U.S. DEPARTMENT OF ENERGY

Hydrogen Posture Plan

Updates Since the 2004 Edition

JoAnn Milliken

Acting DOE Hydrogen Program Manager

Hydrogen Technical Advisory Committee (HTAC) Meeting
Washington, D.C.

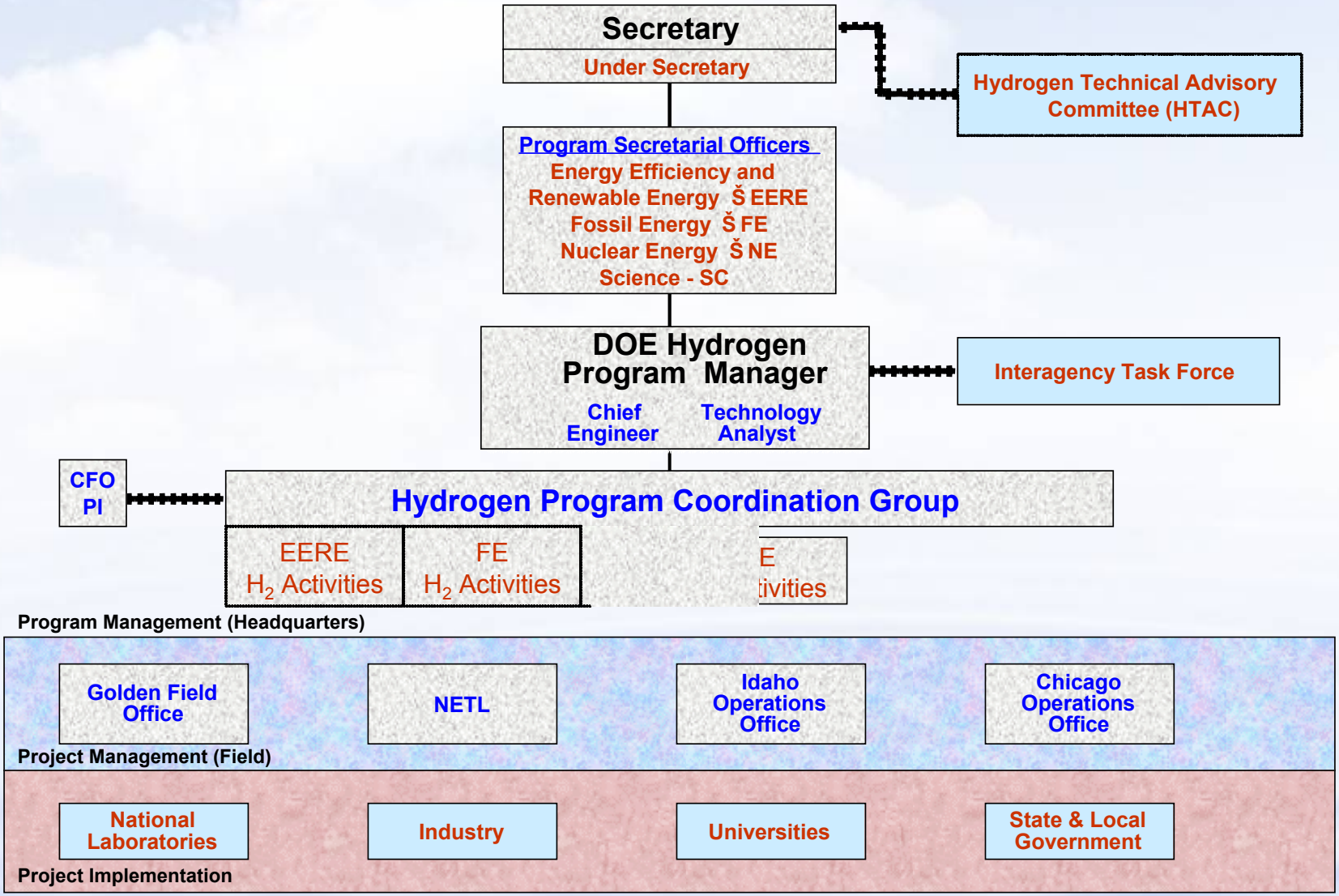
January 9 – 10, 2007

OUTLINE

- Program Organization
- Key Program Activities
- Program Accomplishments
- Milestones
- Budget
- Program Updates
- Analyses
- Systems Integration
- Next Steps

PROGRAM ORGANIZATION

DOE Hydrogen Program Organization



KEY PROGRAM ACTIVITIES

EERE Hydrogen Program

MISSION: By 2015, develop hydrogen and fuel cell technologies that are competitive competitive with conventional transportation and fueling technologies.

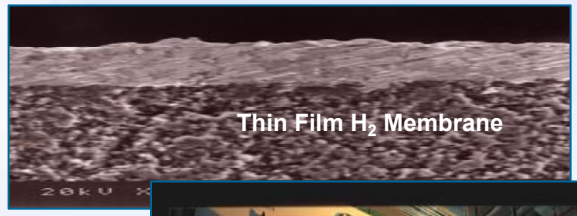
- Hydrogen Production and Delivery Delivery
  - ➔ Natural gas distributed reforming
  - ➔ Renewable liquid reforming
  - ➔ Distributed electrolysis
  - ➔ Central biomass gasification
  - ➔ Central wind/solar electrolysis
  - ➔ Solar high-temperature thermochemical thermochemical water splitting
  - ➔ Photoelectrochemical
  - ➔ Biological
- Hydrogen Storage
- Fuel Cells
- Manufacturing
- Technology Validation
- Safety, Codes and Standards
- Education
- Systems Analysis
- System Integration

GOALS

- On-board hydrogen storage systems systems with >300-mile range
- Fuel cell system with cost and lifetime competitive with current current vehicles – $30 per kW, 5,000-hr durability
- Technologies to produce hydrogen hydrogen that is competitive with with gasoline on a cost-per-mile mile basis – $2.00-3.00 per gallon of gallon of gasoline equivalent

Coal-Based Hydrogen

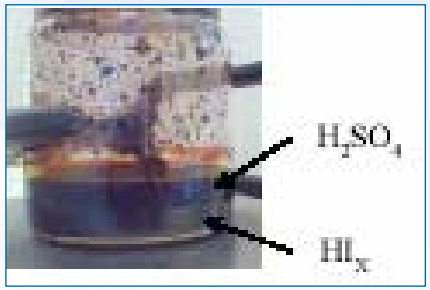
- **MISSION:** Hydrogen production technologies technologies that can utilize the nation's abundant coal resources to produce and deliver deliver affordable hydrogen in a safe and environmentally responsive manner.
- **R&D Focus Areas**
  - ➔ Separations
  - ➔ Membrane Reactors
  - ➔ Process Integration
- **Major Program Milestones**
  - ➔ **FY 2008:** Small scale test system for separation separation of multi-component gases
  - ➔ **FY 2011:** Membrane separation modules and and reactors to meet cost targets of $150 - 200 per 200 per ft^2
  - ➔ **FY 2015:** Near-zero emissions plant producing H_2 producing H_2 and power with CCS at a 25% cost cost reduction that projects to $0.80/gge at plant plant gate

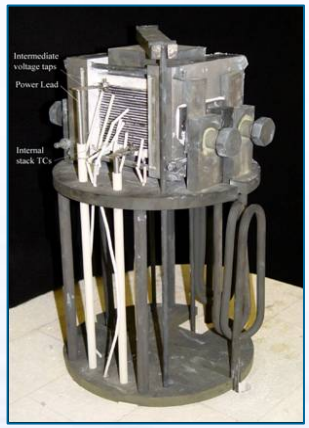


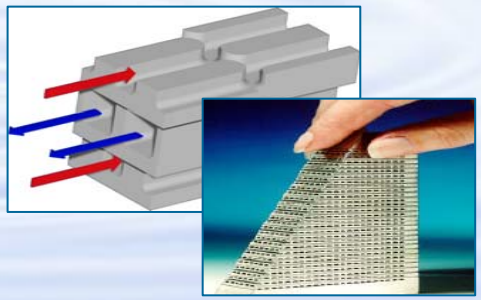
Nuclear-Based Hydrogen

FOCUS: Hydrogen production technologies that are compatible with nuclear nuclear energy systems and do not produce greenhouse gases.

