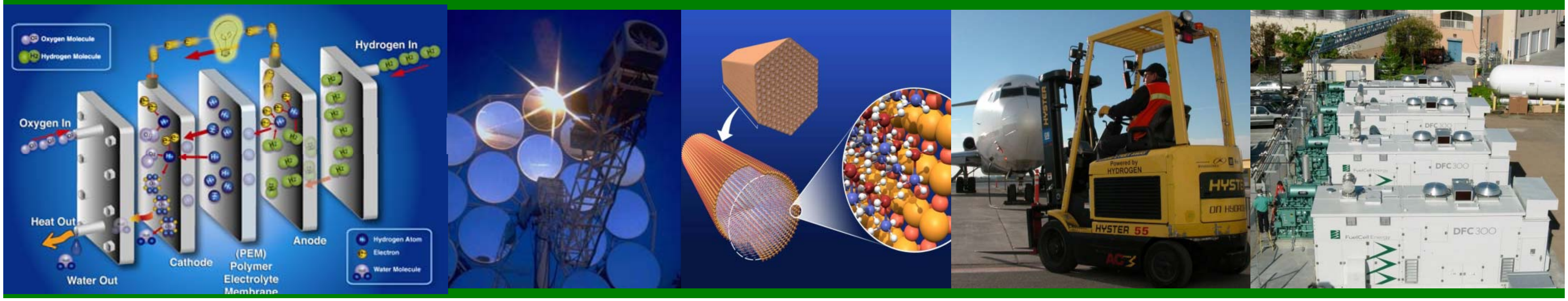
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



Overview of Hydrogen and Fuel Cell Activities

Richard Farmer

Deputy Program Manager

Fuel Cell Technologies Program

United States Department of Energy

Mountain States Hydrogen Business Council

September 14, 2010

Administration's Clean Energy Goals

- ✓ 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 83% by 2050

U.S. Energy Consumption

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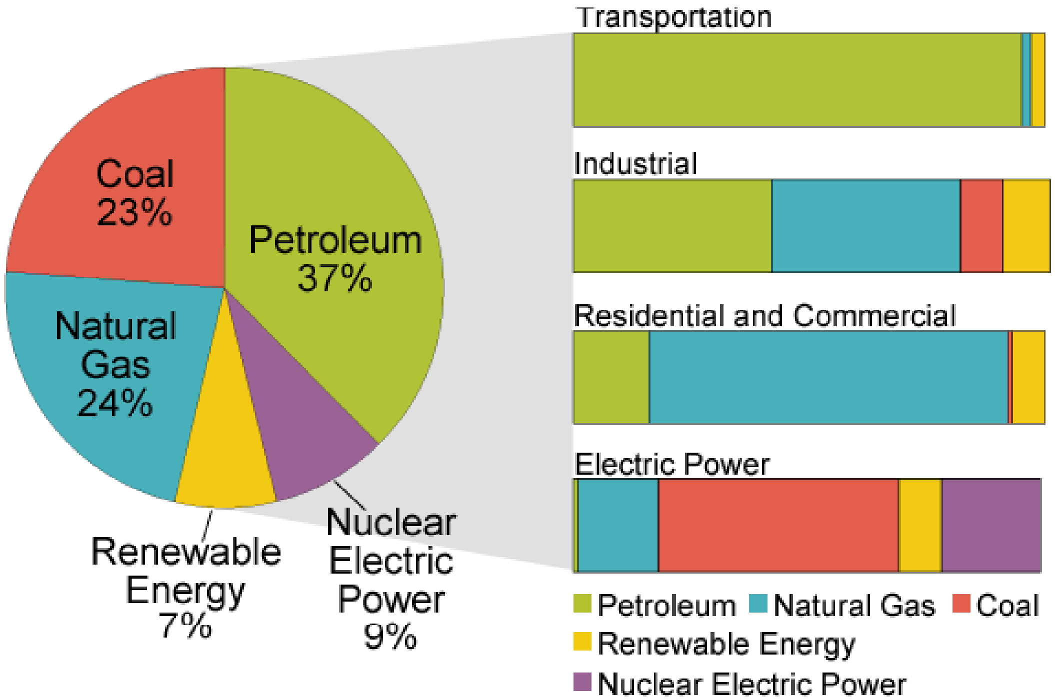
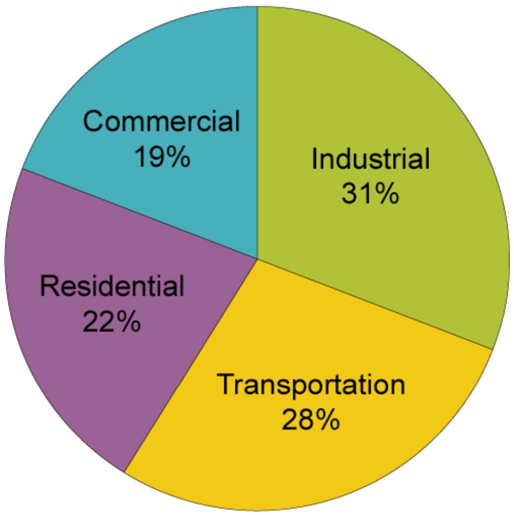
U.S. Primary Energy Consumption by Source and Sector



Total U.S. Energy = 99.3 Quadrillion Btu

Source: Energy Information Administration, *Annual Energy Review 2008,* Tables 1.3, 2.1b-2.1f.

Share of Energy Consumed by Major Sectors of the Economy, 2008



Source: Energy Information Administration, *Annual Energy Review 2008.*

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: **$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.

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

Fuel Cells — *Where are we today?*

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

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

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

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

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

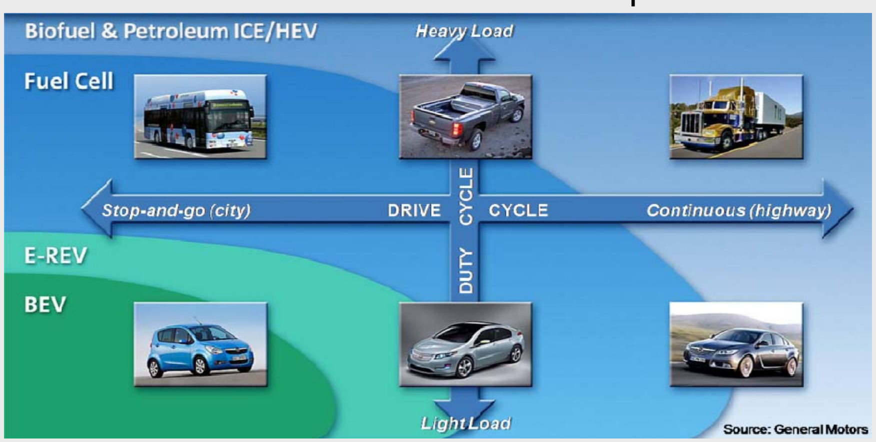
Fuel Cells for Transportation

In the U.S., there are currently:

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

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

The Role of Fuel Cells in Transportation



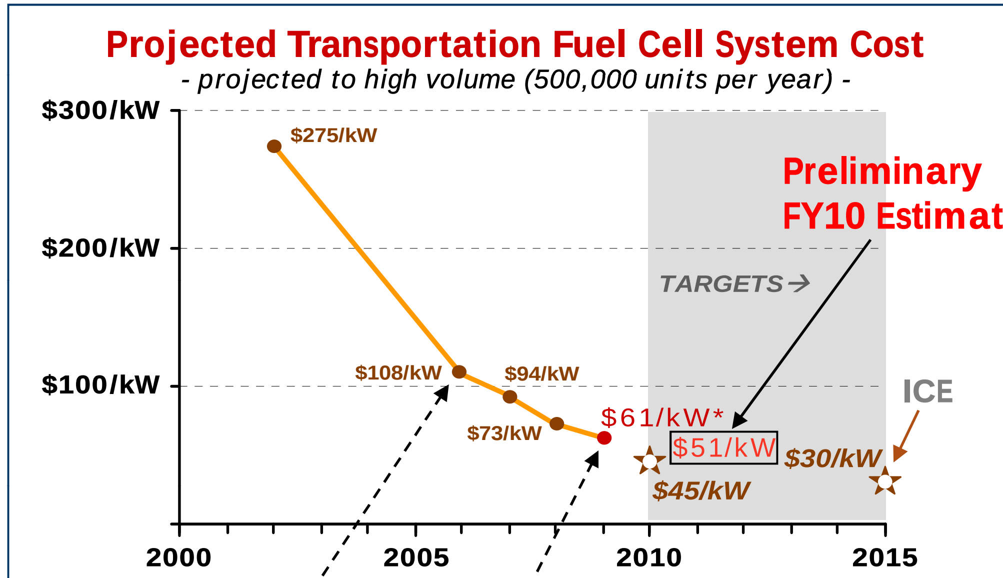
Production & Delivery of Hydrogen

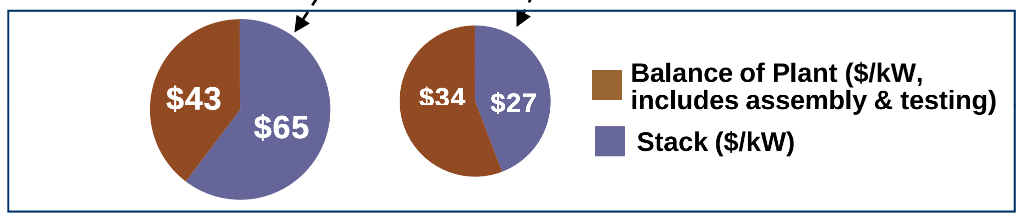
In the U.S., there are currently:

