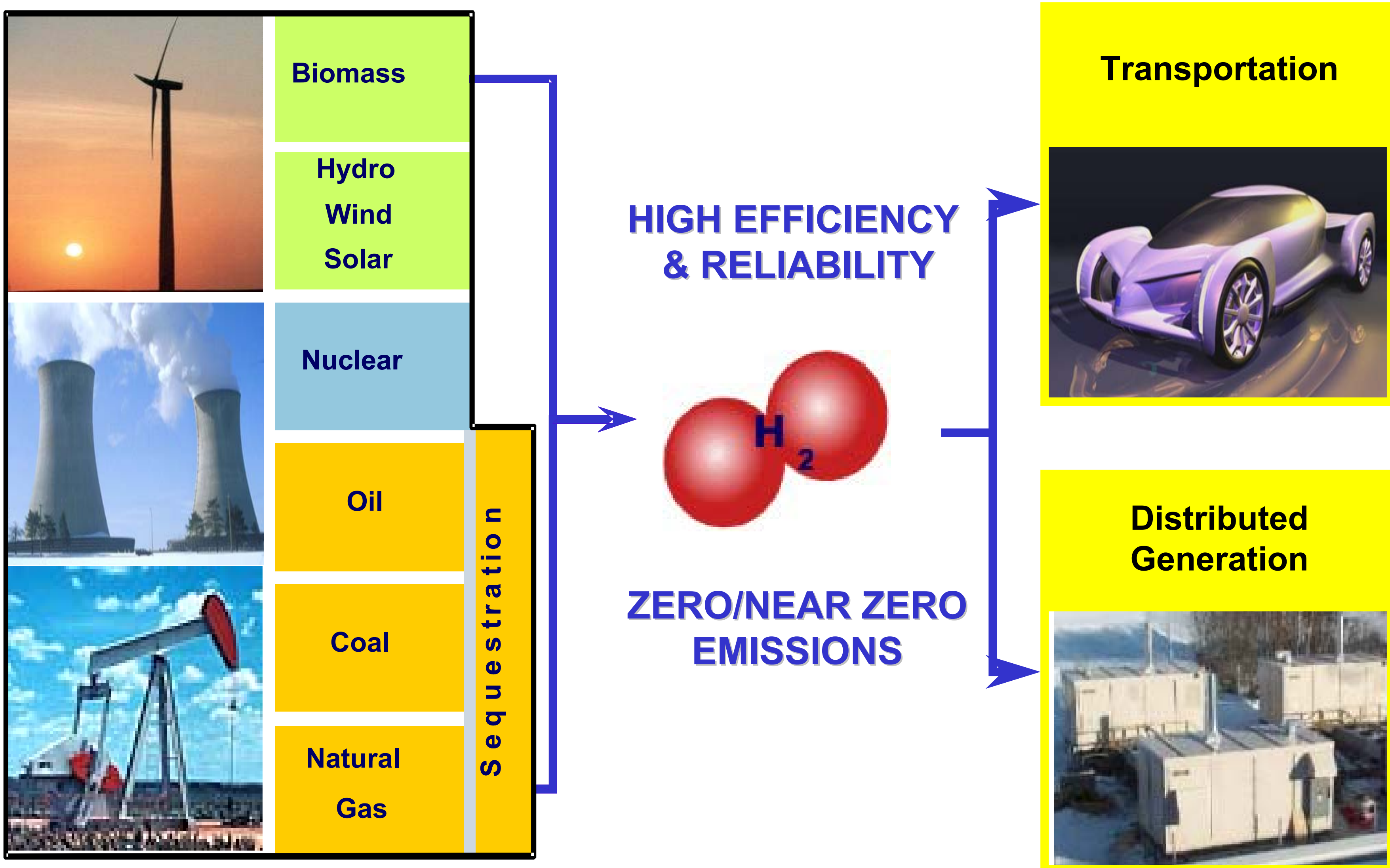
U.S. Department of Energy
Energy Efficiency and Renewable Energy

Why Hydrogen?