- R &D Focus Areas:
  - ➔ Thermochemical Systems
  - ➔ High-Temperature Steam Electrolysis
  - ➔ Reactor/Process Interface Technologies Technologies
- Major Program Milestones:
  - ➔ FY 2008: Operation of laboratory-scale hydrogen production experiments
  - ➔ FY 2011: Select hydrogen production technology for Next Generation Nuclear Nuclear Plant (per Energy Policy Act)
  - ➔ FY 2014: Operation of pilot-scale hydrogen hydrogen production experiments
  - ➔ FY 2019: Demonstrate commercial-scale scale hydrogen production system for use for use with nuclear reactors

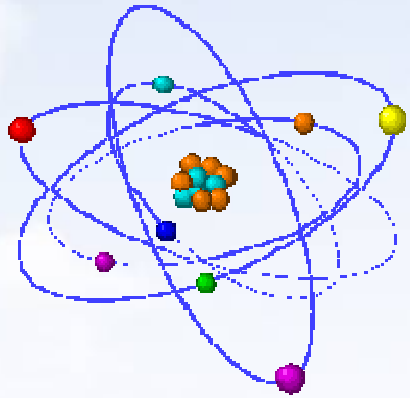


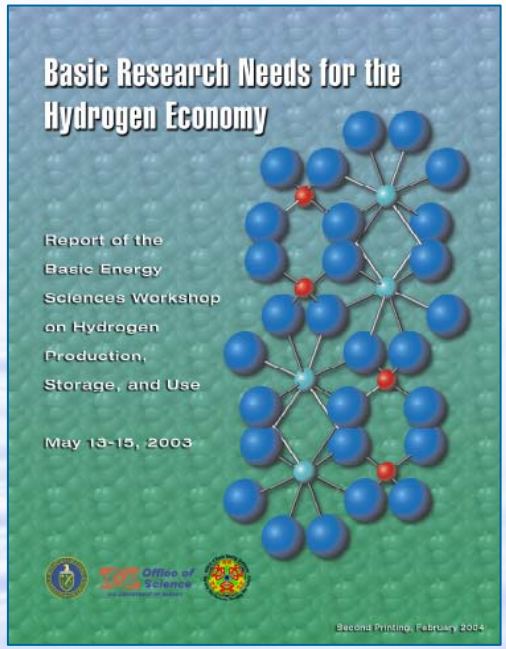




Basic Research Activities

- GOAL: Foster fundamental understanding in understanding in hydrogen production, production, delivery, storage, and conversion conversion technologies in 5 critical basic basic research areas:
  - ➔ Novel materials for hydrogen storage
  - ➔ Membranes for separation, purification and ion and ion transport
  - ➔ Design of catalysts at the nanoscale
  - ➔ Bio-inspired materials and processes
  - ➔ Solar hydrogen
- Research programs will provide foundation foundation for innovative design of materials materials and processes that will improve the improve the performance, cost, and reliability reliability of hydrogen production, storage, storage, and use.





DOT Hydrogen Program

FOCUS: **Ensuring a safe, reliable, and accessible transportation system and system and reducing the environmental impact from transportation. transportation.**

- R&D Focus Areas:
  - ➔ **Vehicle safety & standards**
  - ➔ **Emergency responder & code official education & training**
  - ➔ **Heavy-duty vehicle demonstration**
  - ➔ **Transportation infrastructure and systems analysis**
- Major Program Milestones:
  - ➔ **2008-2010: First responder training program**
  - ➔ **2010: NFCB phase II completed**
  - ➔ **2012 (estimate): NHTSA rulemaking**

U.S. Department of Transportation

Research and Innovative Technology Administration

PROGRAM ACCOMPLISHMENTS

Competitively selected over $640M in projects (over $920M with private cost share), subject to appropriations.

- Hydrogen production and delivery (71 projects, $120M, 4 yrs)
  - ➔ $9.5M for hydrogen from distributed natural gas
  - ➔ $34M for hydrogen from renewables
  - ➔ $15M for separations
  - ➔ $18M for delivery
  - ➔ $43M for hydrogen from coal
  - ➔ $2M for hydrogen from nuclear energy
- Hydrogen storage ($150M, 5 yrs) - includes Centers of Excellence and independent independent projects with universities, Federal labs, and industry
- Fuel cell cost & durability - consumer electronics & other applications (5 projects, $13M, projects, $13M, 3 yrs)
- PEM - improved performance, higher temperatures, lower humidity (12 projects, $19M, projects, $19M, 5 yrs)
- Fuel cells (25 projects, $100M, 4 yrs)
- Vehicle and infrastructure “learning demonstration” project ($170M, 4 teams, 6 yrs) teams, 6 yrs)
- Basic research for hydrogen production, storage, and use (70 projects, $64M, 3 yrs) $64M, 3 yrs)
- Education (4 projects, $5M, 5 yrs)

Established FreedomCAR & Fuel Partnership

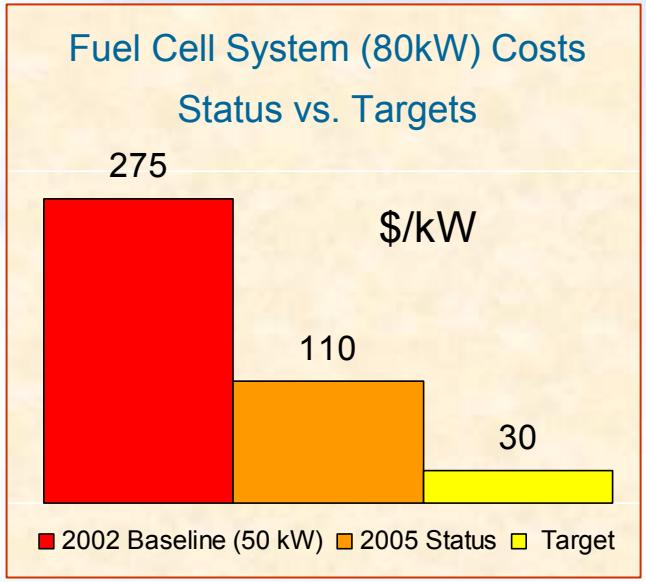
- DOE/industry partnership to establish establish technical requirements and and evaluate research results
- January 2002:
  - ➔ DaimlerChrysler
  - ➔ Ford
  - ➔ General Motors

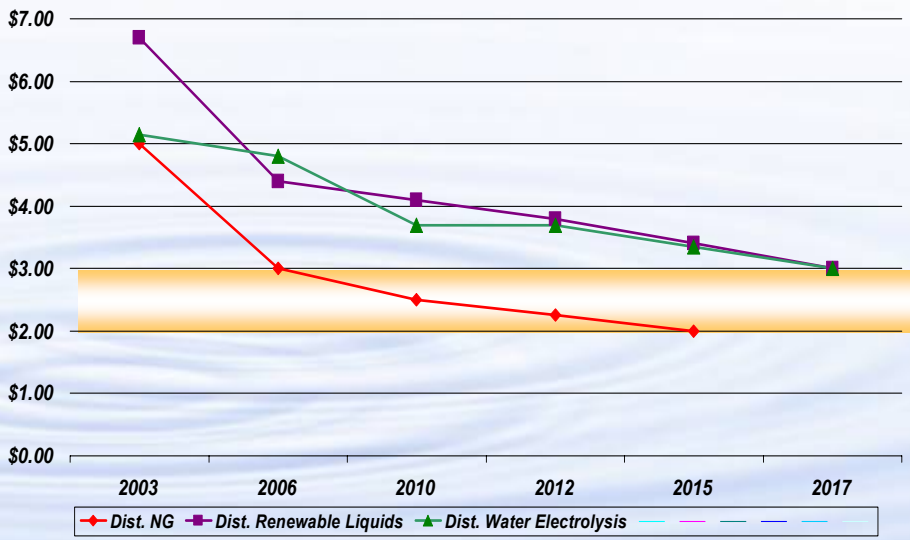
  USCAR
  - ➔ DOE
- September 2003:
  - ➔ DaimlerChrysler
  - ➔ Ford
  - ➔ General Motors

  USCAR
  - ➔ ExxonMobil Corporation
  - ➔ ConocoPhillips
  - ➔ Chevron Corporation
  - ➔ BP America
  - ➔ Shell
  - ➔ DOE

