
Addressing America's Petroleum Dependence



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U.S. Department of Energy

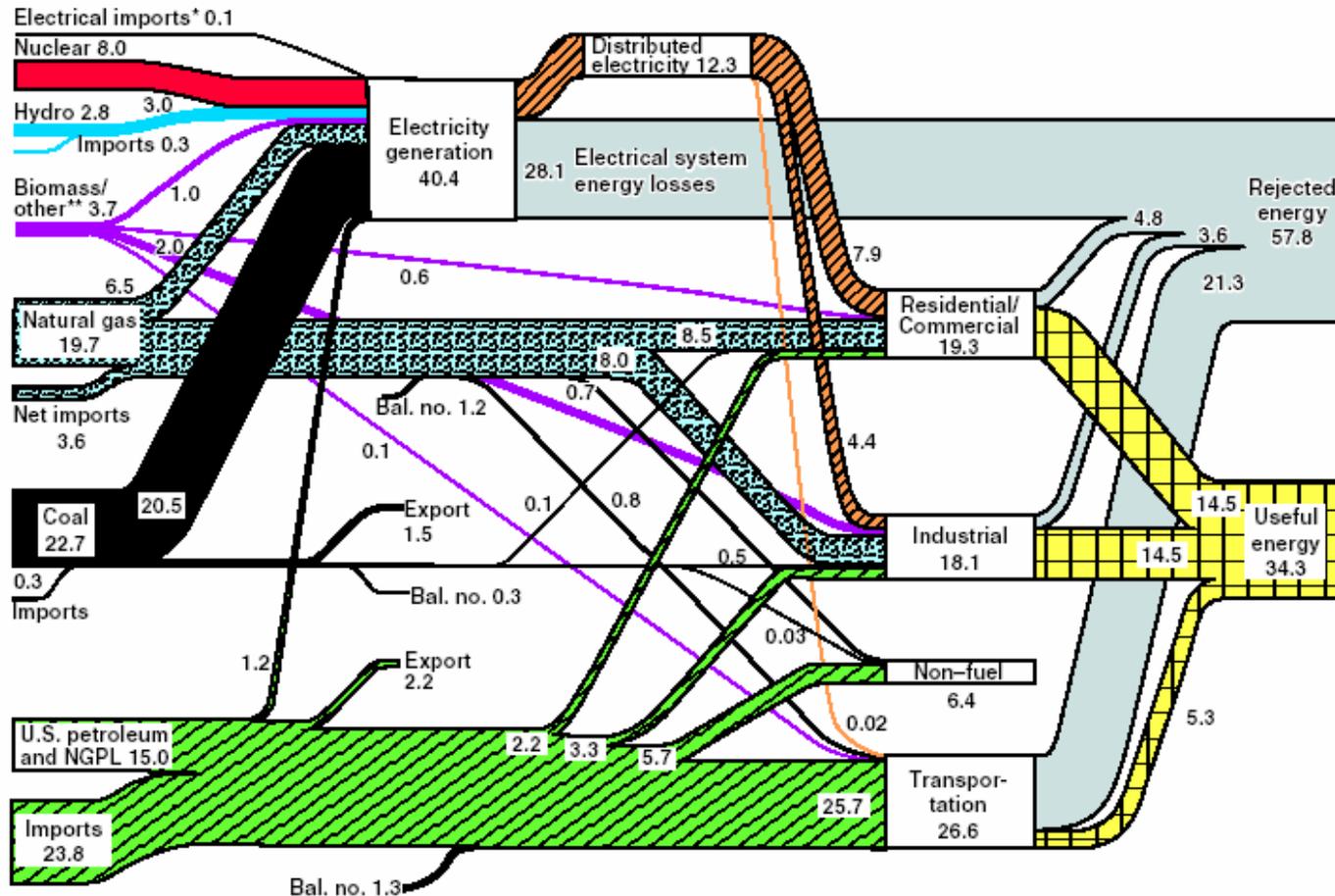
Policy Context



“Keeping America competitive requires affordable energy. And here we have a serious problem: **America is addicted to oil**, which is often imported from unstable parts of the world. The best way to break this addiction is through technology.”

President Bush, 2006
State of the Union Address

Policy Context



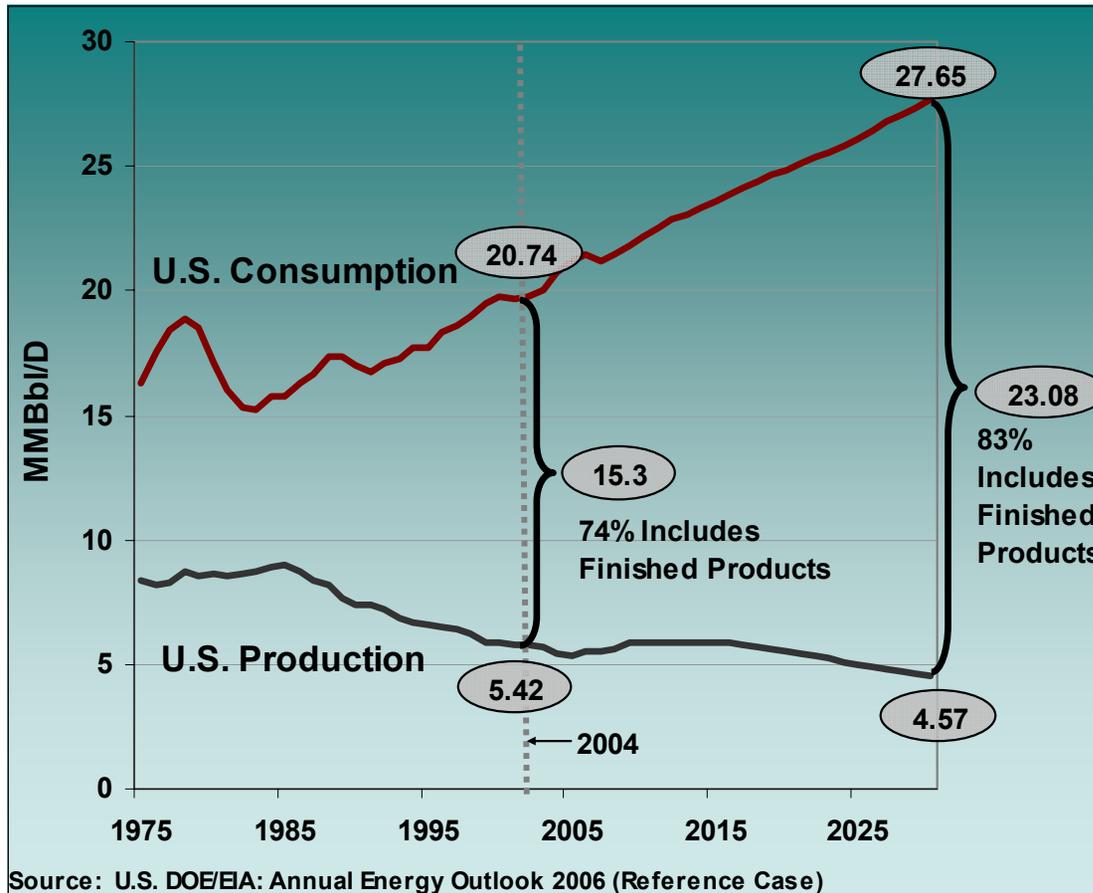
Source: Production and end-use data from Energy Information Administration, *Annual Energy Review 2000*