Hydrogen from Diverse Domestic Resources



Hydrogen Production and Delivery

Hydrogen Delivery Workshop

Office of Hydrogen, Fuel Cells, and Infrastructure Technologies

May, 2003

U.S. Energy Dependence is Driven By Transportation

U.S. Department of Energy
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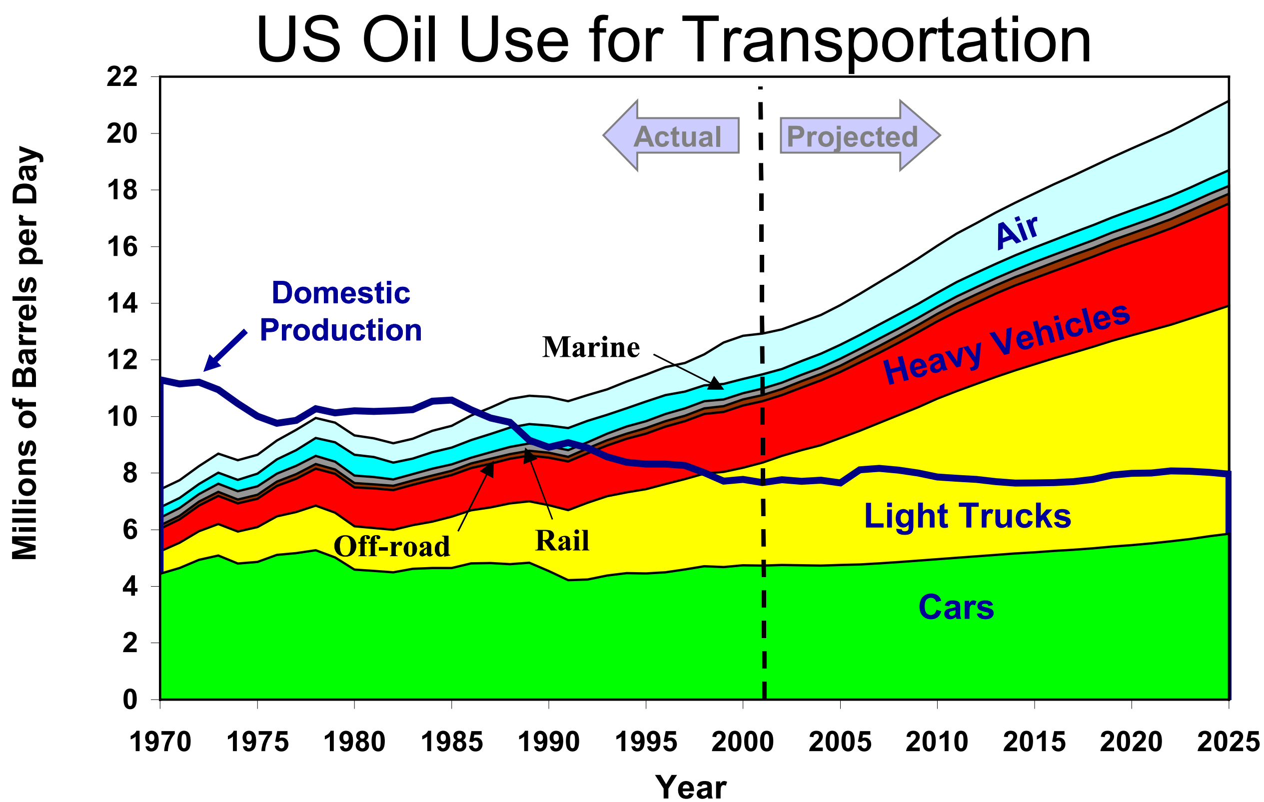
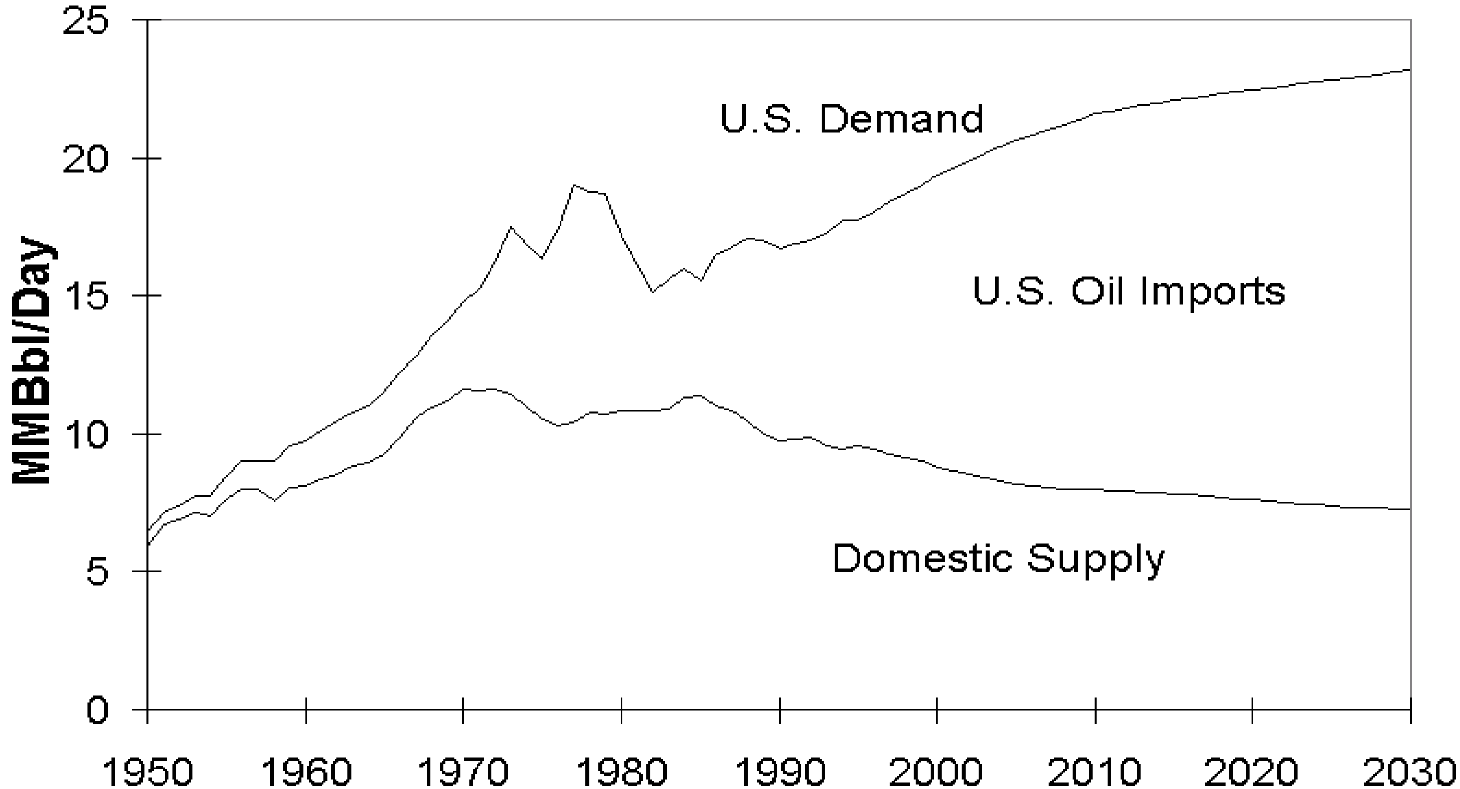