- *~9 million metric tons* ***of H_2 produced annually***
- ***>*** *1,200 miles* ***of H_2 pipelines***

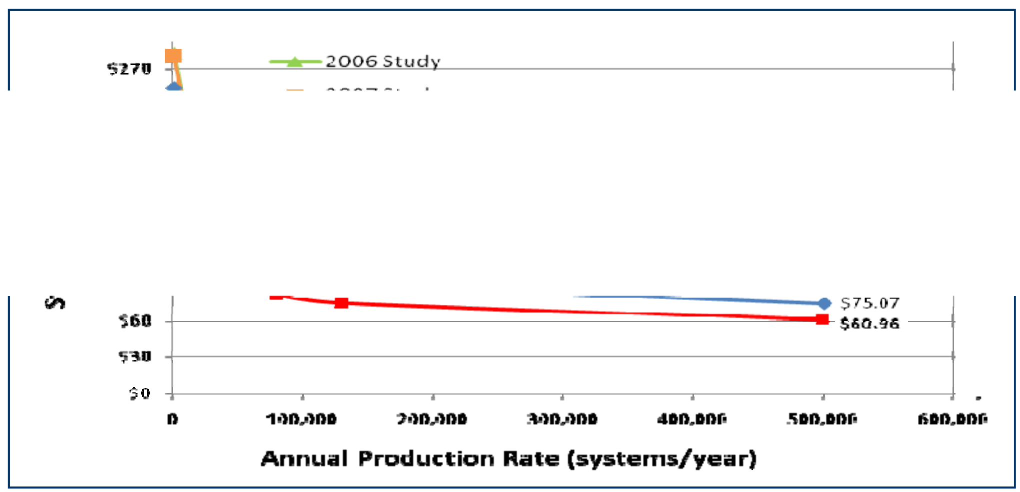
Projected high-volume cost of fuel cells has been reduced to $61/kW (2009)

- ***More than 15% 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



(500,000 units/year).

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

Challenges for Fuel Cell Development

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Key R&D Gaps

Catalysis

- Low and no-content PGM cathode, on corrosive resistant support, with containment and anion tolerance
- Improved catalyst nano-structure design and electrode/MEA optimization for novel catalysts

MEAs, Components & Integration

- Need to develop, test and integrate (into MEA) robust, manufacturable low-cost membranes that are tolerant to reformate impurities and operate at high-T (e.g. 95^0C), low-humidity; related ionomers. High operation and maintenance costs
- Manufacturable, electrodes, MEAs, having optimized ionomer/support structures, with understanding of the interface as it relates to transport and durability for low-T and high-T operation (120-150; 150-200 ^{0}C)
- Standardized, accelerated durability tests of "real-world" degradation mechanisms for integrated systems.

Innovative concepts

- AFCs, high-T fuel cells for transportation applications, reversible SOFCs, novel fuel cell stack designs for early market applications

MCFC and PAFC high-T fuel cells (gap analysis report/workshop)

- Low cost stack components to address durability and performance (electrolyte support and durable cathode - MCFC; durable low-Pt catalysts, supports, bipolar plates - PAFC)

Low and high T fuel cell BOP and fuel processing

- Low cost, durable, converters, blowers, humidifier and sensors for low and high-T
- Catalysts and systems for fuel flexibility, gas clean up, and impurities studies

Hydrogen Production Pathways

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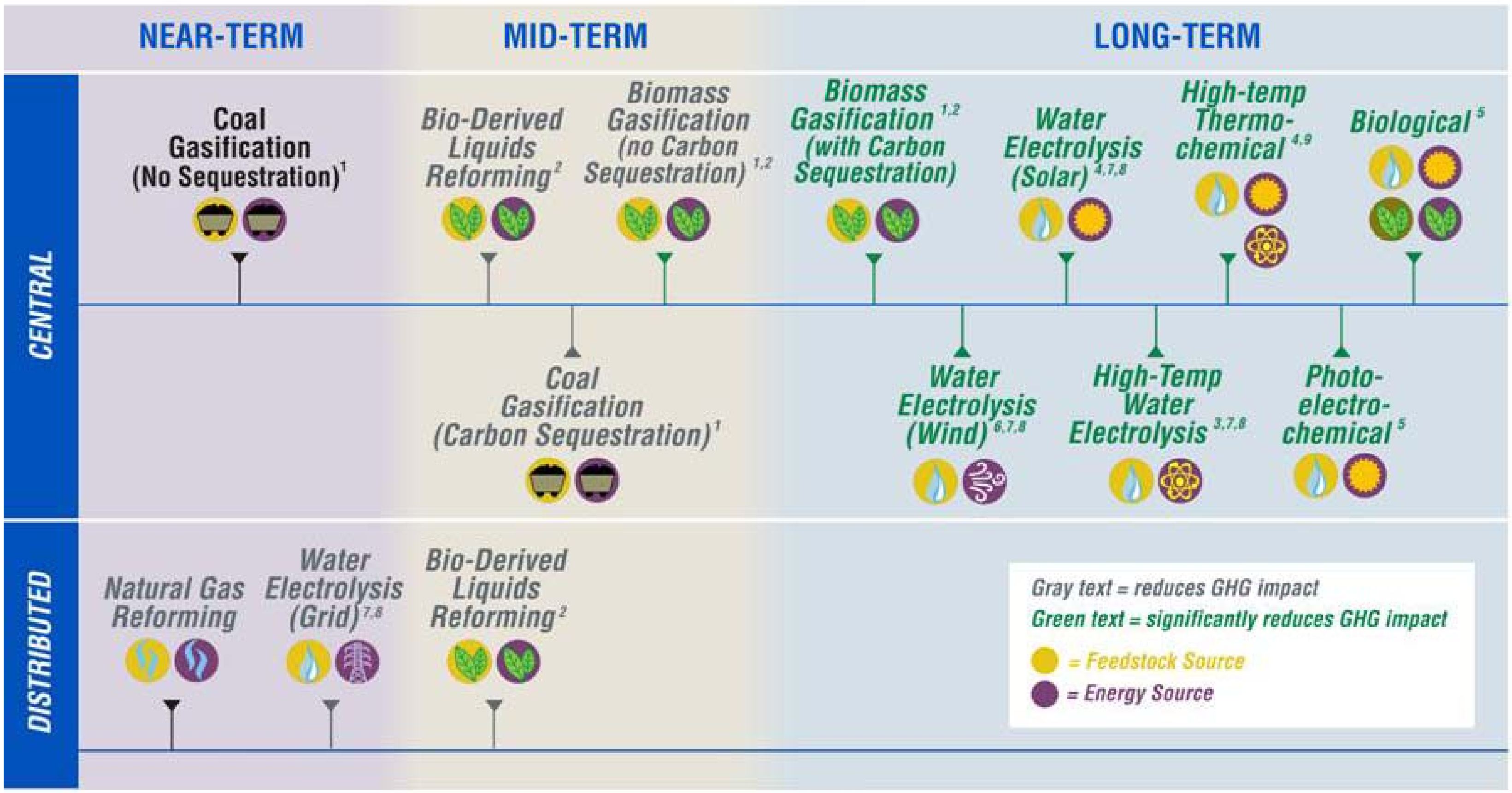
Challenge: Reduce cost of H_2 (delivered, dispensed, and untaxed)



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

Hydrogen Costs Are Being Reduced

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Progress has been made in all distributed production pathways and will continue work to reduce cost in central production pathways.