*Net fossil-fuel electrical imports

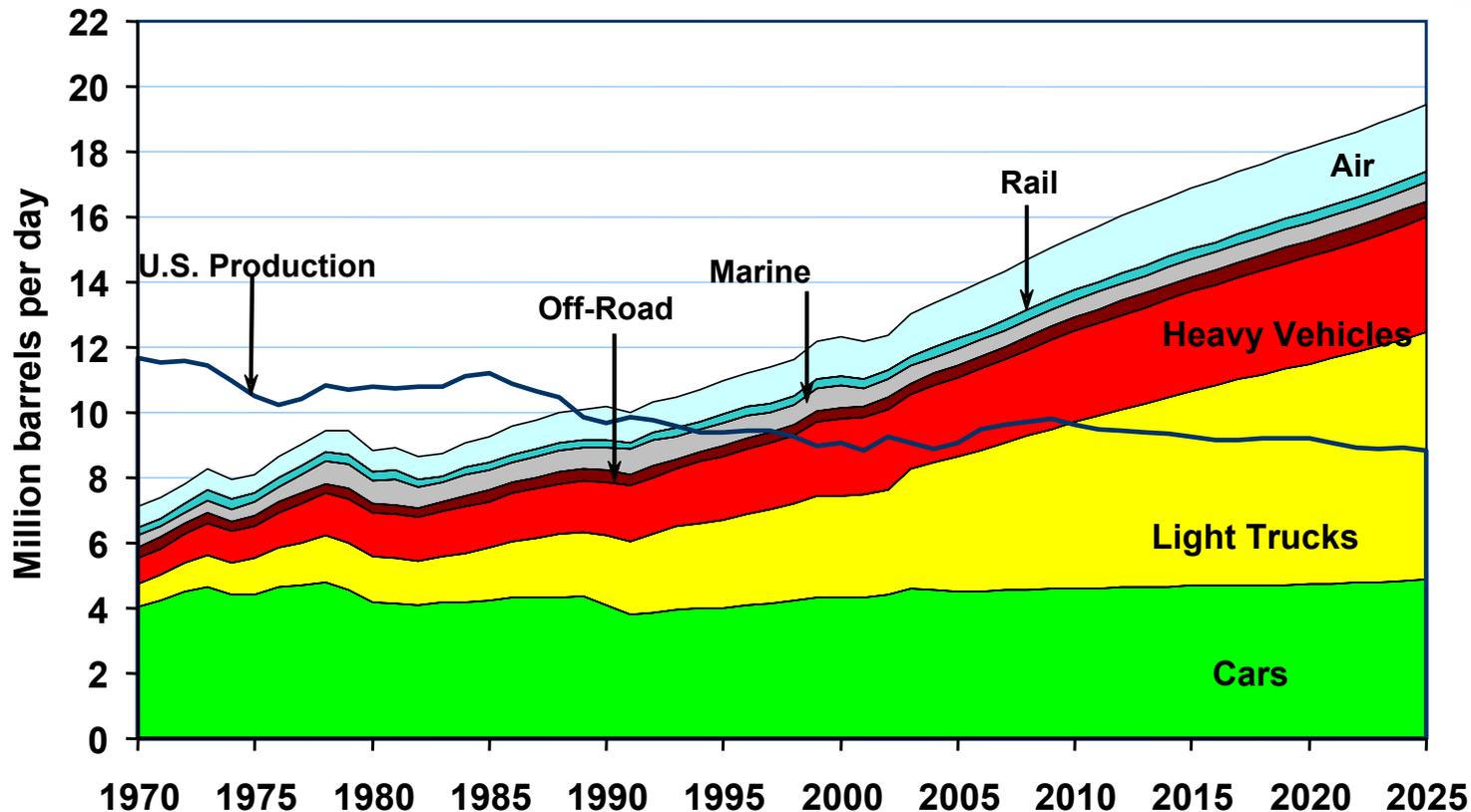
**Biomass/other includes wood and waste, geothermal, solar, and wind.

December 2001
Lawrence Livermore
National Laboratory

Policy Context



Policy Context



- Transportation accounts for 2/3 of the 20 million barrels of oil our nation uses each day.
- The U.S. imports 55% of its oil, expected to grow to 68% by 2025 under the status quo.
- Nearly all of our cars and trucks currently run on either gasoline or diesel fuel.

Partial Menu of Options



- Promoting Efficiency
 - Fuel Economy Standards
 - Intelligent Transportation Systems
 - **Advanced Vehicle Technologies**
- New/Enhanced Conventional Supply
 - **Arctic National Wildlife Refuge**
 - Outer Continental Shelf
 - Enhanced Oil Recovery

Partial Menu of Options



- Unconventional Supply
 - Oil Shale
 - Tar Sands
 - Coal to Liquids
 - Gas to Liquids
- New Fuels
 - Ethanol (grain based and cellulosic)
 - Biodiesel
 - Hydrogen

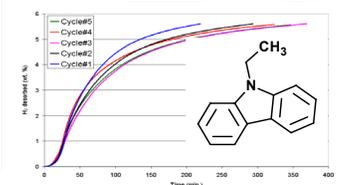
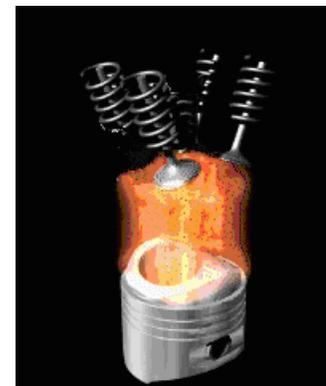
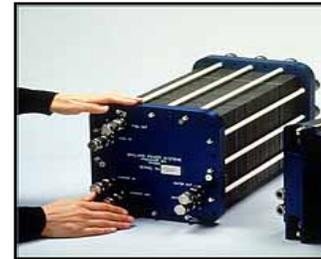
Vehicle Technologies and Hydrogen



Vehicle Technology Portfolio (Partial)



- Hydrogen and Fuel Cells
- Hybrid and Electric Drive
- Batteries
- Power Electronics
- Lightweight Materials
- Advanced Combustion
- Fuels



Partnerships



ExxonMobil



ConocoPhillips

DAIMLERCHRYSLER

“A big strength of the FreedomCAR and Fuel Partnership is that... it is organized around joint industry/government research teams.”