Source: Transportation Energy Data Book: Edition 22, September 2002, and EIA Annual Energy Outlook 2003, January 2003

- Two-thirds of the 20 million barrels of oil Americans use each day is used for transportation
- America imports 55 percent of the oil it consumes, that is expected to grow to 68% by 2025.
- Nearly all of our cars and trucks run on gasoline or diesel.

The National Energy Security Problem



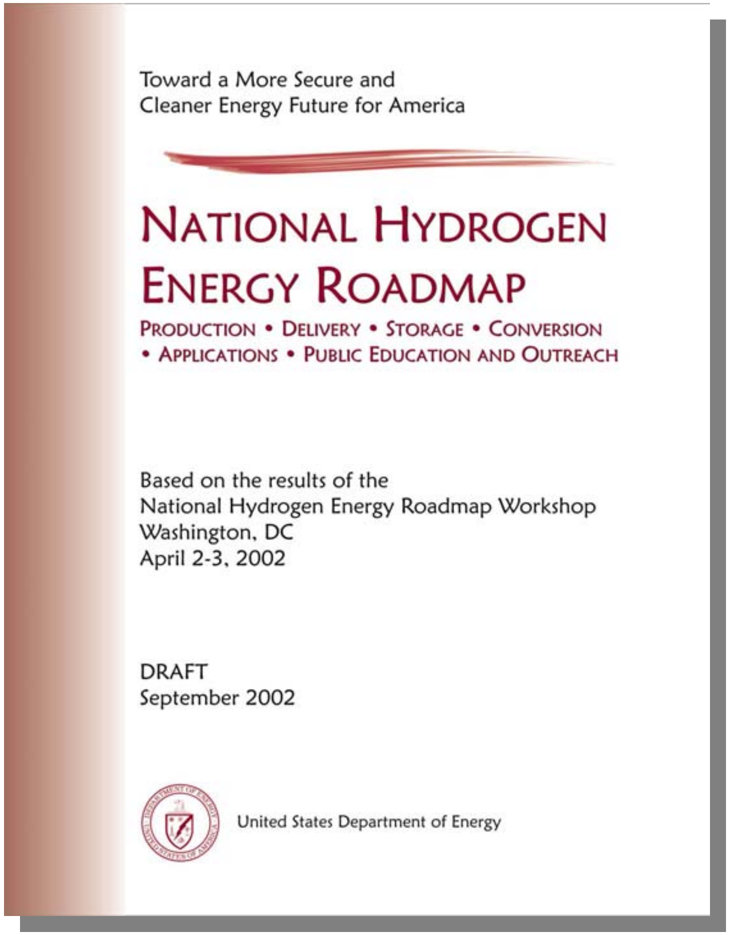
OHFCIT

Develop and validate fuel cells and hydrogen production, delivery, and storage technologies for transportation and stationary applications.

- Dramatically reduce dependence on foreign oil.
- Promote the use of diverse, domestic, and sustainable energy sources.
- Reduce carbon and criteria emissions from energy production and consumption
- Increase the reliability and efficiency of electricity production by utilizing distributed fuel cells

The Roadmap

- **Identifies the "challenges" and "path forward" to realizing vision of a Hydrogen Economy**
  - **System Integration**
  - **Production**
  - **Delivery**
  - **Storage**
  - **Conversion**
  - **Applications**
  - **Education and Outreach**
- **Secretary Spencer Abraham announced release of the final report in November, 2002**



Toward a More Secure and
Cleaner Energy Future for America

NATIONAL HYDROGEN ENERGY ROADMAP

PRODUCTION • DELIVERY • STORAGE • CONVERSION • APPLICATIONS • PUBLIC EDUCATION AND OUTREACH

Based on the results of the
National Hydrogen Energy Roadmap Workshop
Washington, DC
April 2-3, 2002

DRAFT
September 2002

United States Department of Energy

President Bush Announces Accelerated Hydrogen and Fuel Cell Initiative

“Tonight I'm proposing $1.2 billion in research funding so that America can lead the world in developing clean, hydrogen-powered automobiles… With a new national commitment, our scientists and engineers will overcome obstacles to taking these cars from laboratory to showroom, so that the first car driven by a child born today could be powered by hydrogen, and pollution-free.”