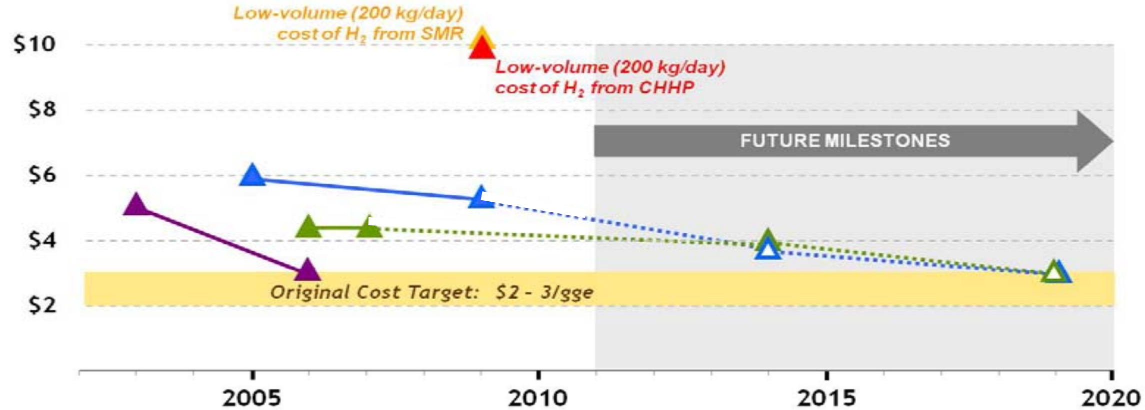
Projected High Volume Cost of Hydrogen (Dispensed) Status

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

NEAR TERM:

Distributed Production

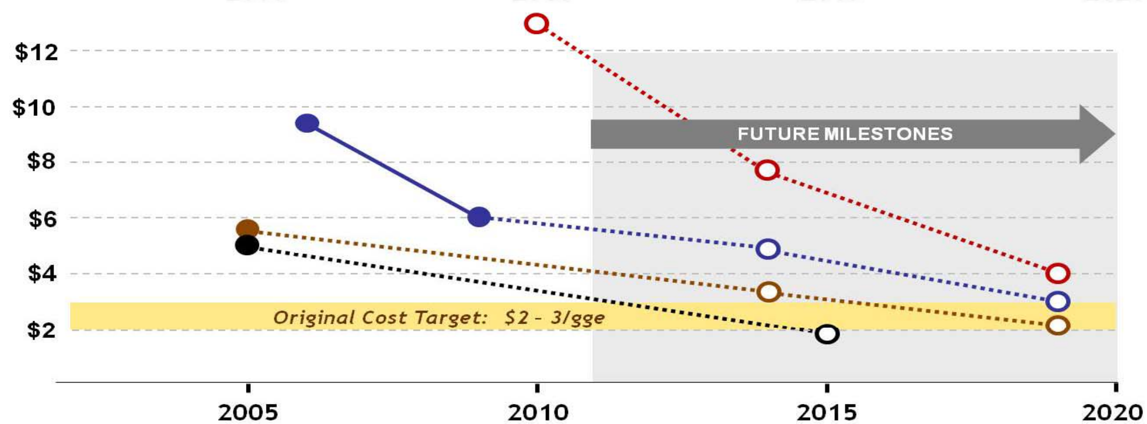
- ▲ **H_2 from Natural Gas**
- ▲ **H_2 from Ethanol Reforming**
- ▲ **H_2 from Electrolysis**



LONGER TERM:

Centralized Production

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



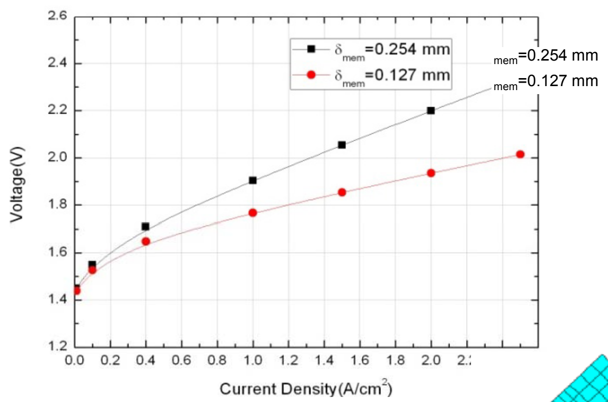
The key objective is to reduce cost of H_2 (delivered, dispensed & untaxed)

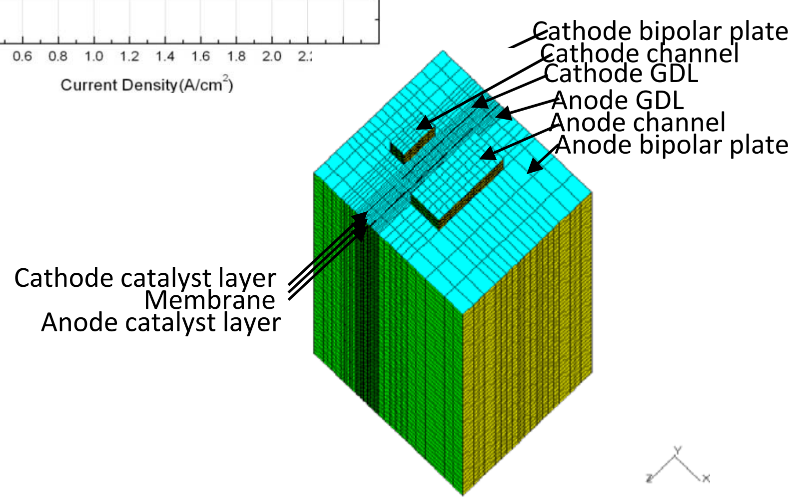
Electrolysis

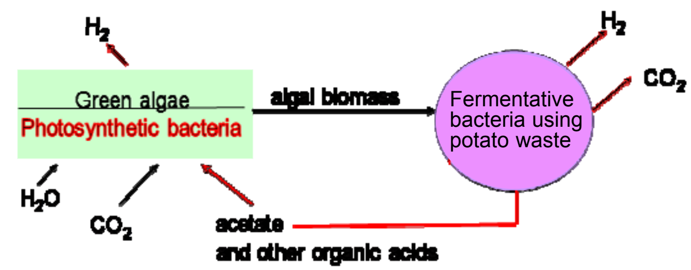
> 20% reduction cost of electrolyzer cell via a 55% reduction in catalyst loading from new process techniques (Proton Energy)

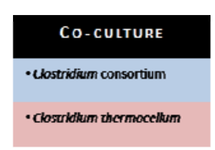
Algae

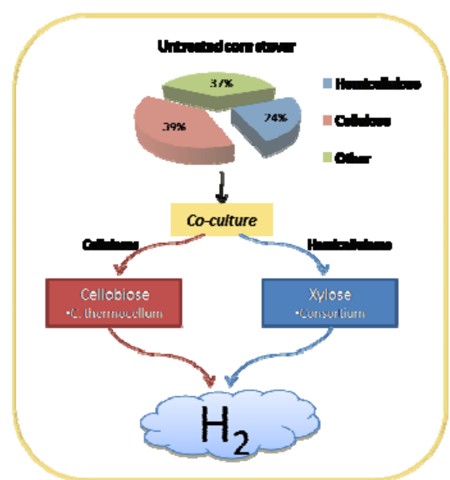
Continuous fermentative / photobiological H_2 production from potato waste achieved a maximum molar yield of 5.6 H_2 / glucose (NREL)







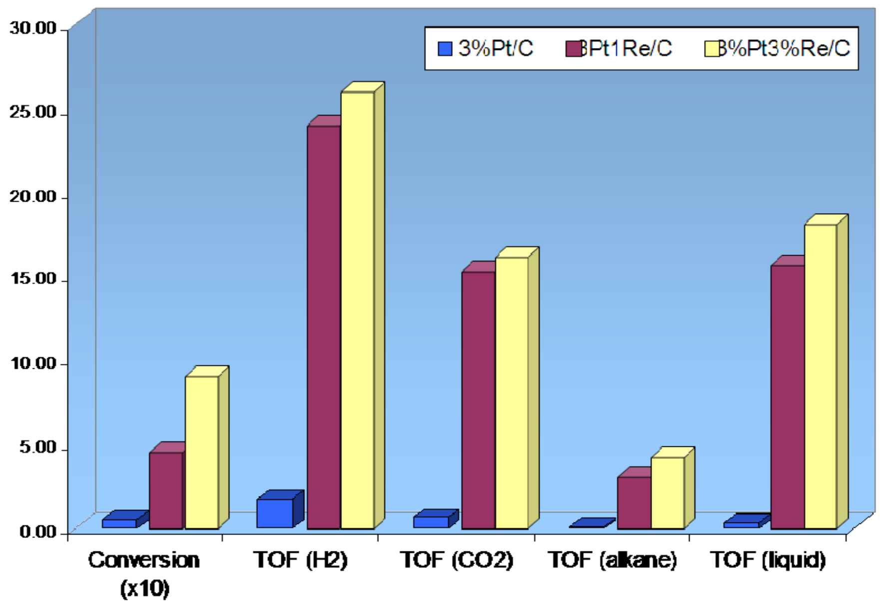




The key objective is to reduce cost of H_2 (delivered, dispensed & untaxed)

Reforming & Separation Processes

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

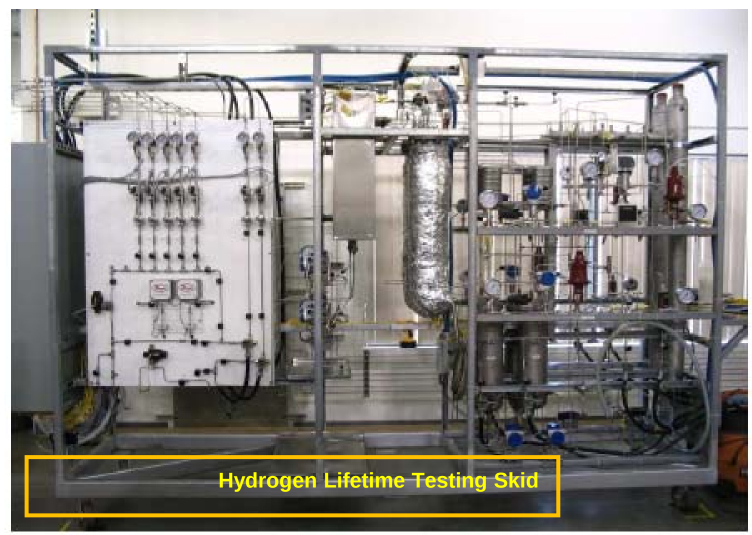


PNNL

Hydrogen from Coal

Initiated tests under water-gas shift feed streams and demonstrated a H_2 flux rate of 411scfh/ft^2. (Eltron)

Lifetime testing reactor operated several tests to 600 hours; initial baseline membrane testing in H_2/N_2 feed streams show stable performance at 200 scfh/ft^2.