Technical Accomplishments

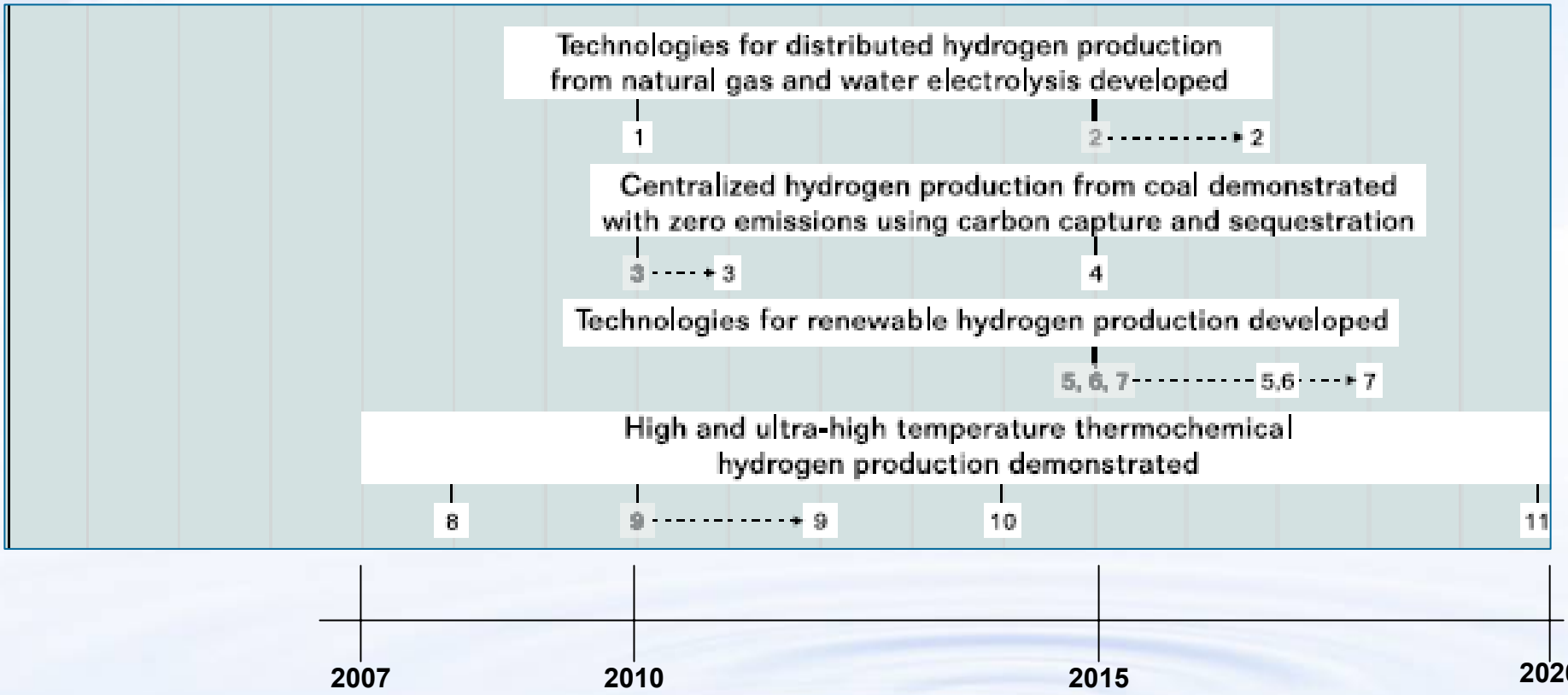
- Reduced high-volume cost of automotive automotive fuel cells from $275/kW (50kW (50kW system) in 2002 to $110/kW (80kW (80kW system) in 2005. (DOE target: $30/kW)
- Reduced cost of hydrogen from natural gas natural gas to $3/gge (DOE target: $2 - - 3/gge, delivered, untaxed, at the pump pump and independent of technology technology pathway)
- Achieved 2,000 hours fuel cell durability in durability in the lab (DOE target: 5,000 5,000 hours)
- Hydrogen Storage:
  - ➔ Materials with higher storage capacities capacities identified
  - ➔ Several issues (temperature, pressure, etc.) etc.) remain but progress is clear