NAS/NRC Review of the Research Program of the FreedomCAR and Fuel Partnership, August 2005

Partnerships



**International Partnership for the
Hydrogen Economy**



**Carbon Sequestration
Leadership Forum**



Hydrogen Production



Coal

- Only with carbon capture & sequestration
- Gasification process produces hydrogen directly
- Electricity not produced as an intermediary

Distributed Natural Gas

- Transition strategy
- “Well-to-wheels” greenhouse gas emissions substantially less than gasoline hybrid-electric vehicle
- Not a long-term source for hydrogen (imports and demand in other sectors)

Nuclear/Renewable

- Electrolysis (one option)
- Electricity not necessarily produced as an intermediary, options being pursued include:
 - Gasification of biomass
 - Reforming of renewable liquids
 - Photoelectrochemical
 - Photobiological
 - Thermochemical (solar and nuclear)



Hydrogen

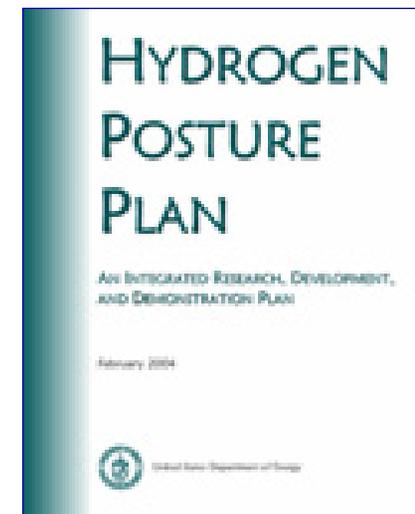


Critical Path Technology Barriers:

- Hydrogen Cost (\$2.00 - 3.00 per gge)
- Fuel Cell Cost (\$30 per kW)
- Hydrogen Storage (>300-mile range)

Economic/Institutional Barriers:

- Codes and Standards (Safety, and Global Competitiveness)
- Hydrogen Delivery (Investment for new Distribution Infrastructure)
- Education

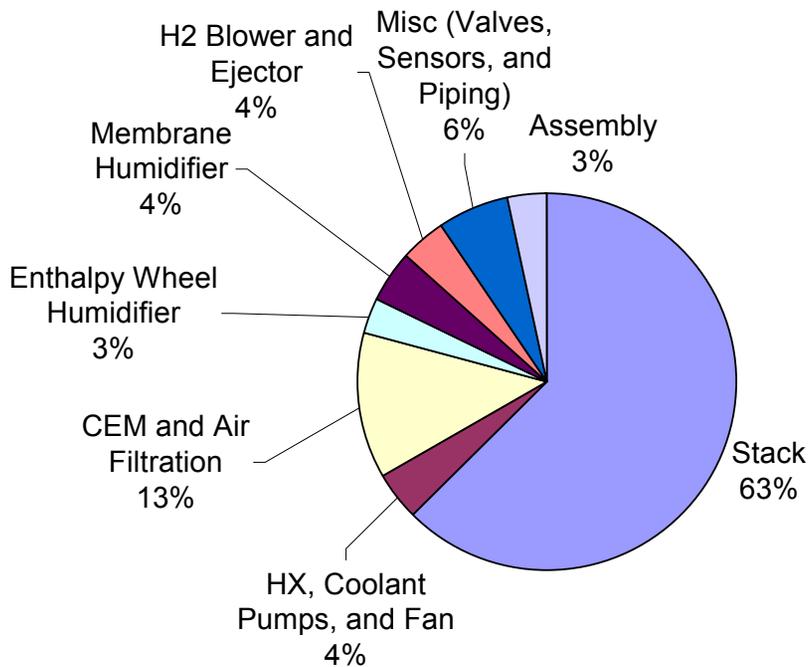


www.hydrogen.energy.gov/pdfs/hydrogen_posture_plan.pdf

Fuel Cell Cost



- High Volume Fuel Cell Cost Estimate: \$110/kW (from \$275/kW in 2002; \$225/kW in 2003; \$200/kW in 2004) (TIAX, LLC)
- Current materials and lab performance scaled up to 500,000 units per year (assumes high volume manufacturing processes are available)



2005 Key Assumptions		
Power density	mW/cm ²	600
Cell voltage	V	0.65
Net power	kW _e	80
Gross power	kW _e	90
Production volume	units/yr	500,000
Pt cost	\$/g (\$/troy)	29 (900)
Pt loading	mg/cm ²	0.75

Technology Validation



- Obtain detailed component data under real-world conditions to re-focus the Department's hydrogen and fuel cell component and materials research
- Validate the technology against time-phased performance-based targets, by 2009
 - 2,000 hour fuel cell durability
 - \$3.00 per gge (high cap fac., vol.mfg)
 - 250 mile range



Key 2006 Hydrogen Goals



Systems Integration

- Independent verification of achievement of \$3.00/gge of hydrogen from distributed natural gas
- Independent validation of achievement of \$110/kW for PEM fuel cells at high production volume
- Independent assessment of cryo-compressed technology for on-board storage against 2010 targets
- Go/No-go decision on 6 wt.% (material) on single walled carbon nanotubes

Other Initiatives

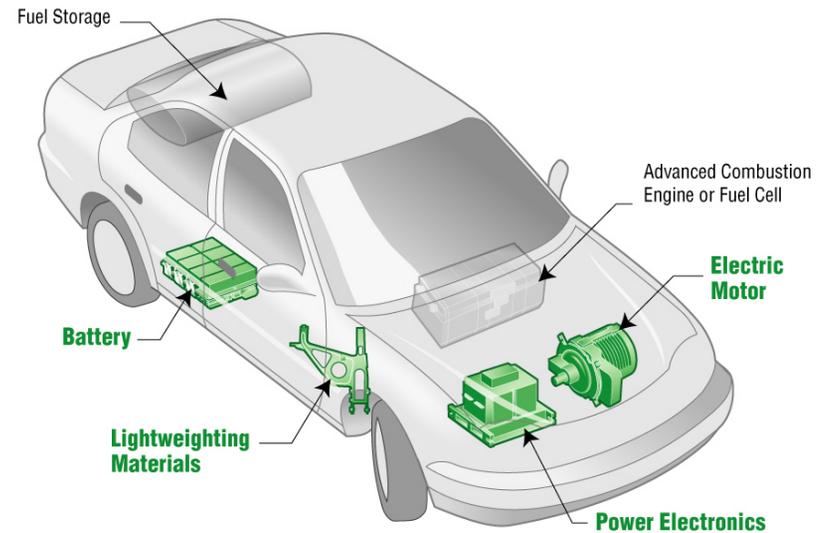
- Manufacturing Roadmap
- Hydrogen Quality (x-cut)
- Advisory Panel (HTAC)