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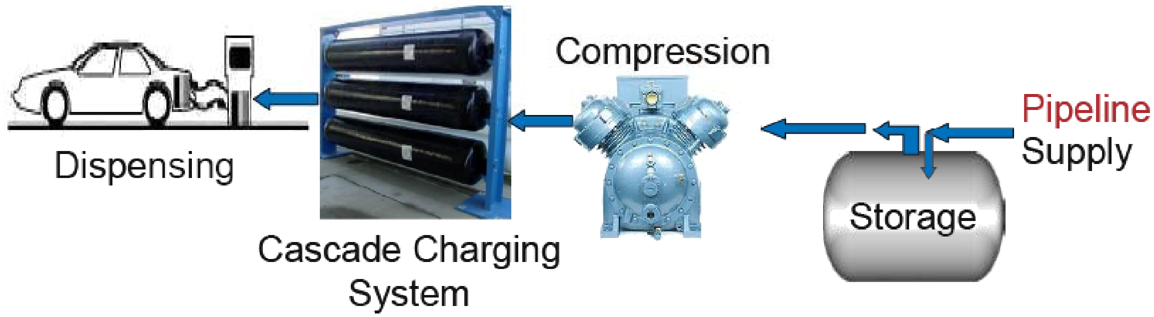
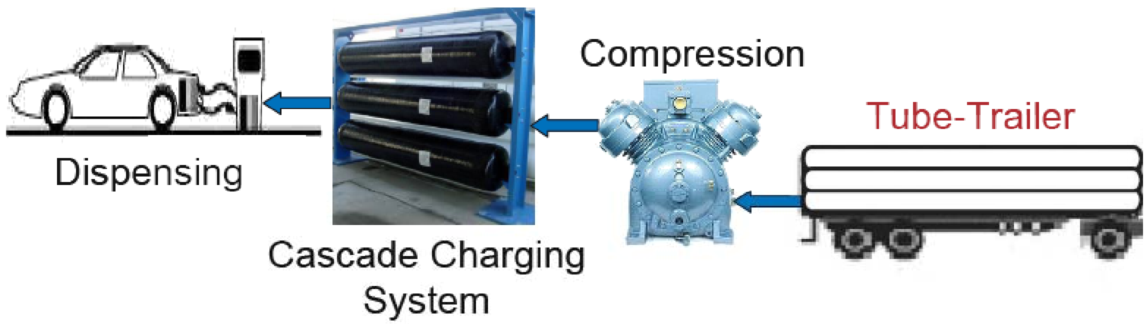
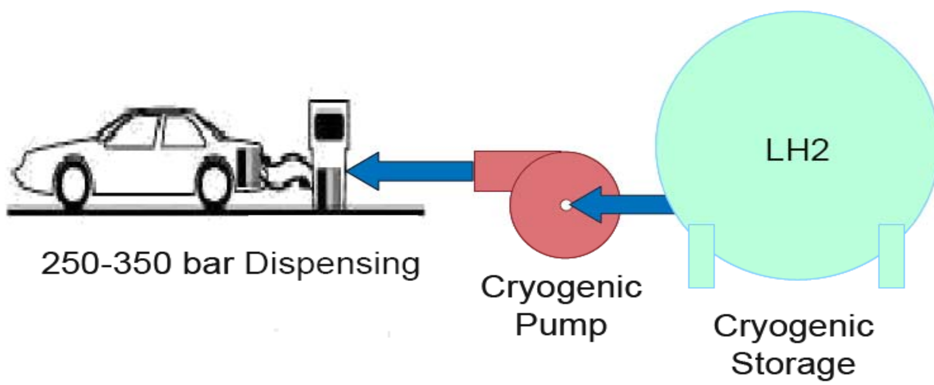
Delivery Technologies

Stations Using Compressed Gaseous Hydrogen





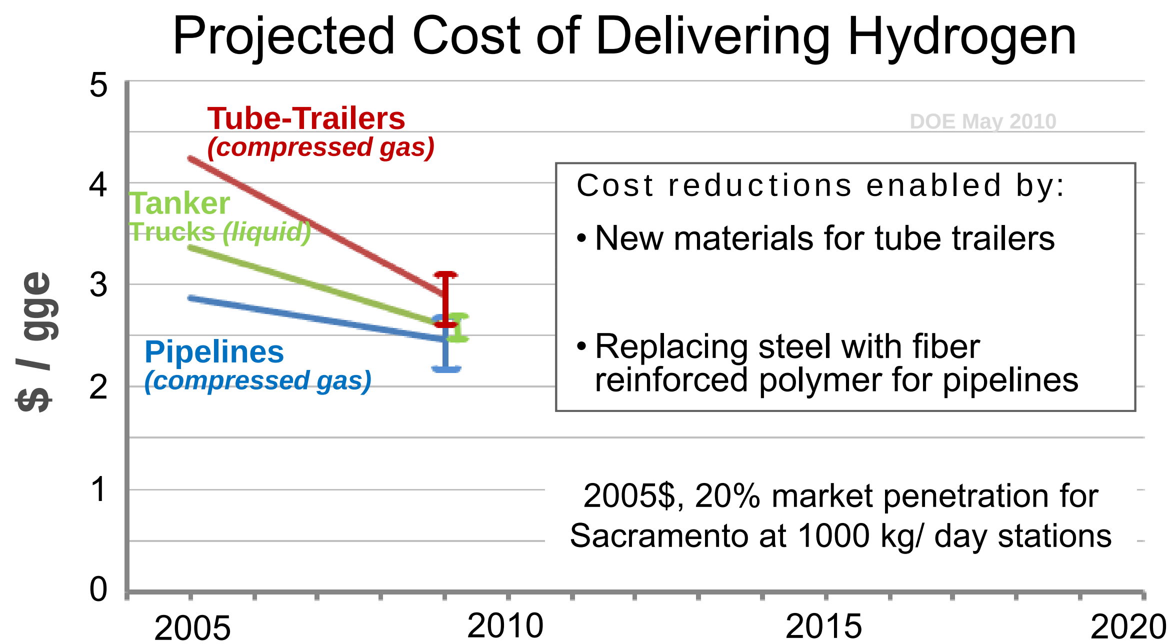
Stations Using Cryo-compressed Hydrogen *(from liquid hydrogen delivery)*



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*



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)

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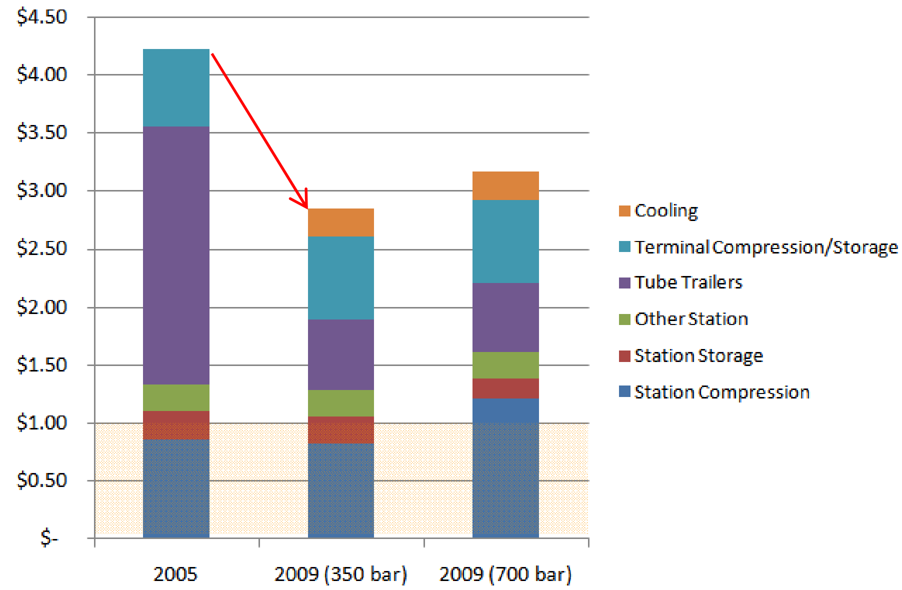
Tube Trailers (Gaseous Hydrogen)