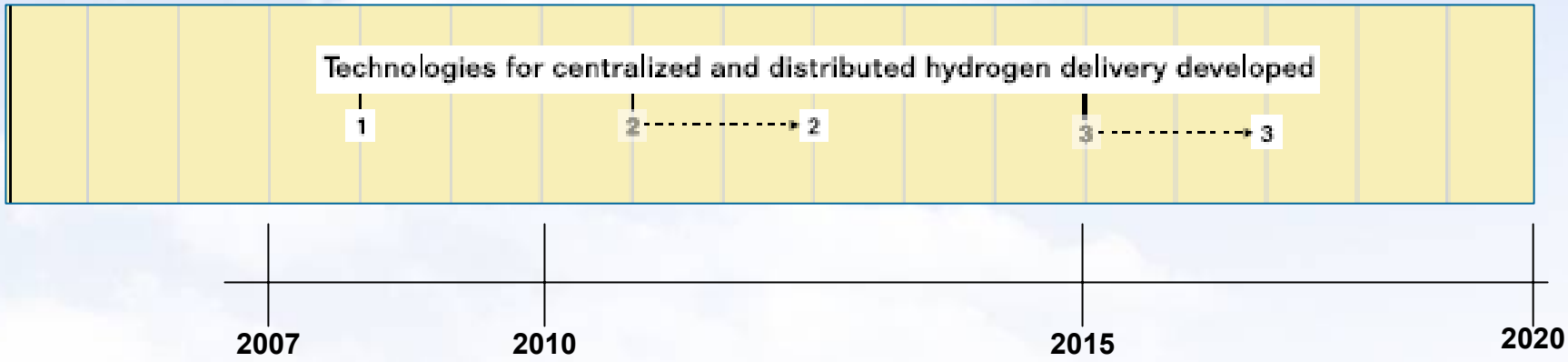


MILESTONES

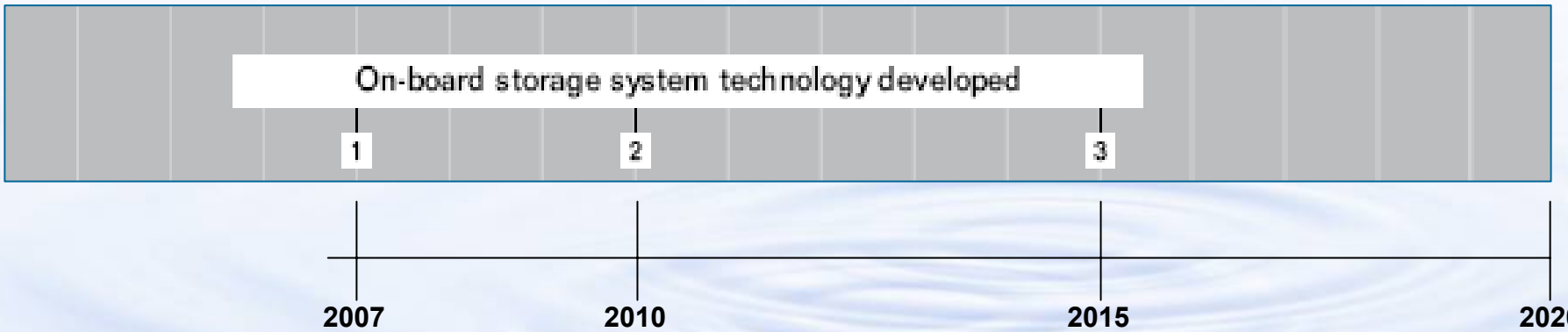
Hydrogen Production



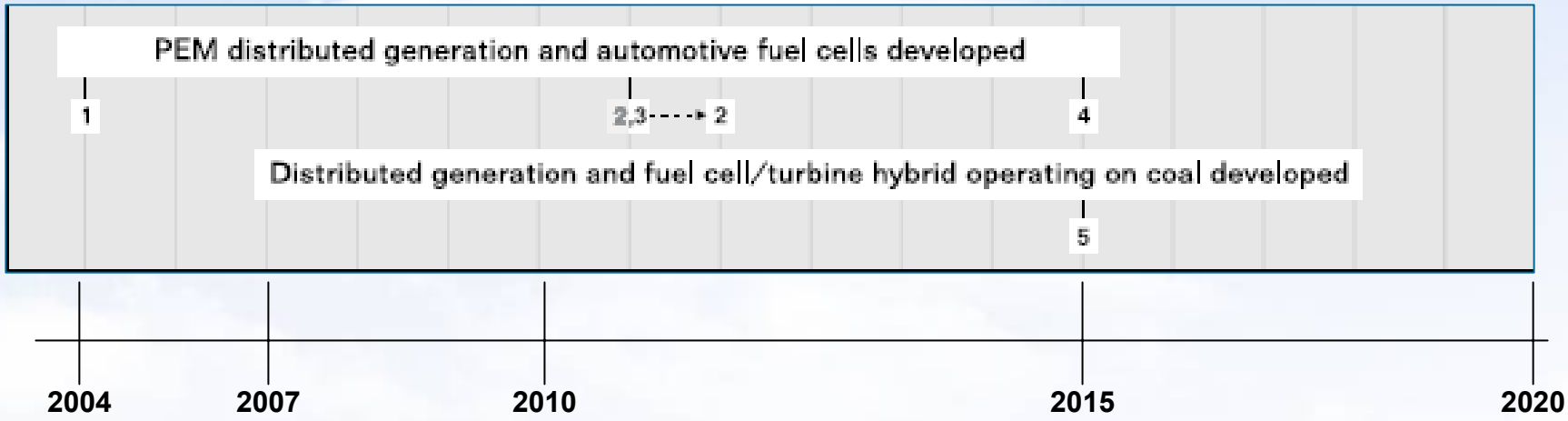
Centralized Delivery



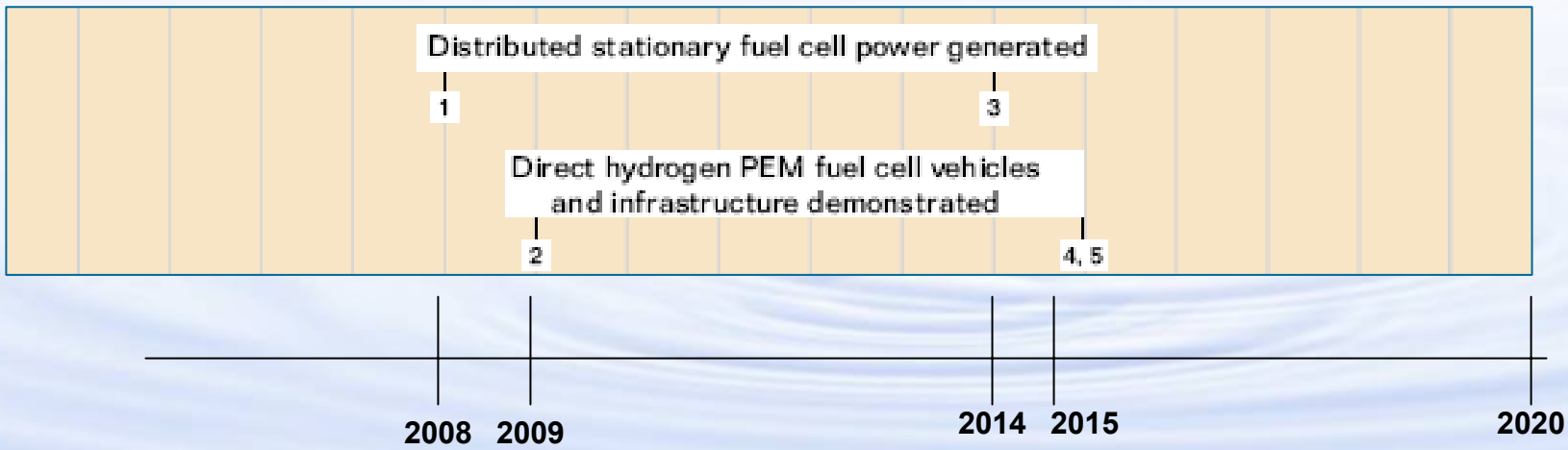
Storage



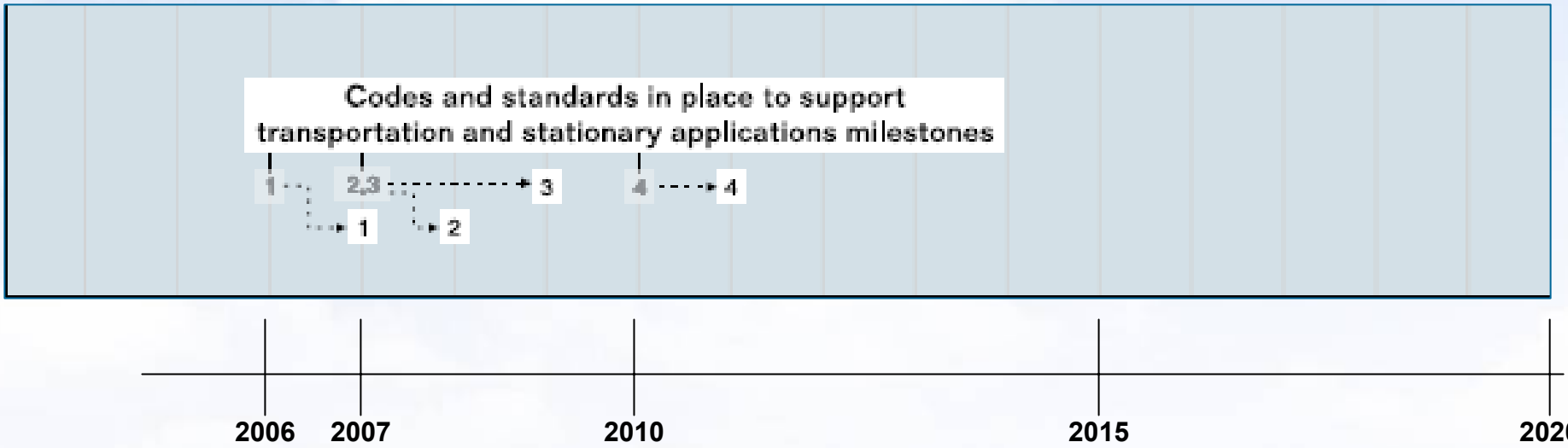
Conversion (Fuel Cells)



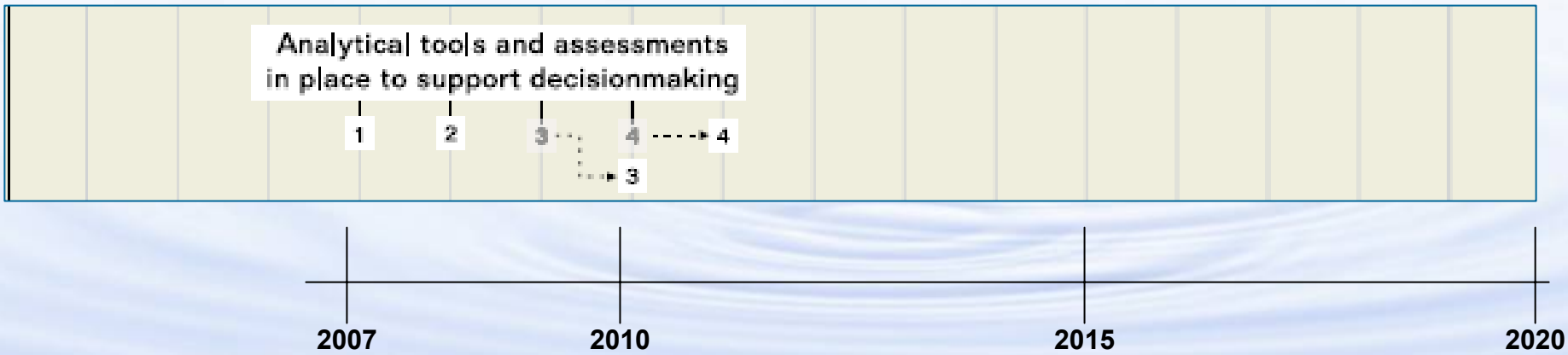
Technology Validation



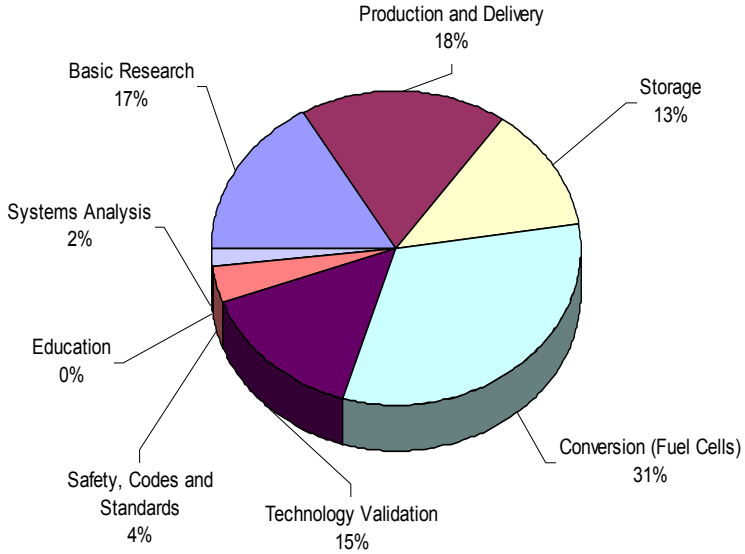
Education, Safety, and Codes & Standards



Systems Analysis



BUDGET



Graph excludes Congressionally directed funds.