It's Not Just About Hydrogen



- Common Elements in a Hydrogen Fuel Cell and Hybrid-Electric Vehicle

- Advanced battery
- Lightweight materials
- Electric drive
- Power electronics



Battery RD&D



- Advanced NiMH battery technology to the point of commercialization feasibility.
- Every hybrid vehicle sold in the U.S. today, including those by foreign manufacturers, contains elements of battery technology licensed from one of DOE's battery research partners. Technology licensed to major battery developers (Sanyo, Panasonic).
- COBASYS is also selling HEV NiMH batteries developed under USABC contract.
- LBNL invented lithium sulfur battery technology now being used by PolyPlus to develop a high-energy lithium metal battery under a USABC contract.



Lithium Ion Battery Advances



SAFT

Increased HEV cell performance (18 sec discharge)

	1999	2004
Specific Power (W/kg)	1,344	1,636
Power Density (W/l)	2,785	3,385



- In 1999, baseline 25 kW battery system cost \$1,750 (\$70/kW), based on 100,000 batteries/annually. In 2005, reduced this cost to \$875 (\$35/kW).
- Two SAFT 25 kW systems achieved 300,000 cycle life.
 - Systems used to validate Hardware-in-the Loop (HIL) testing at ANL Center for Transportation Research.
 - Cells demonstrated more than 1,000,000 cycle life.



Johnson Controls Inc., Milwaukee, Wisconsin, inaugurated a new limited prototype production facility to develop lithium ion batteries for hybrid electric vehicles on September 28, 2005.

Key 2006 Vehicle Tech Goals



- **Advanced Combustion**
 - Light-duty engines will reach 41 percent thermal efficiency at Tier 2 emissions levels and heavy-duty engines will reach 50 percent efficiency while meeting EPA 2010 emissions.

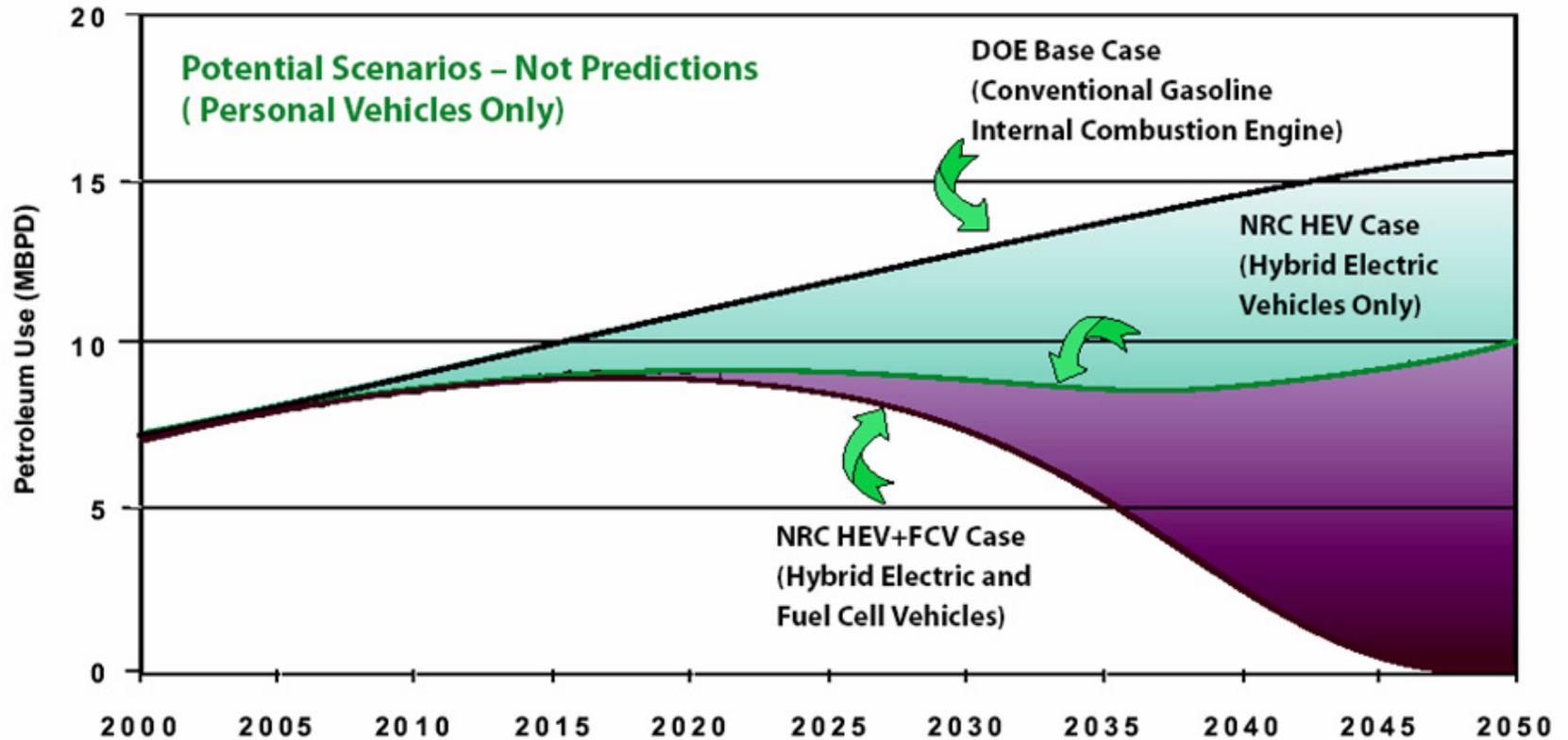
- **Vehicle Systems Electrochemical Energy Storage**
 - An intermediate goal of the Hybrid and Electric Propulsion R&D subprogram is to reduce, by 2006, the production cost of a high power 25kW battery for use in light hybrid vehicles from \$3,000 in 1998 to \$750.