2009 Modeled High-Volume Hydrogen Delivery Cost: **$2.85 – $3.15/gge**

Recent Progress ***(Lincoln Composites and Livermore National Laboratory):***

- **Higher capacity with carbon fiber Doubled capacity to 600 kg H_2**
  - **Demonstrated large scale dome molding, tubular welding, and filament winding of tanks**
- **Trailer with glass fibers**
  - **Demonstrated stronger glass fibers at lower temperatures to project reduced delivery tank costs**
  - **Identified pathway to triple capacity : 1,100 kg H_2**
  - **Potential for up to 50% trailer cost reduction**



Future Work:

- **High performance glass fiber composite pressure vessels**
- **High pressure hydrogen tank for storage and gaseous truck delivery**
- **CF testing and failure analysis**
- **Integrated alloy/concrete vessel design and fabrication for low-cost storage at the station**

Critical Challenges for H_2 Delivery

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Key R&D Gaps

Compression Technologies

- Reliability
- Efficiency
- Cost
- Materials Compatibility

Bulk Storage

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

Pipeline

- Safety
- Reliability
- Durability

Liquefaction

- Cost
- Energy Efficiency

On-board Hydrogen Storage

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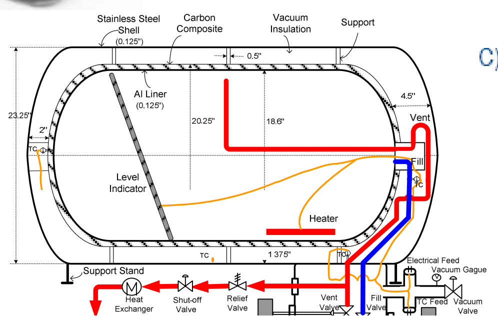
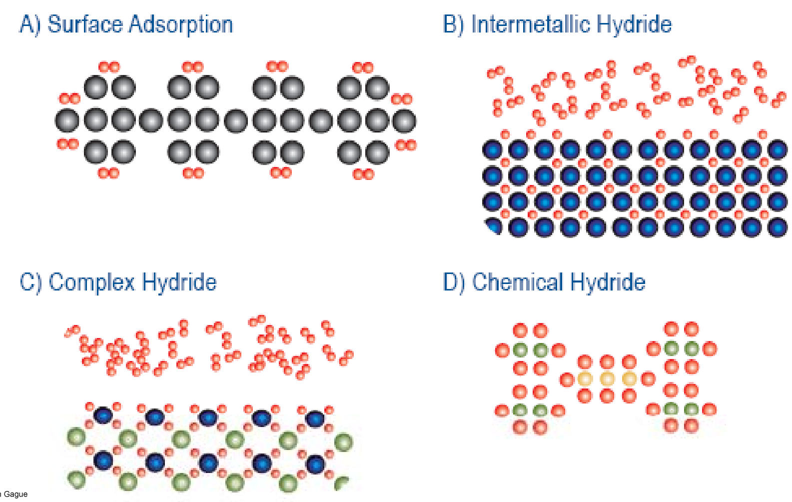
Challenge: Providing a 300 mile driving range without sacrificing passenger and cargo space

Compressed 350 bar

Compressed 700 bar and Cryo-compressed

Low-pressure, Materials-based: Adsorbents; Metal Hydrides; Chemical Hydrides





Near-term | Mid-term | Long-term

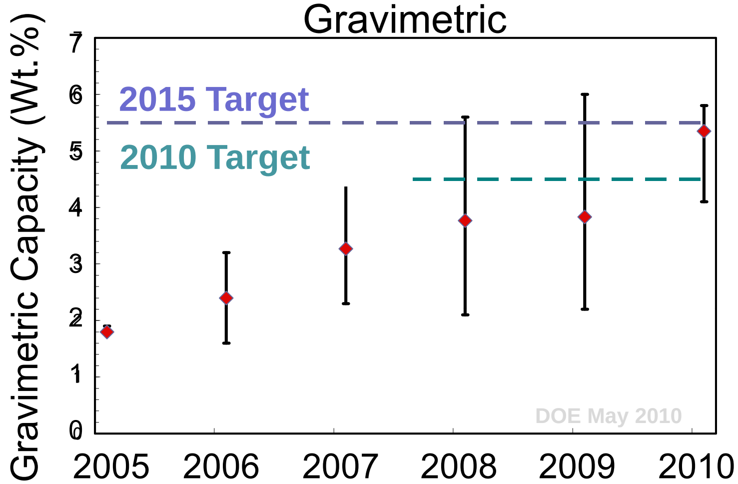
DOE 09/09/2010

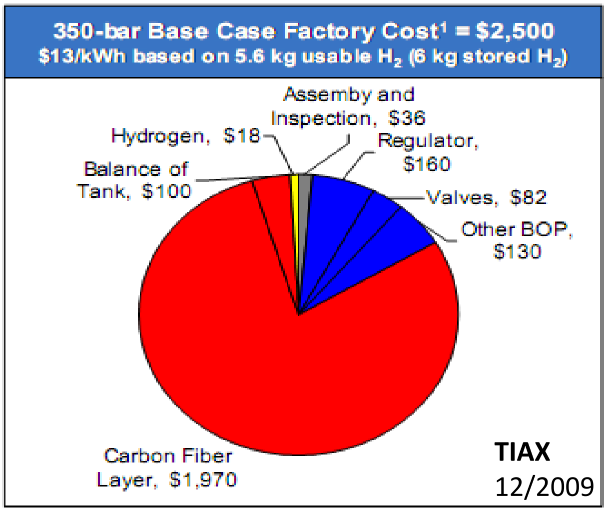
Compressed gas offers a near- term option, but cost is an issue

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

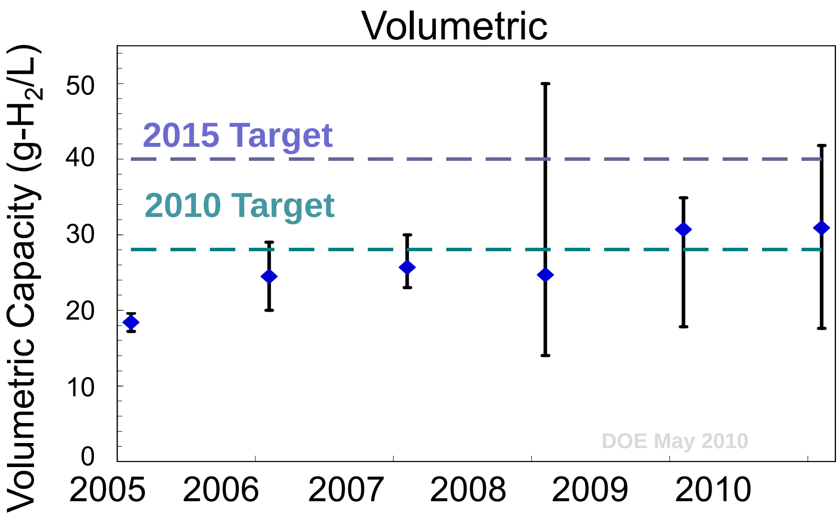
- **Validated driving range of up to ~ 430 mi**
- **Cost of composite tanks is challenging**
  - **carbon fiber layer estimated to be >75% of cost**
- **Advanced materials R&D under way for the long term**

Projected Capacities for Complete 5.6-kg H_2 Storage Systems





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



Critical Challenges for H_2 Storage

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Key R&D Gaps

System

- Cost
- Performance
  - Gravimetric
  - Volumetric
  - Lifecycle
  - Manufacturability

Materials

- Capacity
- Thermodynamics
- Kinetics
- Cycling

Technology Validation

2010 Vehicles Progress & Accomplishments

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

RECENT ACCOMPLISHMENTS

Vehicles & Infrastructure

- Fuel cell durability
  - 2,500 hours projected (nearly 75K miles)
- Over 2.8 million miles traveled
- Over 114 thousand total vehicle hours driven
- Fuel cell efficiency 53-59%
- Vehicle Range: ~196 – 254 miles
- Over 134,000 kg- H_2 produced or dispensed*
- 152 fuel cell vehicles and 24 hydrogen fueling stations have reported data to the project

Buses

- DOE is evaluating real-world bus fleet data (DOT collaboration)
  - H_2 fuel cell buses have a range of 39% to 141% better fuel economy when compared to diesel & CNG buses

Forklifts

- Forklifts at Defense Logistics Agency site have completed more than 18,000 refuelings

Recovery Act

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

* Not all hydrogen produced is used in vehicles

CHHP: A promising system

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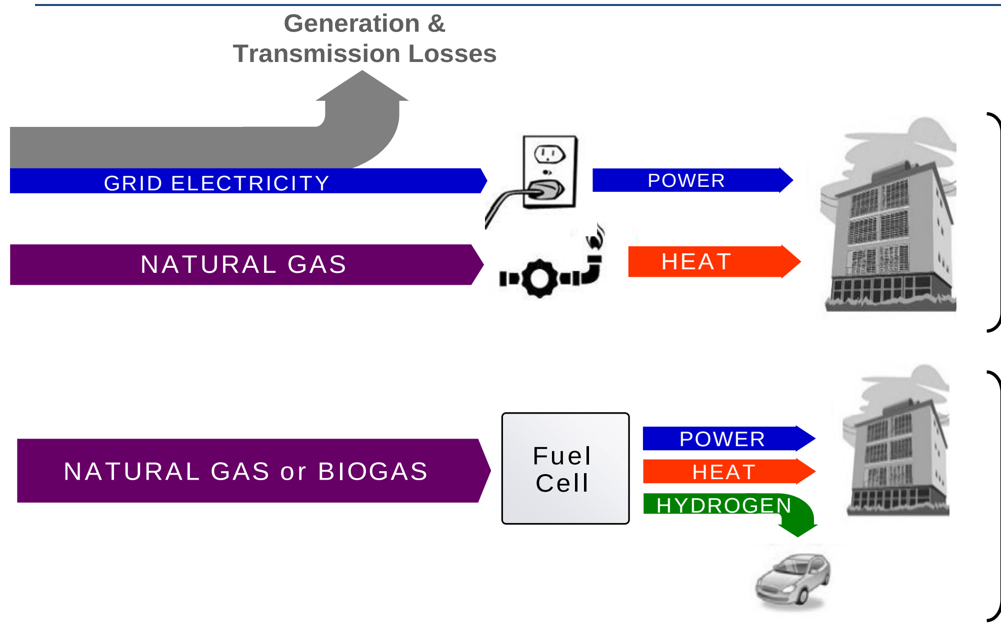
We are participating in a project to demonstrate a combined heat, hydrogen, and power (CHHP) system using biogas.