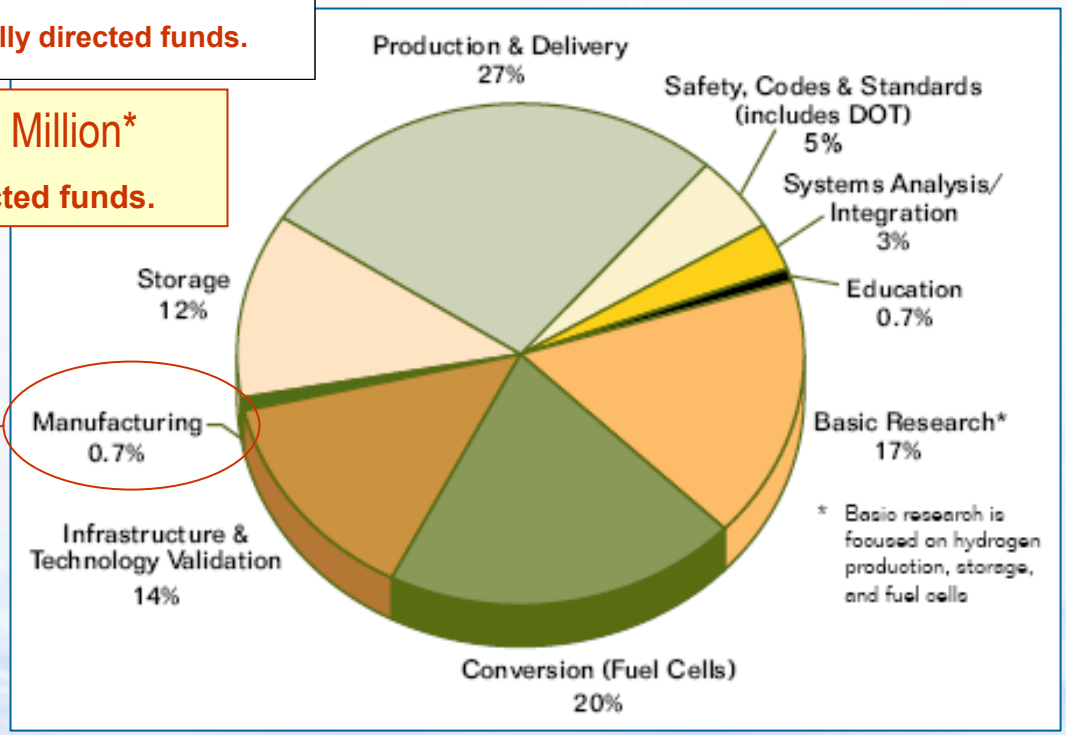
FY 2005 APPROPRIATION: $221.7 Million*

*** Includes $47.2M in Congressionally directed funds.**

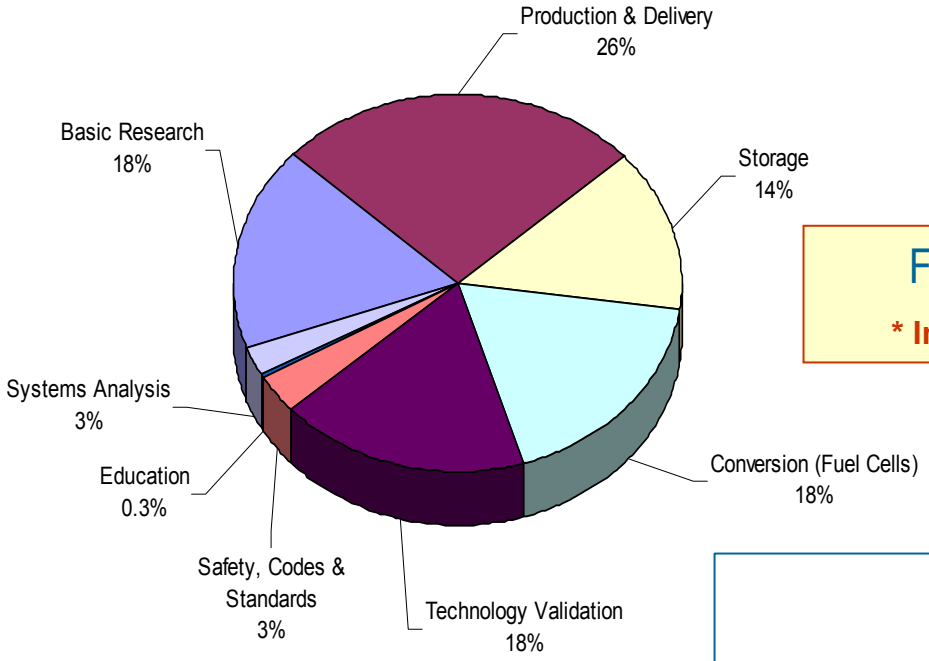
FY 2007

- Hydrogen Production: $74M
  - ➔ Distributed NG: $4M
  - ➔ Coal-based: $23M
  - ➔ Nuclear-based: $18M
  - ➔ Renewable-based $27M
- Hydrogen Delivery: $7M

NEW



FY 2007 REQUEST: $289.5 Million

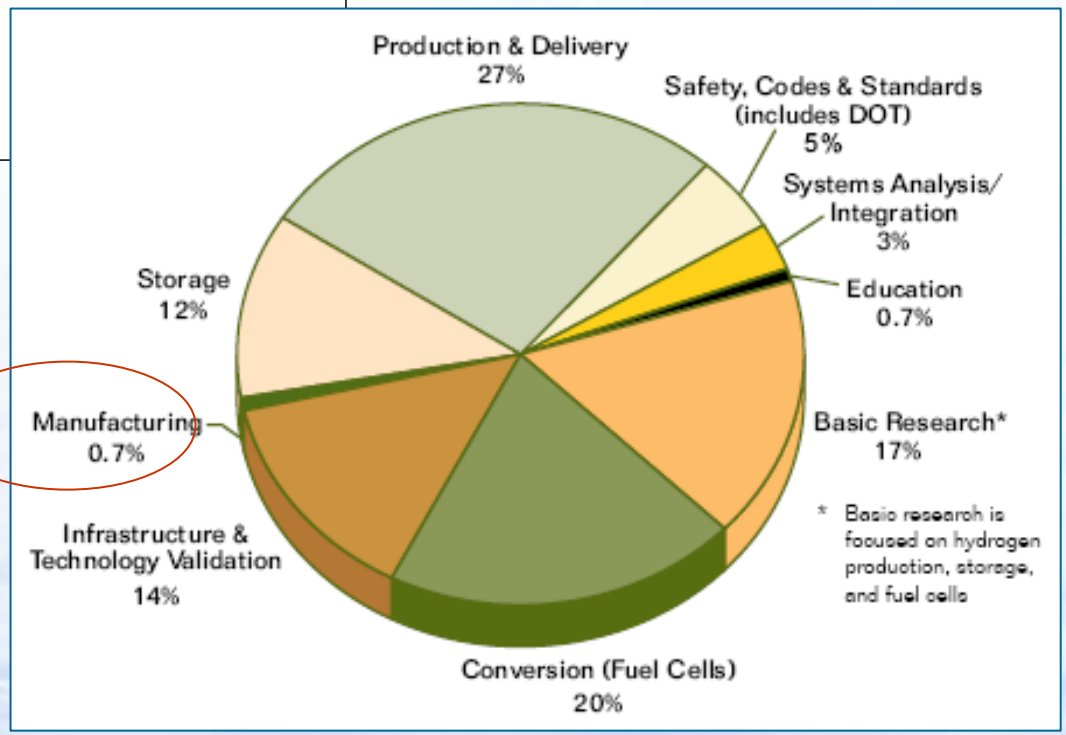


Graph excludes Congressionally directed funds.

FY 2006 APPROPRIATION: $232.5 Million*

*** Includes $47.5M in Congressionally directed funds.**

NEW



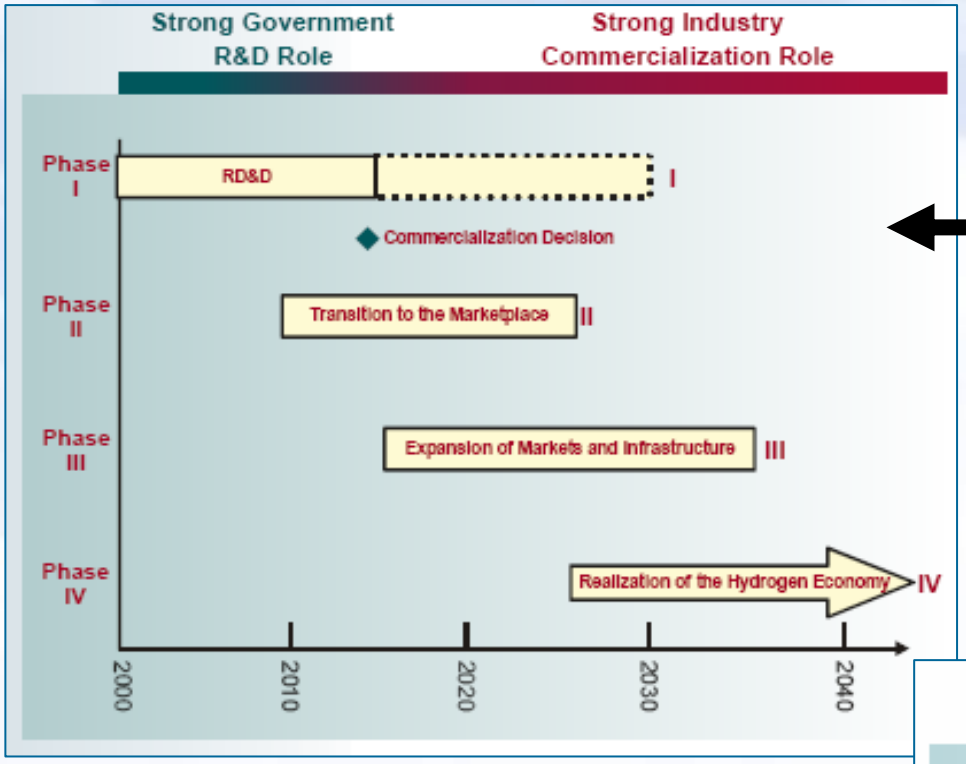
FY 2007 REQUEST: $289.5 Million

Related Research within Other DOE Programs and DOT

- Hybrid electric vehicle research: $109.8M
- Carbon sequestration and carbon management:
  - ➔ applied R&D: $73.9M
  - ➔ basic research: $5.9M
- Biomass and biorefinery systems:
  - ➔ applied R&D: $150M
  - ➔ basic research: $15.4M
- Wind energy:
  - ➔ applied R&D: $43.8M
  - ➔ basic research: $260K
- Solar energy:
  - ➔ applied R&D: $148.4M
  - ➔ basic research: $62.3M
- High-temperature stationary fuel cells: $63.3M
- Basic research on biological hydrogen production: $50.6M
- DOT fuel cell bus RD&D, infrastructure development, and SAFETEA-SAFETEA-LU activities: $28M