- President Bush, January 28, 2003, State-of-the-Union Address

The Fuel Initiative and FreedomCAR

- Fuel Initiative
  - Development of low-cost hydrogen production, delivery, and storage technologies
- FreedomCAR
  - Development of low-cost fuel cells and hybrid component technologies
- Both initiatives directly address energy security
- Both initiatives include DOE partnerships with industry
- President Bush's request commits $1.7 billion over 5 years
  - $1.2 billion for hydrogen and fuel cells
    - $720M in new money
  - $0.5 billion for hybrid and vehicle technologies
- Enables industry commercialization decision by 2015

Fuel Cell Vehicles in the Showroom and Hydrogen at Fueling Stations by 2020

FreedomCAR

Hydrogen, Fuel Cells and Infrastructure Technologies Program

Steve Chalk, Program Manager

Tia Alexander, Administrative Support

Technology Validation Manager - **Sigmund Gronich**

Education and Outreach - **Christy Cooper**

Safety and Codes/Standards - **Neil Rossmeissl**

Hydrogen Production and Delivery

Peter Devlin

Mark Paster
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Arlene Anderson

Hydrogen Storage

JoAnn Milliken

Lucito Cataquiz
1-2 Vacancies

Fuel Cells

Patrick Davis

Donna Ho
Valri Lightner
John Garbak
Kathi Epping
Nancy Garland

OHFIT

- Advanced production technologies
- Advanced hydrogen storage technologies (carbon, hydrides, etc.)
- Safety, performance & connectivity standards for hydrogen fueled devices
- Integrated fuel cell vehicle and hydrogen infrastructure technology validation
- Fuel cell stack component cost reduction (catalyst & membrane) and stationary systems development

Major Activities	**FY02 Approp.**	**FY03 Request**	**FY04 Request**
Hydrogen Production & Delivery	$11M	$12M	$23M
Hydrogen Storage	$6M	$11M	$30M
Safety, Codes & Standards, Education	$6M	$6M	$22M
H2 Infrastructure/FC Vehicle Demo	$6M	$12M	$28M
Fuel Cell Systems & Components	$47M	$56M	$62M
TOTAL	**$76M**	**$97M**	**$165M**

DOE Integration

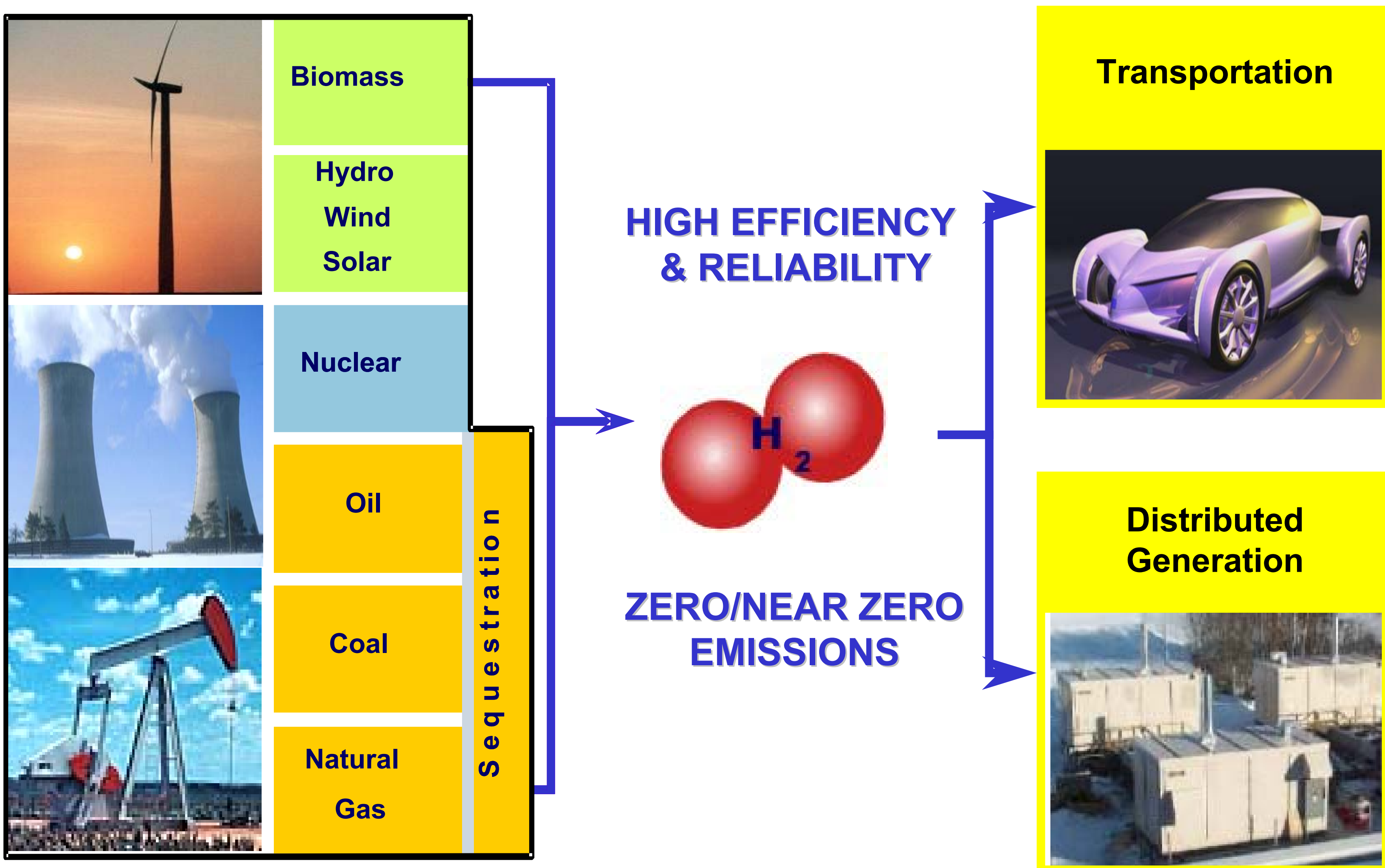
- EERE
  - Office of Hydrogen, Fuel Cells, and Infrastructure Technologies Program
  - Office of Vehicle Technologies Program
  - Biomass, Solar, and Wind Programs
- Fossil Energy
  - Coal
  - Natural Gas
  - Natural Gas Pipelines
- Nuclear Energy
- Office of Science