- **System has been designed, fabricated and shop-tested**
- **Improvements in design have led to higher H_2-recovery (from 75% to >85%)**
- **On-site operation and data-collection planned for FY10 – FY11**

Tri-Generation (CHHP) Concept



Combined heat, hydrogen, and power systems can:

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

Public-Sector Partners: *South Coast Air Quality Management District* *California Air Resources Board*

Fuel Cell Energy & Air Products

Infrastructure Analysis

CHHP vs. SMR

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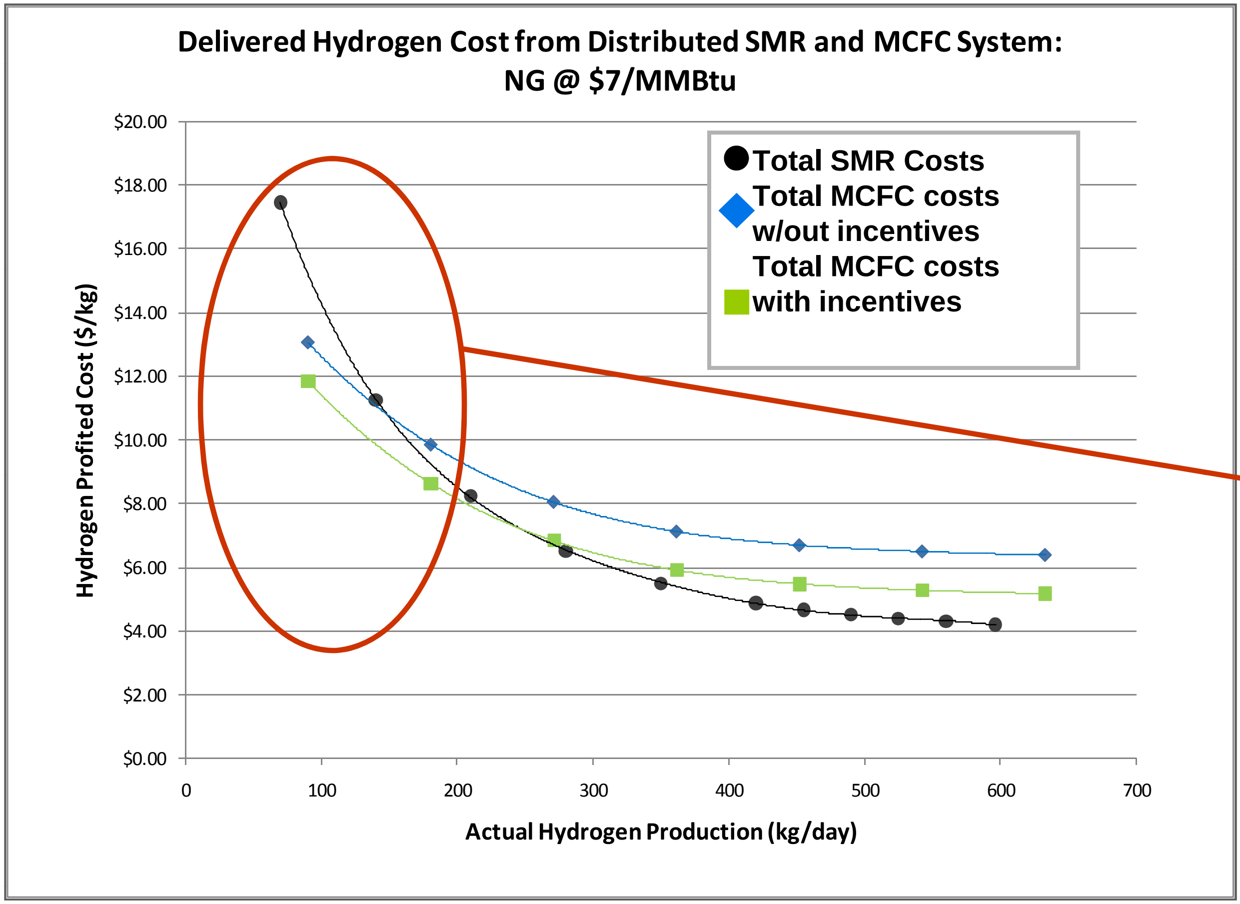
Hydrogen production costs for a stand-alone steam methane reforming (SMR) station and high-temperature CHHP application were compared. Costs are dependent on natural gas costs. CHHP applications may be more cost-effective at lower production capacities.



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

Source: Fuel Cell Power Model

Recovery Act Funding for Fuel Cells

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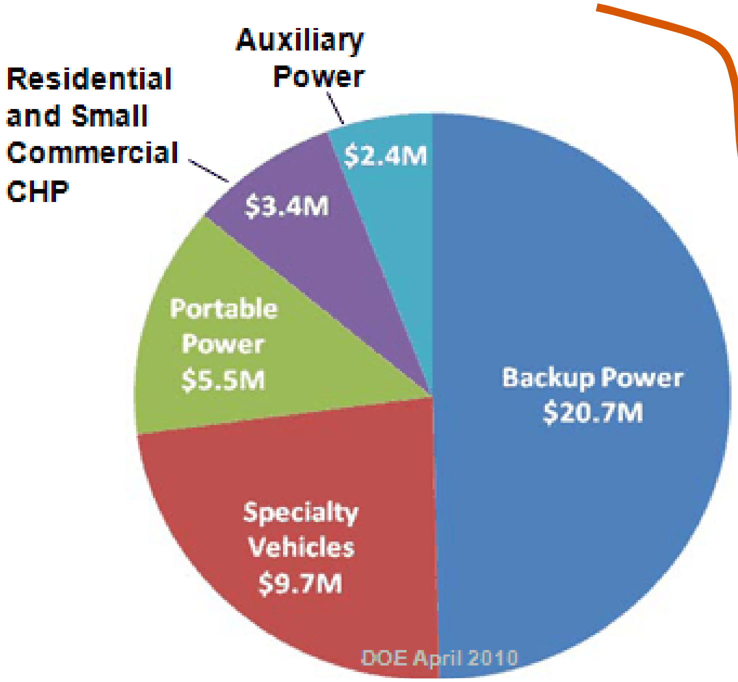
DOE announced more than $40 million from the American Recovery and Reinvestment Act to fund 12 projects, which will deploy up to 1,000 fuel cells — to help achieve near term impact and create jobs in fuel cell manufacturing, installation, maintenance & support service sectors.

FROM the LABORATORY to DEPLOYMENT:

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



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

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

ARRA Fuel Cell Units in Operation

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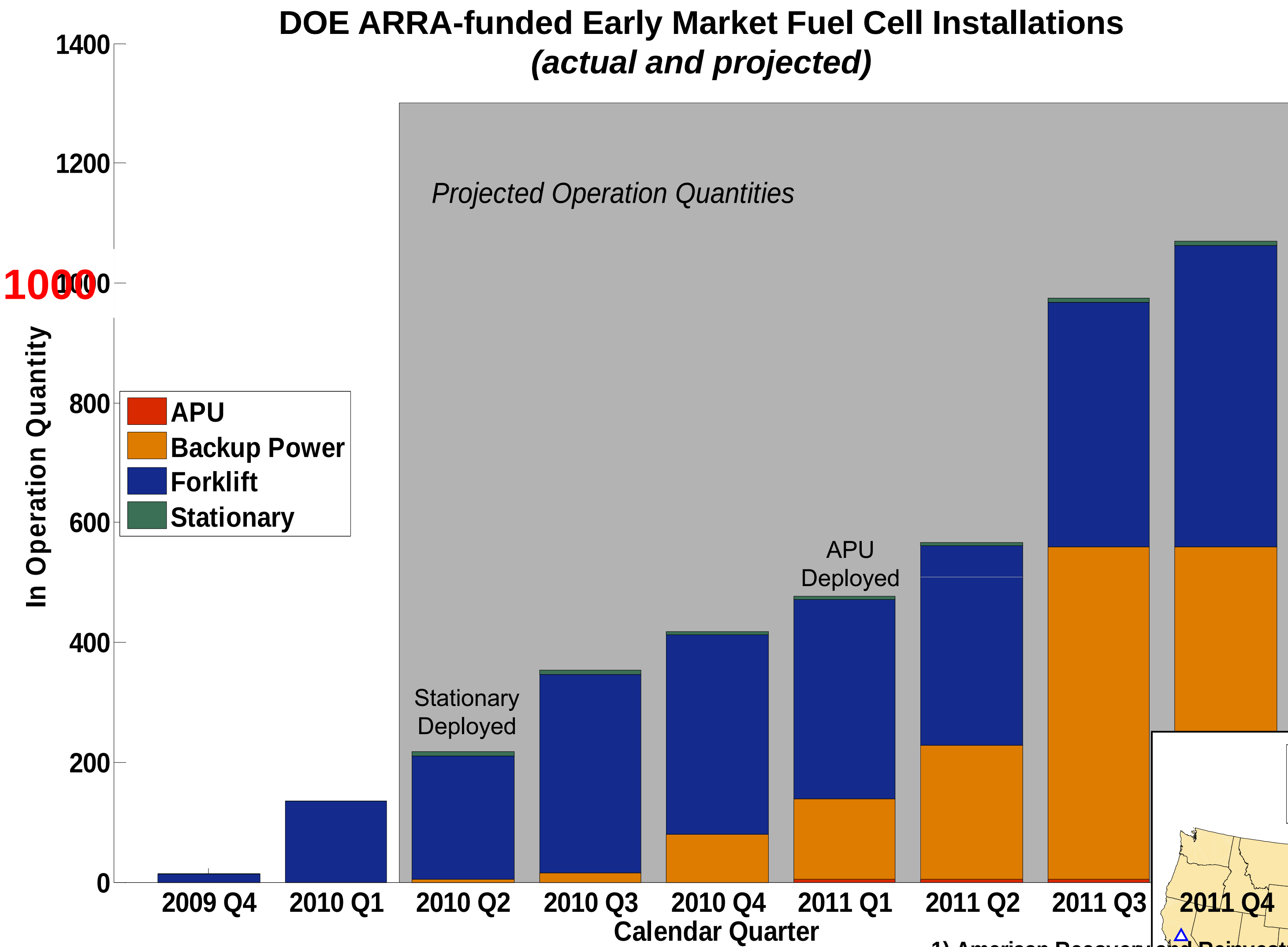

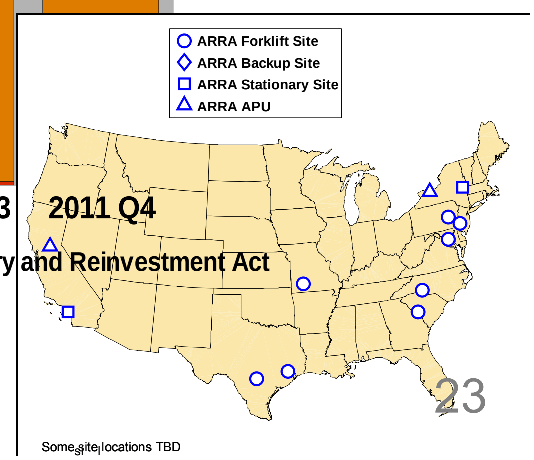

1) American Recovery and Reinvestment Act

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From National Renewable Energy Laboratory

U.S. Fuel Cell Deployments Using Market Transformation and Recovery Act Funding

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Example: California

Potential H2 Communities in Southern California

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

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

http://www.fuelcellpartnership.org/

Example - Executive Order 13514

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

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

Examples:

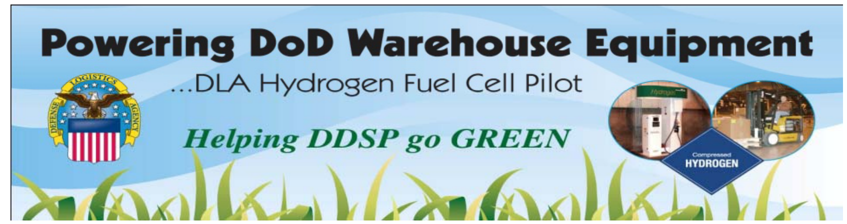
- Achieve 30% reduction in vehicle fleet petroleum use by 2020
- Requires 15% of buildings meet the *Guiding Principles for High Performance and Sustainable Buildings* by 2015
- Design all new Federal buildings which begin the planning process by 2020 to achieve zero-net energy by 2030

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

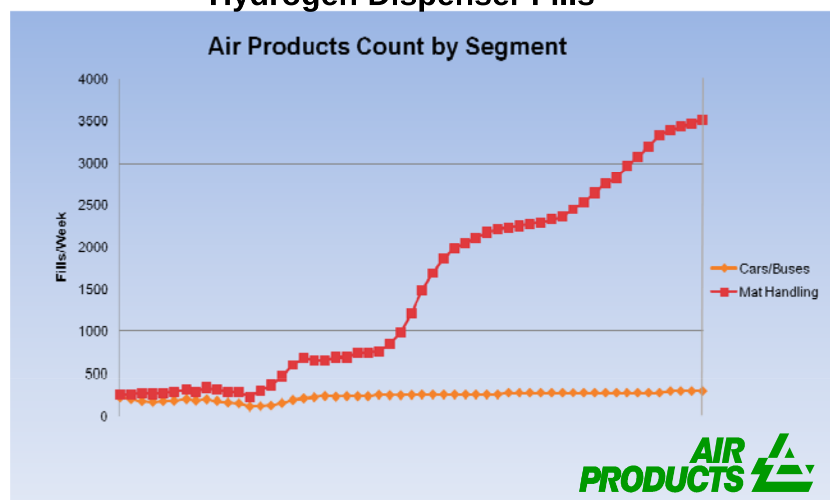
http://www1.eere.energy.gov/femp/regulations/eo13514.html

Examples

- DLA: material handling equipment and H_2 ICE shuttle buses
- FAA: ground support equipment and backup power
- APTO: ground support equipment and H_2 ICE shuttle buses
- Army incl. CERL/TARDEC: backup power, waste to energy, and H_2 ICE shuttle buses
- NPS: renewably generated backup power and H_2 ICE shuttle buses
- ONR/USMC: utility scale renewable hydrogen generation and H_2 ICE shuttle buses
- NASA: backup power and H_2 ICE shuttle buses



Hydrogen Dispenser Fills



DLA, DDSP – First of several 15,000 fills/yr sites

Collaborations

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Federal Agencies

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

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

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

Universities

~ 50 projects with 40 universities

International

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

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 SC&S,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
Idaho P

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

Key Program Documents

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 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

→ ***Latest edition released October 2009***

www.hydrogen.energy.gov/annual_review08_report.html

Annual Progress Report

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

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

www.hydrogen.energy.gov/annual_progress.html

Next Annual Review: May 9 – 13, 2011

Washington, D.C.

http://annualmeritreview.energy.gov/

Thank you

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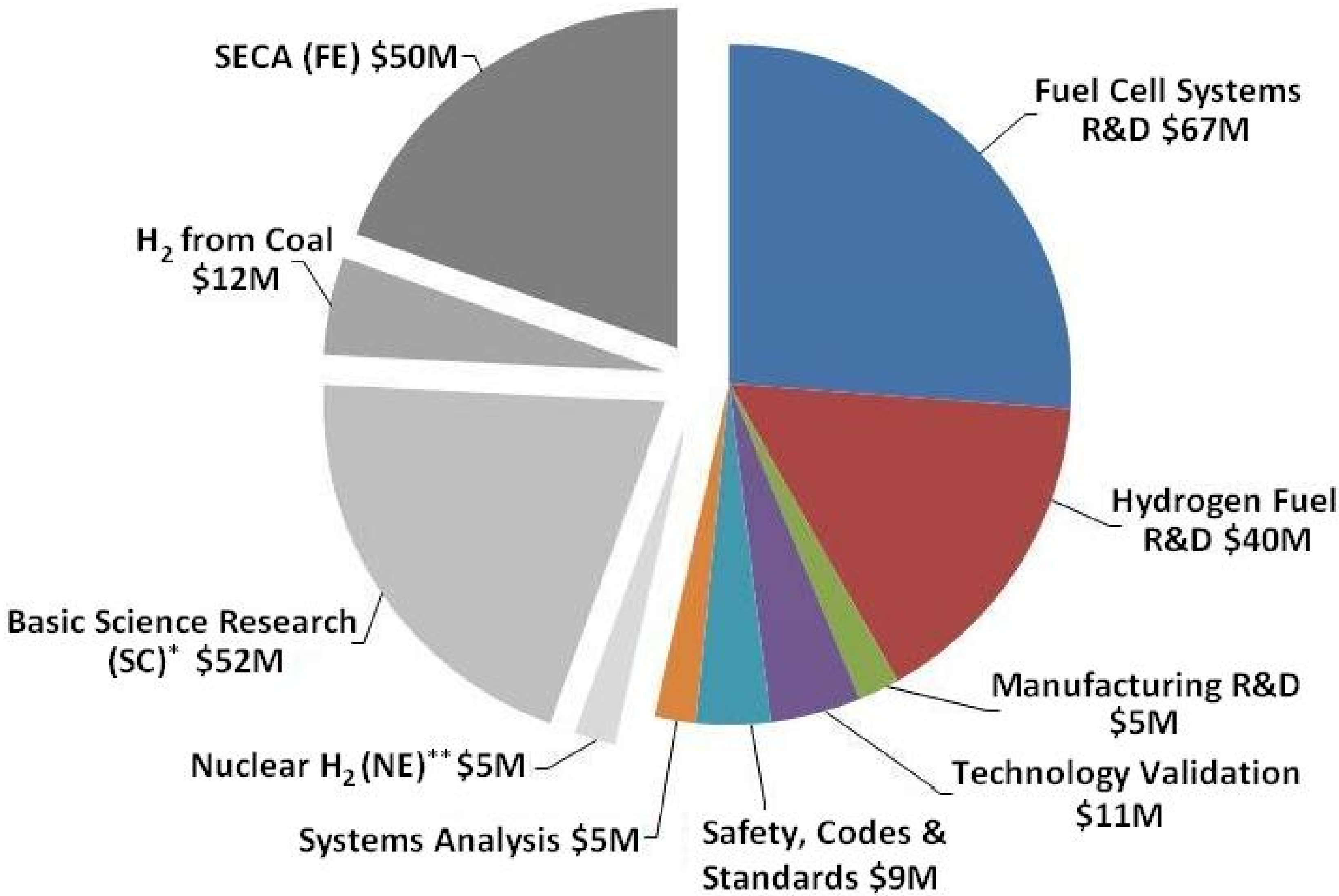
hydrogenandfuelcells.energy.gov