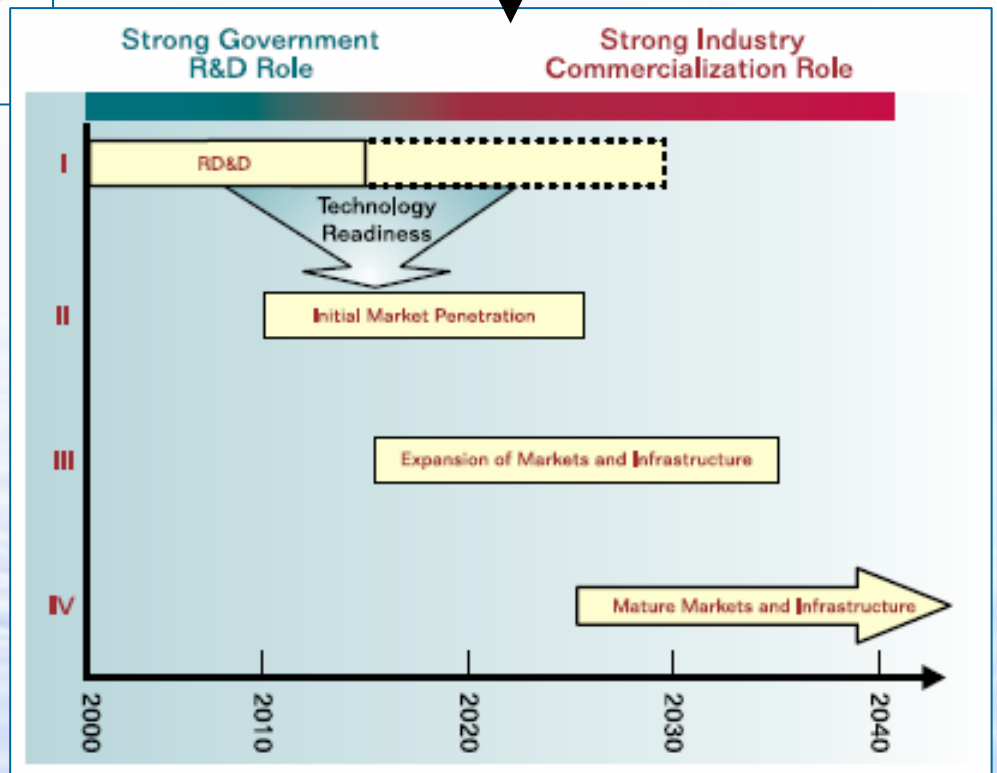
FY 2007

PROGRAM UPDATES



2004 Posture Plan

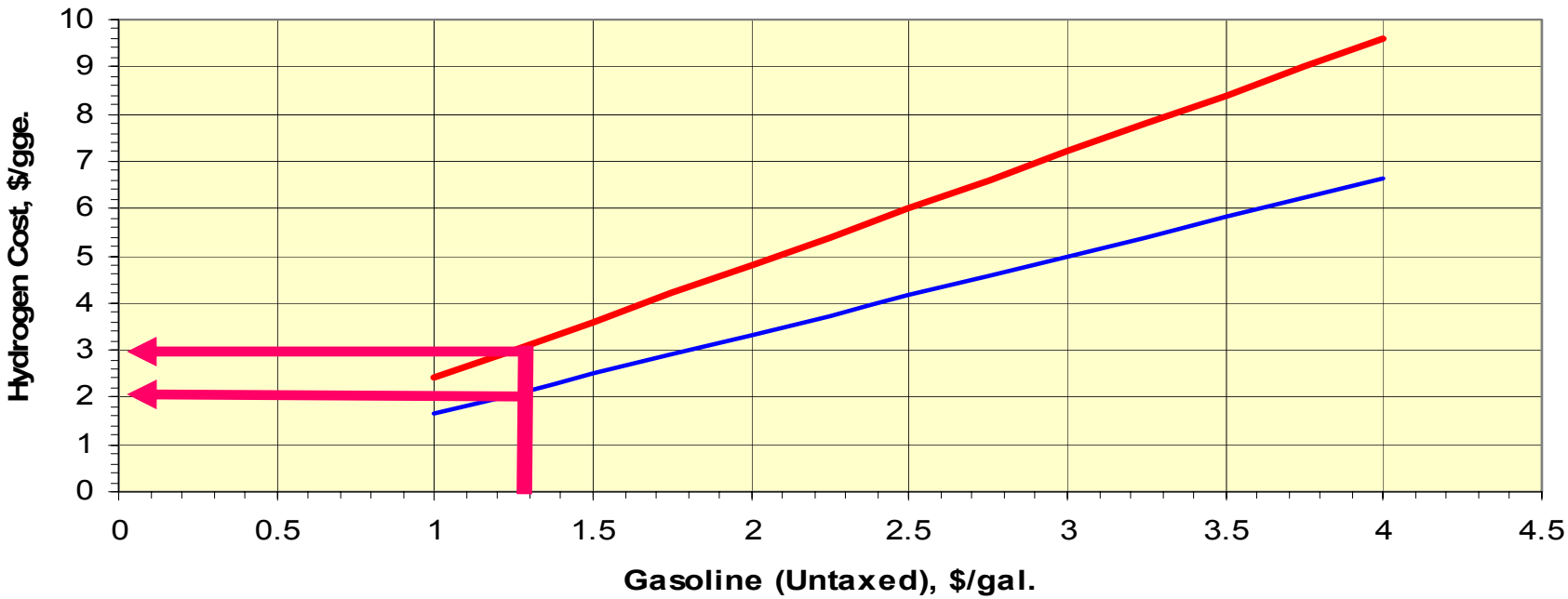
2007 Posture Plan



Possible Scenarios for Hydrogen Technology Development & Market Transformation

Revised Hydrogen Cost Goal

- Adjusted from $1.50/gge to $2.00 - $3.00/gge
- Independent of hydrogen production pathway
- Based on:
  - ➔ EIA forecast of gasoline cost in 2015
  - ➔ Relative fuel economy of hydrogen fuel cell vehicles to advanced vehicle technology in 2015
- Consumers' operating cost ($/mile) of hydrogen fuel cell vehicle less than or equal to competitive competitive gasoline vehicle in 2015



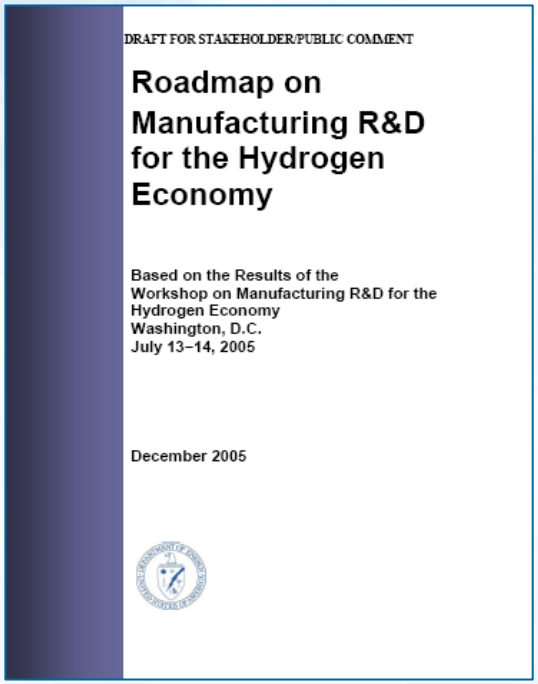
Learning Demonstration Progress

- Teams:
  - ➔ Chevron/Hyundai-Kia
  - ➔ DaimlerChrysler/BP
  - ➔ Ford/BP
  - ➔ GM/Shell

Hydrogen refueling station, Chino, CA Photo: NREL

- Progress:
  - ➔ 10 hydrogen fueling stations currently; total of 18 planned by 2009 planned by 2009
  - ➔ 63 hydrogen FCVs currently; additional 68 planned for 2007 - 2008 2007 - 2008 with 50,000-mile fuel cell systems
  - ➔ Fuel cell system achieved 53 - 58% efficiency, vehicles demonstrated range of 103 - 190 miles, fuel cells demonstrated a demonstrated a max of 960 hrs durability (<30,000 miles)
  - ➔ No major safety problems encountered

New Start: Manufacturing R&D


DRAFT FOR STAKEHOLDER/PUBLIC COMMENT

Roadmap on Manufacturing R&D for the Hydrogen Economy

Based on the Results of the Workshop on Manufacturing R&D for the Hydrogen Economy
Washington, D.C.
July 13–14, 2005

December 2005

Manufacturing R&D Roadmap – based on results of July 2005 workshop with industry.

- Objectives:
  - ➔ Move from laboratory processes to *high-high-volume/cost effective* manufacturing of manufacturing of hydrogen/fuel cell technologies; develop domestic supplier base supplier base
- Coordination with:
  - ➔ Department of Commerce
  - ➔ White House OSTP – Interagency Working Working Group on Manufacturing R&D
- Research on fabrication and process techniques critical to *near-term* technology technology deployment
  - ➔ Membrane electrode assemblies and bipolar bipolar plates for fuel cells
  - ➔ Distributed reforming
  - ➔ Electrolysis systems and components
  - ➔ Vessels, valves, and regulators for hydrogen hydrogen storage and dispensing
- Solicitation planned for FY 2007 or 2008 2008

Hydrogen Safety, Codes & Standards

- DOE and DOT have initiated first responder and responder and code official training
- Established two online databases:
  - ➔ **Hydrogen Incidents Database:** Information on Information on hydrogen incidents and lessons lessons learned http://**www.h2incidents.org** http://**www.h2incidents.org**
  - ➔ **Bibliographic Database:** Publications related to hydrogen safety http://**www.hydrogen.energy.gov**

Hydrogen Quality

- Established working group to examine trade-offs and draft R&D roadmap

Hydrogen Quality Sampling Adapter

International Partnership for the Hydrogen Economy Economy (IPHE)

- Implementation-Liaison Committee (ILC) sub-groups formed:
  - ➔ Education Work Group
  - ➔ Regulations, Codes & Standards Work Group
  - ➔ Demonstration & Infrastructure Task Force
- Priority Scorecard Workshop:
  - ➔ Rank critical objectives
  - ➔ Identify areas for international collaboration
  - ➔ Draft report to be published December 2006
- 13 hydrogen and fuel cell research projects endorsed by IPHE
- Master Class Activities of the Education Work Group:
  - ➔ Safety education for local government officials and planners - end of 2006
  - ➔ Course on bio-hydrogen through the University of Rio de Janeiro – Brazil, April 2007 2007
  - ➔ Renewable Hydrogen – Seville, Spain, May 2007
  - ➔ International Student Forum at WHEC 2008

DOE Hydrogen Program Record	
Record #: 5008	**Date:** December 28, 2005
Title: FCV Hydrogen Demand in 2040	
Originator: Fred Joseck, Mark Paster	
Approved by: JoAnn Milliken	**Date:** January 3, 2006

Items:

- 64 million metric tons of hydrogen would be needed to power 300 million hydrogen fuel cell vehicles in 2040.
- 300 million FCVs would be 80% of the vehicle fleet of 375 million vehicles projected for 2040.