Extending Collaborations

- Other Federal Agencies
  - DOT, EPA, Others
- International Collaborations

Hydrogen Production

Hydrogen from Diverse Domestic Resources



Production Strategies/Creating Options
(Under development with stakeholders)

- Multiple feedstocks
- End Game
  - Fossil (coal, NG) <u>with sequestration</u>
  - Renewable Feedstocks: Biomass and derivatives, water
  - Renewable/non-carbon emitting energy use: Biomass, wind, solar, nuclear, hydro, geothermal
  - Central and distributed production are likely
- Transition
  - Distributed production (NG, Electrolysis, Biomass derivatives)
  - Central production as risk is reduced

Short Term

- Distributed: NG, Liquids (including biomass derivatives), Electrolysis
- Central NG, Coal and Biomass
- Renewable Power: Wind, Solar, Hydro, Geothermal
- Central Coal with Sequestration and Biomass
- Photolytic: Photovoltaics, Photosynthetic organisms
- Water Splitting Cycles: Nuclear and Solar

Long Term

Draft

OHFCIT: Production Objectives

- Improve the efficiency and reduce the cost of distributed production of hydrogen from natural gas and liquid fuels.

  FreedomCAR Target-70% energy efficiency well-to-pump; cost of hydrogen equivalent to gasoline **($1.50/kg)** by 2010.

- In collaboration with the Office of Fossil Energy, develop advanced reforming, shift, separations and purification technology for hydrogen production.

  By 2015 develop technology to produce hydrogen in a centralized coal based operation for $.79/kg at the plant gate with carbon sequestration.

  Develop advanced OTM, HTM, technology, advanced reforming and shift technology for application to central fossil (with sequestration), central biomass and distributed production of hydrogen.

Draft

OHFCIT: Production Objectives

- Develop advanced low cost technologies for producing hydrogen from biomass (gasification/pyrolysis, fermentation).

  Demonstrate technology that projects to \$2.60/kg of hydrogen by 2010 with the long term goal of being competitive with gasoline.

- Develop advanced renewable photolytic hydrogen generation technologies.