- **Fuels**
 - Provide the energy industry with critical information on the effects of blending biodiesel with diesel fuel.

- **Materials**
 - Complete R&D on technologies which, if implemented in high volume, could reduce the price of automotive grade carbon fiber to less than \$3 per pound (modeled).

- **Technology Introduction**
 - Develop on line guidance for filing fuel petitions for EPA Act Consideration and further define environmental and energy security benefits of new fuels under consideration.

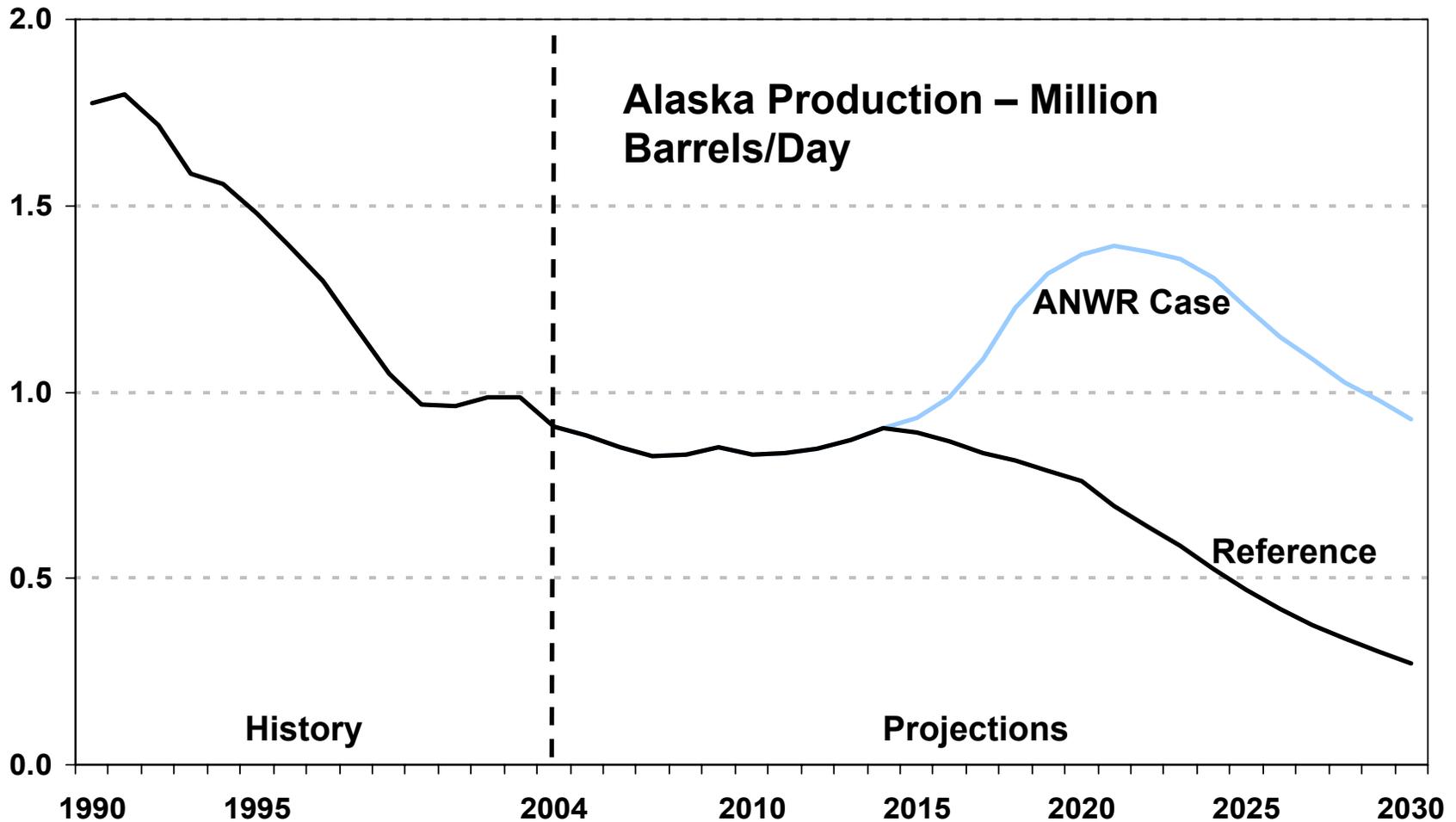
Petroleum Displacement Scenarios



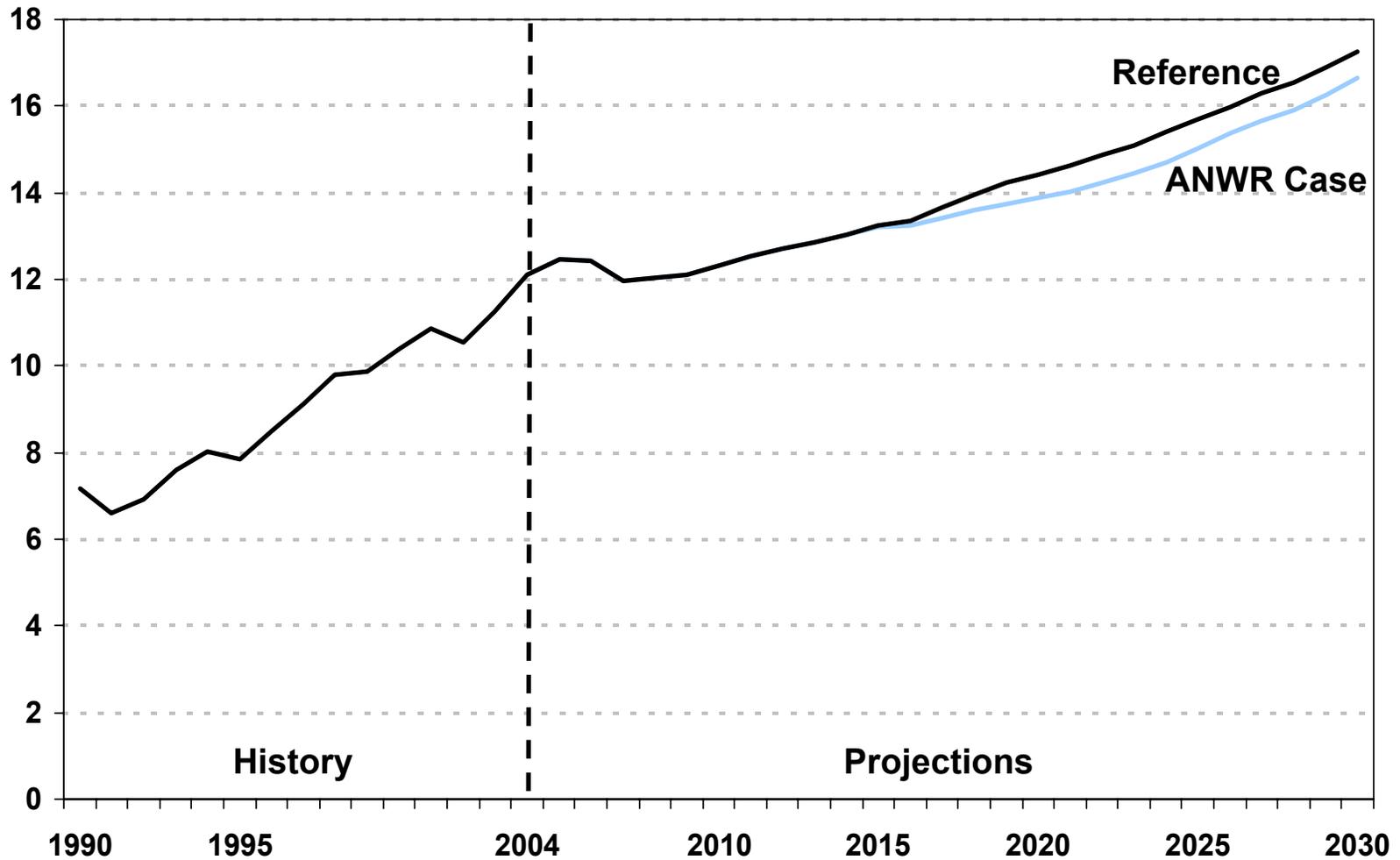
ANWR



Arctic National Wildlife Refuge



Arctic National Wildlife Refuge

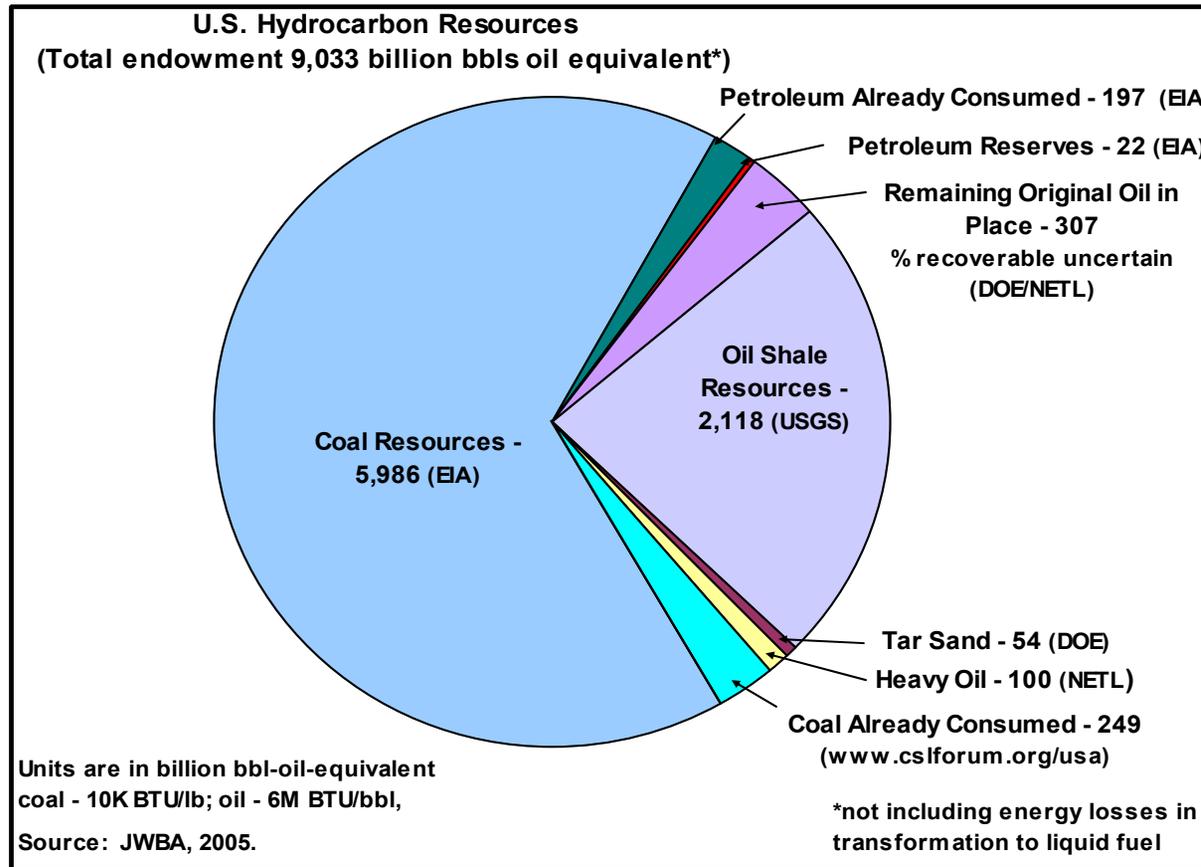


Unconventional Hydrocarbons



-
- Coal to Liquids
 - Oil Shale
 - Gas to Liquids

America's Endowment of Solid and Liquid Fuels Resources



Approximate Liquid Fuel Yields



- Coal to Liquids: One ton of coal can yield approximately 2 barrels of premium liquid fuel
- Gas to Liquids: 10,000 standard cubic feet of gas can yield approximately 1 barrel of premium liquid fuel
- Tar Sands: One ton of material can yield approximately one barrel of “oil.”
- Oil Shale: One ton of material can yield approximately 25 gallons of “oil.”

Coal to Liquids



● Experience

- Sasol Fischer-Tropsch (FT) plants in South Africa
- China Shenhua Sasol Feasibility studies for two large FT CTL plants
- China Shenhua Direct Liquefaction Plant
- No large scale plants yet built with advanced technology
- 1990's Bechtel Study: \$4 billion for modern, FOAK 50,000 bbl/day plant.
- Current estimates of CTL fuel production cost indicate profitable operations for full-scale plants when crude oil prices are between \$40-\$55/barrel.

Coal to Liquids



● Challenges

- Large scale integration of modern technology has not occurred
- CO₂ and criteria pollutant emissions
- High capital and operations costs amid uncertainties about future world oil price
- Most efficient CTL plant designs use tail gas for electricity production. Business models for liquid fuels/electricity co-production are untested.