Data/References:

The following values were based on the *VISION Model: Description of Model Used to Estimate the Impact of Highway Technologies and Fuels on Energy Use and Carbon Emissions to 2050.* Singh M., A. Vyas, and E. Steiner, Argonne National Laboratory, December 2003, ANL/ESD/04-1 (www.transportation.anl.gov/pdfs/TA/299.pdf).

1- 375 million vehicles projected for 2040 in the U.S. Vehicles refer to light duty vehicles as defined in the model.

2- 300 million FCVs is based on the model's assumption of the following FCV market sales rates: 4% in 2018, 27% in 2020, 78% in 2030, and 100% by 2038.

3- 13,000 miles per light duty vehicle in 2040. (Also from *Transportation Energy Data Book: Edition 23-2003*, Table 7.4 (7-4)).

4- 24.3 miles per gallon for conventional light duty vehicles in 2040.

5- 2.5 is the assumed ratio of FCVs miles per kg (or gge) of hydrogen to miles per gallon of gasoline for conventional vehicles.

Calculations:

300 million Fuel cell vehicles x 13,000 miles per vehicle per year = 3,900 billion miles driven per year

24.3 miles per gallon for conventional vehicles x 2.5 factor for fuel cell vehicle in 2040 = 60.75 miles/kg of H2 for a fuel cell vehicle.

3,900 billion miles divided by 60.75 miles/kg of hydrogen = 64 million metric tons of hydrogen required.

New Records System

- Enhanced management and and improved transparency transparency for Program Program documents
- "Records" created to:
  - ➔ Provide full references
  - ➔ State all assumptions
  - ➔ Provide detailed calculations calculations

http://www.hydrogen.energy.gov/program_records

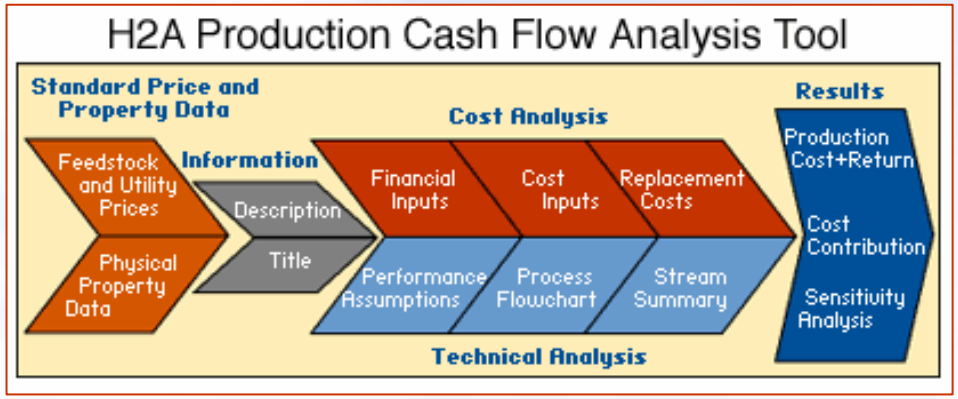
ANALYSES

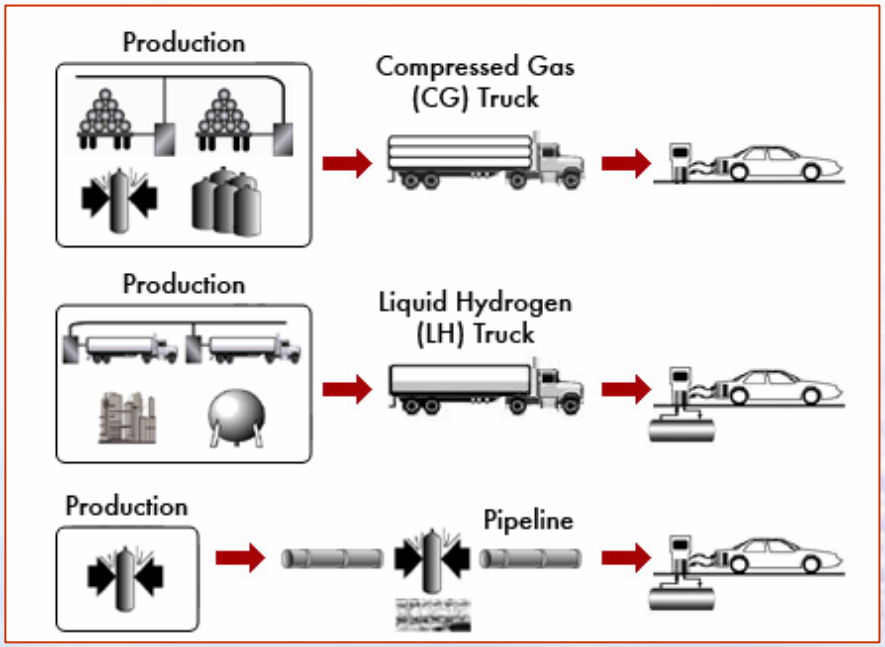
Hydrogen Production & Delivery Pathways

- Continuing analysis to revise, refine and expand results results
- Use of systems analysis methods and modeling tools: tools:
  - ➔ H2A Model
  - ➔ GREET Model
  - ➔ Well-to-wheels analysis
- In-depth results obtained

H2A Model

- Life-cycle approach to evaluating hydrogen systems as a whole
- Analysts from national labs, universities and industry involved



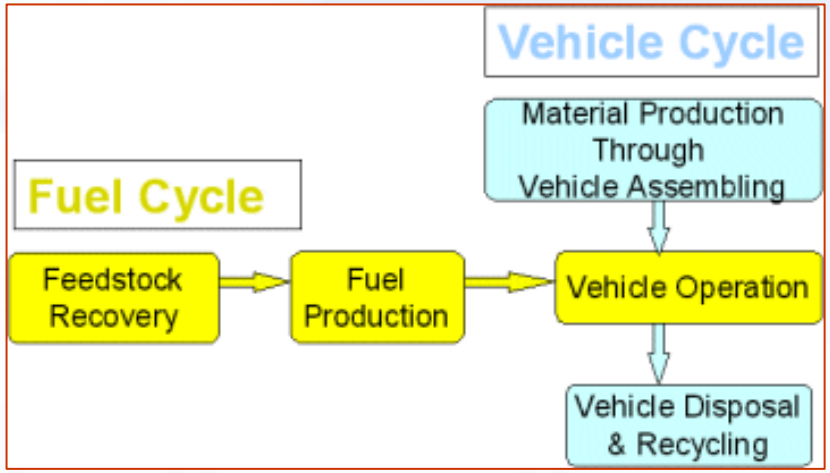


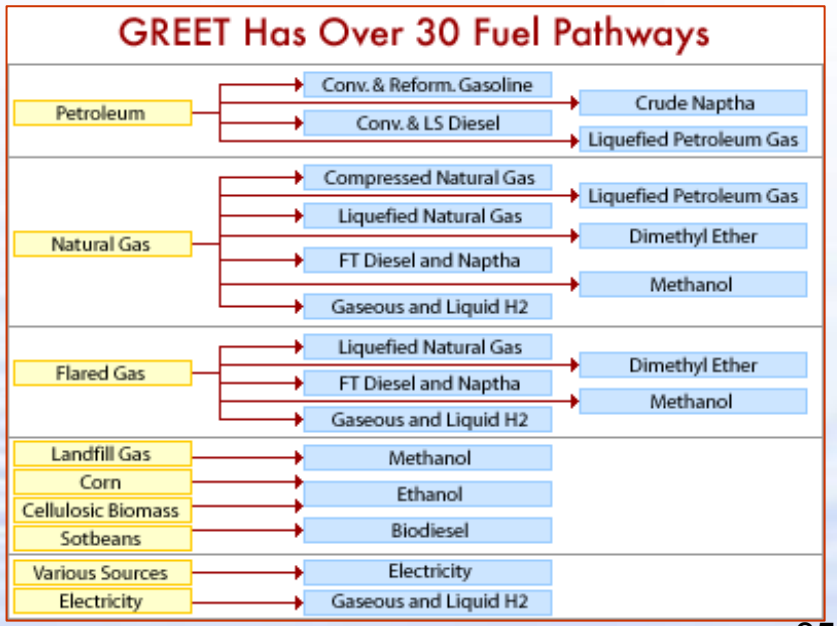
- Initiated in February 2003, to:
  - ➔ Establish consistent set of parameters and methodologies
  - ➔ Enhance transparency and consistency of approaches
  - ➔ Provide understanding of differences between analyses
  - ➔ Obtain validation from industry