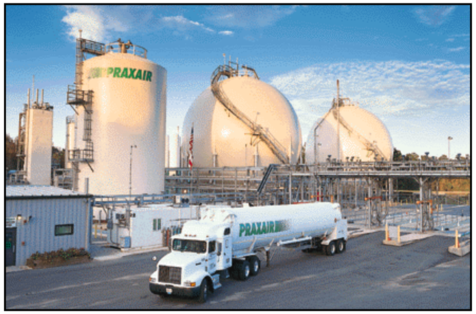
  By 2015 demonstrate biological technology that projects to a cost of \$10/kg at the plant gate and photoelectrochemical technology that projects to \$5/kg at the plant gate.

- Develop highly efficient and lower cost water electrolyzer systems capable of producing 5000 psi of compressed hydrogen at \$300/kWe at 240 kg/day by 2008 at \$2.50/kg of hydrogen.

OHFCIT: Production Objectives

- Research and develop high and ultra-high temperature processes to produce hydrogen through chemical cycle-water splitting technology or other non-carbon-emitting technology utilizing heat from nuclear or solar sources.

By 2015, demonstrate technology that is competitive with gasoline.



Hydrogen Delivery: Goal

Gaseous
- Pipeline
- Truck
- Onsite reforming

Liquid H_2 & Chem. Carriers
- Liquid H_2
  - Pipeline
  - Truck
  - Rail
- Hydrides
- Other Carriers

Develop *hydrogen fuel delivery* technologies that enable the introduction and long-term viability of hydrogen as an energy carrier for transportation and stationary power.

Delivery Options

- End Game
  - Pipeline Grid
  - Other as needed for remote areas
    - Breakthrough Hydrogen Carriers
    - Truck: HP Gas & Liquid Hydrogen
  - Electrolysis and Distributed reforming of NG, Renewable Liquids (e.g. ethanol etc.)
- Transition
  - Electrolysis and Distributed reforming of NG, Renewable Liquids (e.g. ethanol etc.)
  - Truck: HP Gas & Liquid Hydrogen
  - Regional Pipeline Grids
  - Breakthrough Hydrogen Carriers

Delivery

Key Challenges

- Pipelines
  - Retro-fitting existing NG pipeline for hydrogen
  - Utilizing existing NG pipeline for Hythane
  - New hydrogen pipeline: lower capital cost
- Lower cost and more energy efficient compression technology
- Lower cost and more energy efficient liquefaction technology
- Novel solid or liquid carriers

Objectives

- By 2006, define a cost effective and energy efficient fuel delivery infrastructure for the introduction and long-term use of hydrogen for transportation and stationary power.

- By 2010, develop enabling technologies to reduce the cost of hydrogen fuel delivery from central/semi-central production facilities to the gate of refueling stations and other end users to <$0.70/kg.

- By 2010, develop enabling technologies to reduce the cost of hydrogen movement and handling within refueling stations and stationary power facilities to a vehicle or stationary power unit to <$0.60/kg.

- By 2015, develop enabling technologies to reduce the cost of hydrogen fuel delivery from the point of production to the point of use in vehicles or stationary power units to <$1.00/kg in total.

Key Delivery Milestones

- 2Q 2005: Complete definition of a cost effective hydrogen fuel delivery infrastructure for the introduction and long term use of hydrogen for transportation and stationary power
- 4Q 2008: Verify 20% cost reduction for hydrogen compression
- 4Q 2010: Verify 50% cost reduction for hydrogen liquefaction
- 4Q 2010: Verify 50% reduction in capital cost for hydrogen pipelines

Draft

Targets

Characteristics	Units	2003 status	2005	2010
Gaseous Hydrogen Compression				
Cost	\$/kg H_2	0.18	0.17	0.14
Energy efficiency	%	90	92	95
Hydrogen Liquefaction				
Cost	\$/kg H_2	1.11	1.01	0.53
Energy efficiency	%	65	70	87
Hydrogen Gas Pipelines				
Trunk lines	\$/mile	1.4M	1.2M	600k
Distribution lines[d]	\$/mile	600k	500k	350k
Hydrogen Carrier Technology				
Hydrogen Content	% by wt	3	6.5	10
Energy efficiency	%	80	82	85