Coal to Liquids



- Even if we assume 200,000 barrels of new capacity can be brought on line each year in the U.S., a 2 million barrel/day CTL industry is at least 20 years away



● Projected Costs

- Shell believes \$25-\$30 barrel equivalent may be possible (in-situ)
- RAND estimates that mining and surface retorting techniques will require crude prices in the range of \$70-\$95/barrel for the FOAK 50,000 BPD operation to be profitable. With learning, RAND estimates that the price could drop by 50% after 500 million barrels have been produced



● Challenges

● Surface Retorting

- CO₂ emissions from both HC processing and decomposition of carbonate matrix
- Water consumption, waste management, land disturbance, reclamation

● In-Situ Production

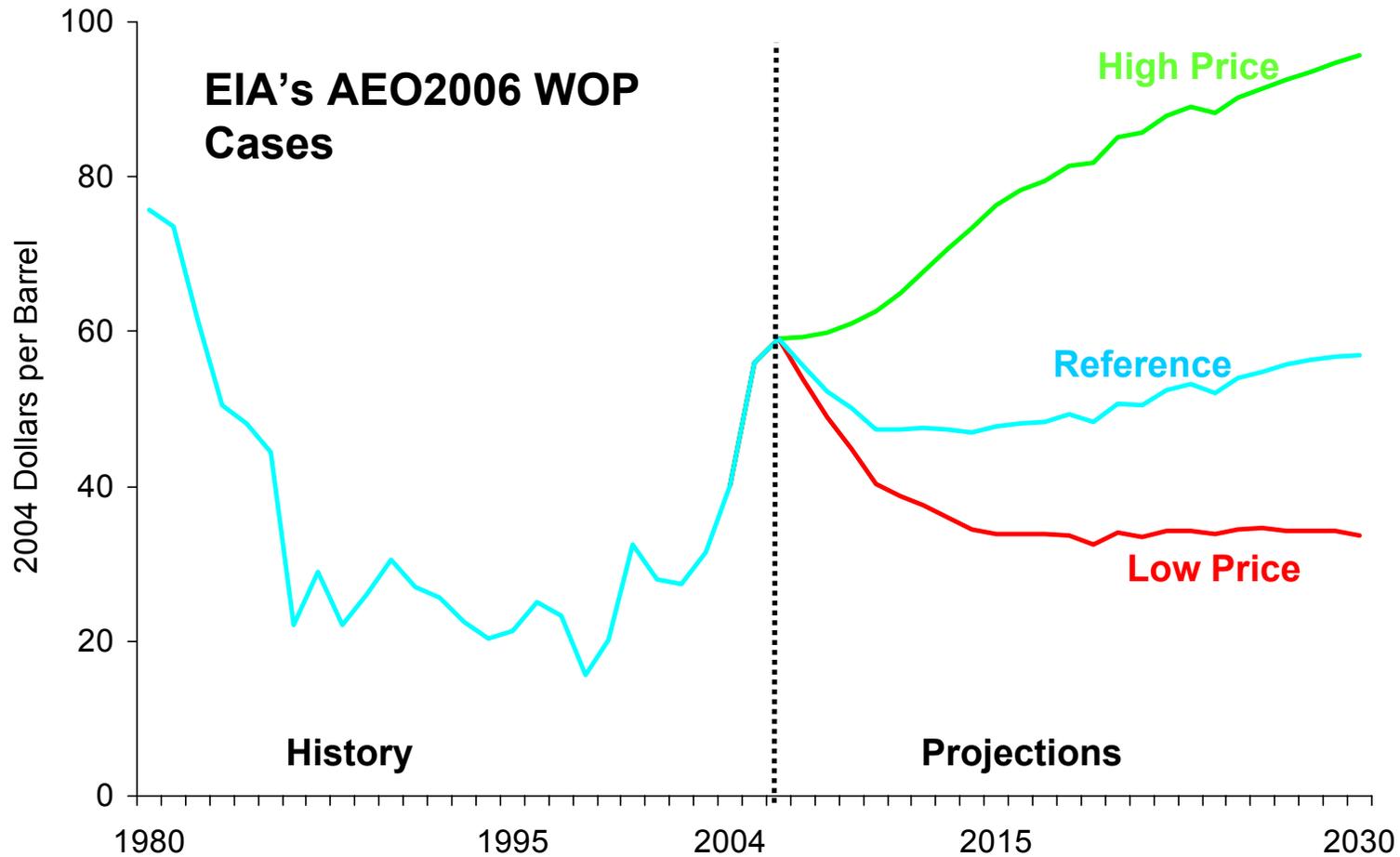
- CO₂ emissions from expanded electric power requirements
- Prediction of underground product and potential pollutant flows
- Controlling and monitoring groundwater