Backup Slides

Funding for Fuel Cells and Hydrogen
DOE FY11 Budget Request

U.S. DEPARTMENT OF ENERGY

Total Requested Funding: ~$256 Million

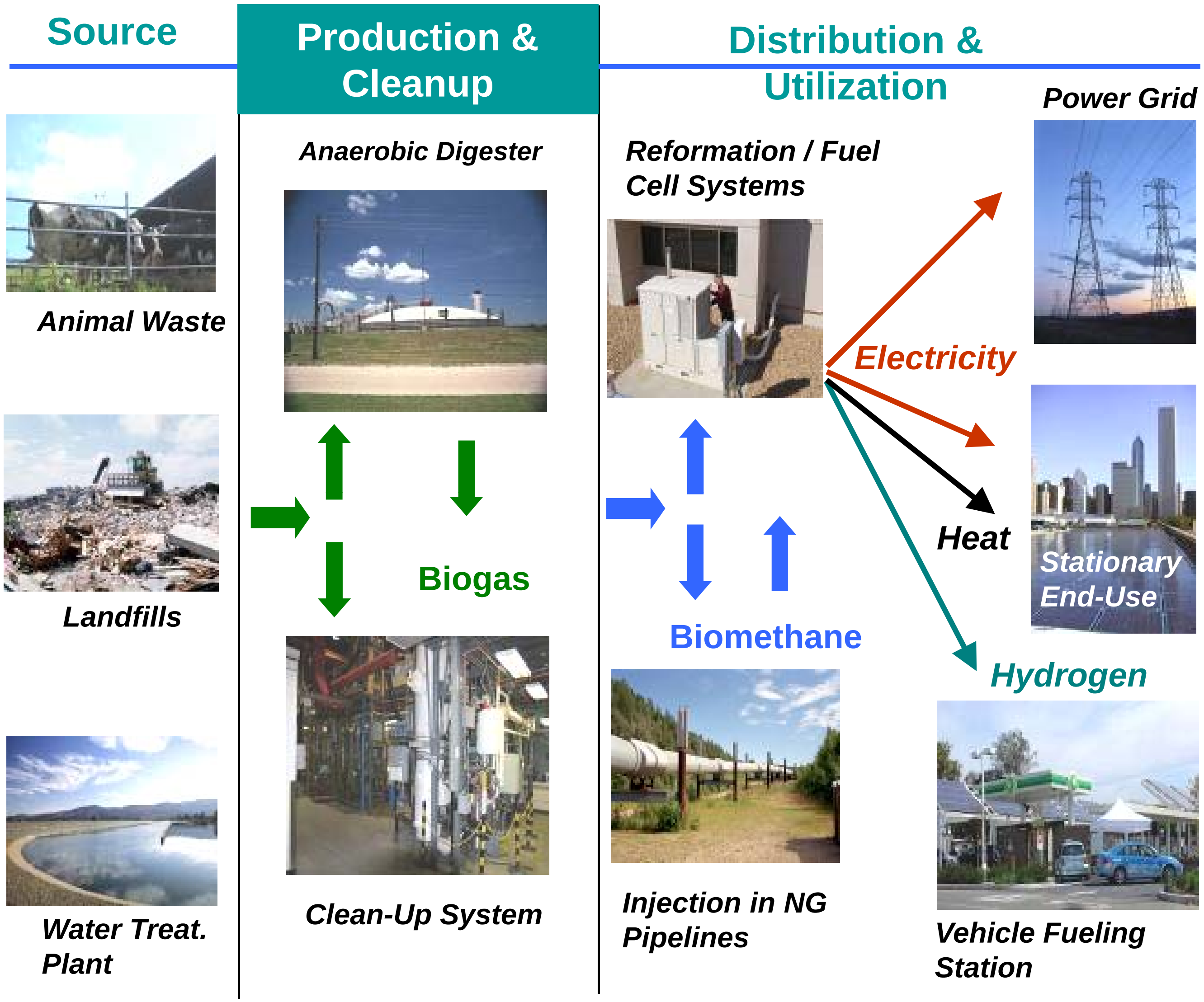


* SC funding includes BES and BER
** NE FY11 Request TBD (FY10 funding was $5M)

Transformation of Biogas to Fuel & Power

U.S. DEPARTMENT OF ENERGY

Models were developed to quantify the benefits of fuel cells operating on bio-methane, or hydrogen derived from bio-methane. These applications may mitigate energy and environmental issues and provide an opportunity for the commercialization of fuel cells.



Source: National Renewable Energy Laboratory

H2A Production Model
Platform for new cost analysis model aimed at calculating levelized cost of biomethane (from biogas).

Fuel Cell Power Model
Analysis of stationary fuel cell systems—in standalone and CHHP models.

SERA Model
Optimization tool, may also be used for related infrastructure analysis upon modification.

- ***13M tons/yr of bio-methane from biogas are available in the U.S. for fuel and power production.***

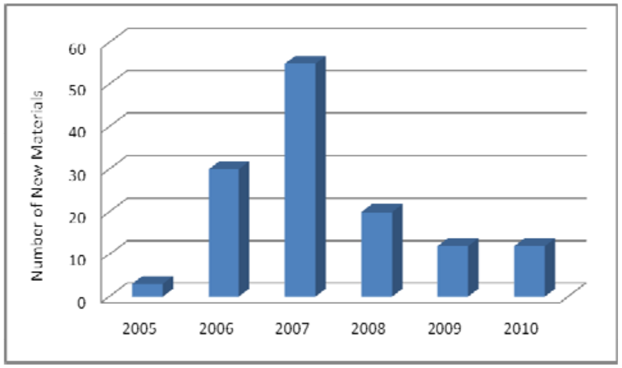
Portfolio Management & Progress

U.S. DEPARTMENT OF ENERGY

Many new material systems have been investigated through the three Materials Centers of Excellence.

Chemical Hydrogen Storage

- > 130 materials/combinations have been examined
- ~ 95% discontinued
- ~ 5% still being investigated-Ammonia Borane (AB) solid, ammonium borohydride, or mixture of AB with ionic liquids as liquid fuels

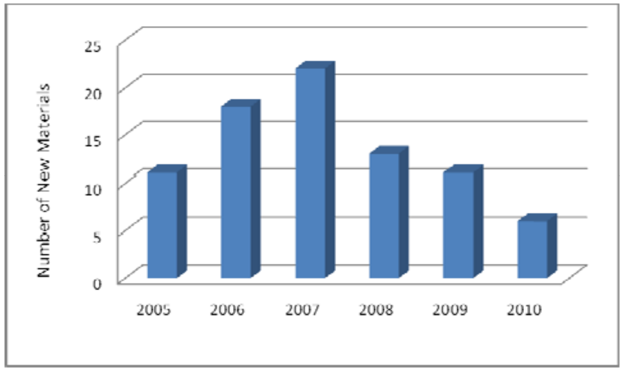


Metal Hydrides

More than 81 distinct material systems assessed experimentally—not including catalyst/additive studies

- ~ 75% discontinued
- ~ 25% still being investigated

Computational/theoretical screening done on more than 20 million reaction conditions for metal hydrides



Hydrogen Sorption

- ~ 210 materials investigated
- ~ 80% discontinued
- ~ 20% still being investigated