GREET Model

Greenhouse Gases, Regulated Emissions and Energy Use in Transportation

- Multi-dimensional spreadsheet spreadsheet model
- Developed by Argonne National National Lab with support from from DOE
- Well-to-wheels fuel cycle
- Vehicle cycle through materials materials recovery and vehicle vehicle disposal
- For given vehicle and fuel system, model determines:
  - ➔ Total energy consumption
  - ➔ Emission of CO_2-equivalent GHGs
  - ➔ Emissions of criteria pollutants pollutants





Well-to-Wheels Analysis for Transportation

Vehicles

- Internal combustion engine (ICE)
- Hybrid
- Fuel cell

Hydrogen for Fuel Cell Vehicles

2005

- Distributed natural gas reforming
- Distributed wind electrolysis
- Central wind electrolysis
- Central biomass gasification
- Central coal gasification (w/ carbon sequestration)

2015

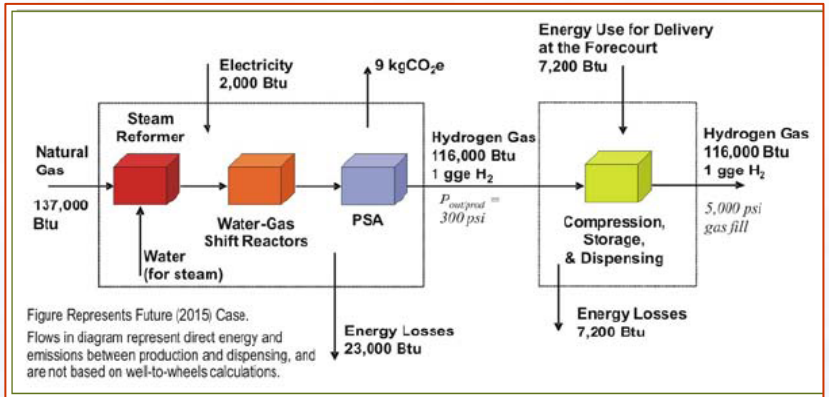
- Distributed natural gas reforming
- Distributed wind electrolysis

2030

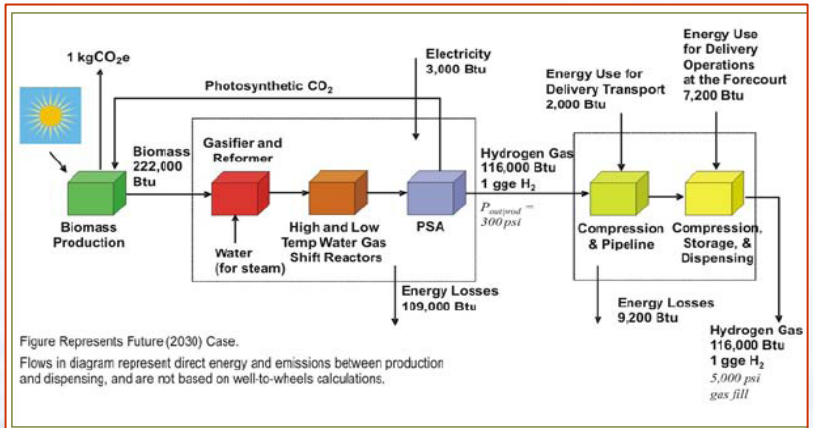
- Central wind electrolysis
- Central biomass gasification
- Central coal gasification (w/ carbon sequestration)
- Central nuclear sulfur-iodine process

Detailed Results

- Well-to-wheels energy, petroleum, and greenhouse gas emissions information information from GREET model
- Cost, resource requirements, energy requirements, all fuel and feedstock feedstock energy contents and efficiency values from H2A model cases cases



Well-to-Wheels Energy and Greenhouse Gas Emissions Data				
	Current (2005) Gasoline ICE Vehicle	Current (2005) Gasoline Hybrid Electric Vehicle	Current (2005) Distributed SMR - FCV	Future (2015) Distributed SMR - FCV
Well-to-Wheels Total Energy Use (Btu/mile)	5,900	4,200	3,700	2,800
Well-to-Wheels Petroleum Energy Use (Btu/mile)	5,300	3,800	40	40
Well-to-Wheels Greenhouse Gas Emissions (gCO_2e/mile)	470	340	260	200
Cost of Hydrogen ($/gge, Delivered)			3.10	2.00



Well-to-Wheels Energy and Greenhouse Gas Emissions Data				
	Current (2005) Gasoline ICE Vehicle	Current (2005) Gasoline Hybrid Electric Vehicle	Current (2005) Biomass Gasification - FCV	Future (2030) Biomass Gasification - FCV
Well-to-Wheels Total Energy Use (Btu/mile)	5,900	4,200	6,600	3,600
Well-to-Wheels Petroleum Energy Use (Btu/mile)	5,300	3,800	200	100
Well-to-Wheels Greenhouse Gas Emissions (gCO_2e/mile)	470	340	190	30
Cost of Hydrogen ($/gge, Delivered)			5.10	2.40

SYSTEMS INTEGRATION

Systems integration function utilized more extensively to manage Program activities…

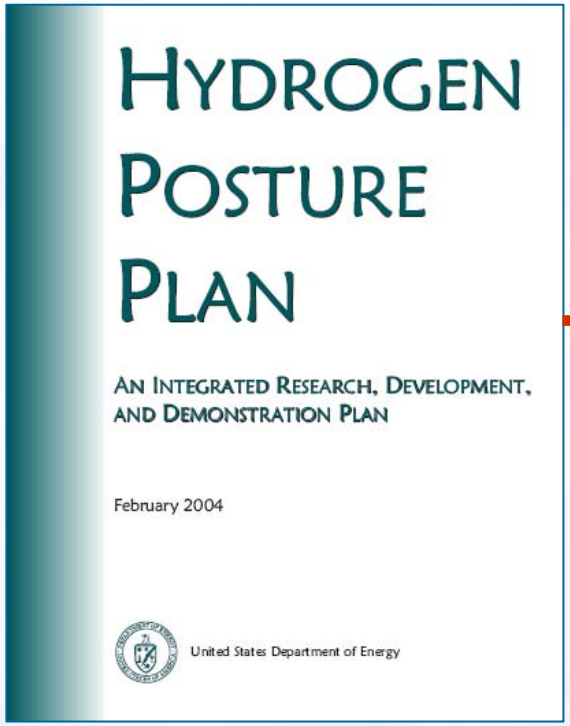
- Recommended by the NAS
- Integrated approach to reduce risk and maximize potential for success success
- Management of complex interactions between technical and programmatic programmatic elements to cost-effectively achieve objectives
- Ongoing and planned activities:
  - ➔ *Integrated Baseline* – technical requirements linked to programmatic requirements requirements
  - ➔ Independent systems analysis in support of program decision-making
  - ➔ *Macro-System Model* of overall hydrogen infrastructure
  - ➔ Configuration management / change control
  - ➔ Risk management
  - ➔ Verification of performance of R&D projects and progress towards achieving achieving technical targets
  - ➔ Independent peer review panels for critical program milestones/decisions milestones/decisions

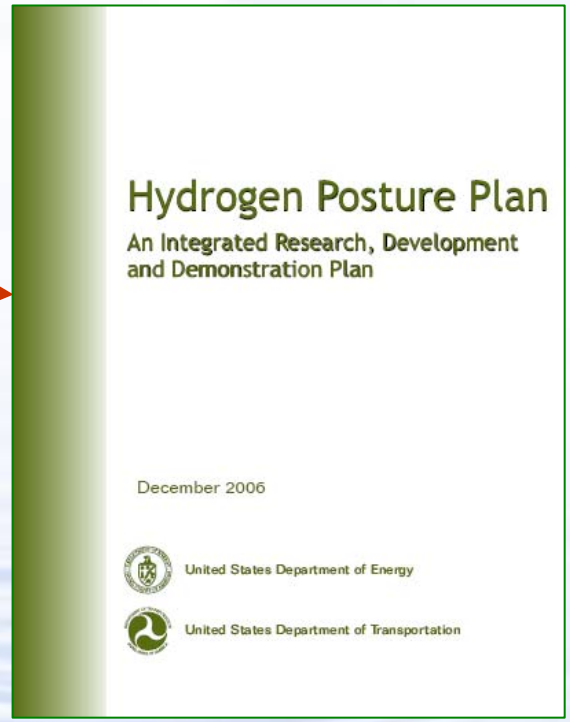
NEXT STEPS

Next Steps

- Conduct Independent Review:
  - ➔Assess potential of cryogenic compressed hydrogen hydrogen tanks to meet DOE's 2010 targets
- Analyze Distributed Reforming of Renewable Liquids: Liquids:
  - ➔Utilize lessons learned from distributed reforming of reforming of natural gas
- Publish:
  - ➔Hydrogen Program Safety Plan
  - ➔Hydrogen Program Risk Management Plan
- Conduct 4th annual integrated Hydrogen Program Merit Merit Review and Peer Evaluation Meeting
- Collaborate with DOT:
  - ➔Develop Global Technical Regulations for light duty fuel duty fuel cell vehicles
- Work more closely with emerging state-led initiatives initiatives

THANK YOU….





Questions?