Gas to Liquids

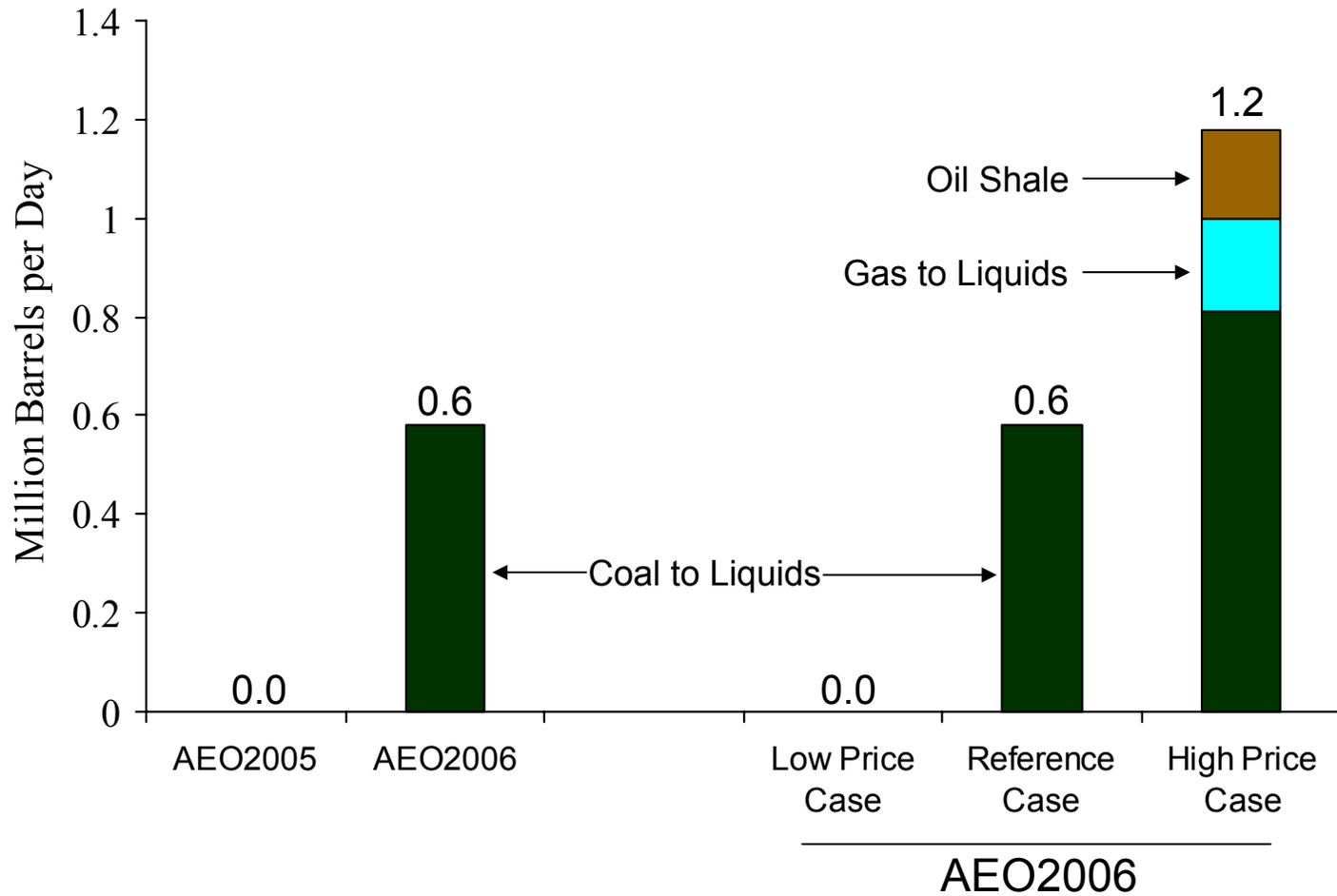


- Gas to Liquids (GTL) technology is commercially proven
- Exxon-Mobil, Shell and Sasol are planning plants in Qatar and Nigeria where natural gas is available at less than \$1/million BTUs.

Policy Context



Unconventional Liquids - 2025



Source: EIA, AEO2006 Note: Biofuels excluded

My Conclusions

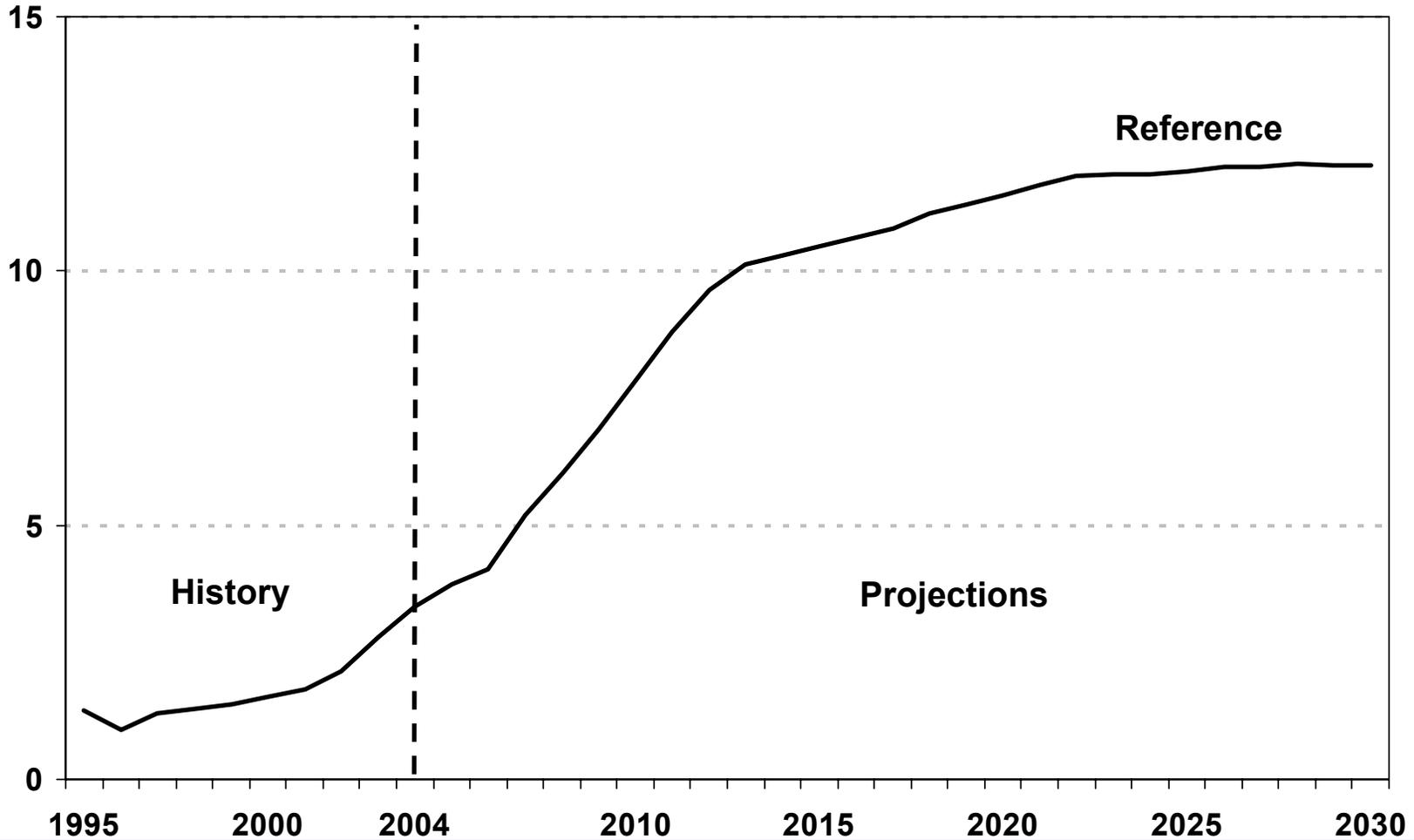


- We need to take a serious look at *all* the items on the menu.
- Efficiency is critically important.
- Hydrogen remains the ultimate opportunity, and worth pursuing even if it takes some time.
- Biofuels can make an important contribution.
- Meanwhile, we need to get our hydrocarbons the best way we can, mindful of the practical limitations on the water we can divert, the carbon we may emit, and various other environmental/economic/social considerations.



Background Slides

EIA Estimates of Ethanol Fuel Consumption 1995-2030



FreedomCAR Goals



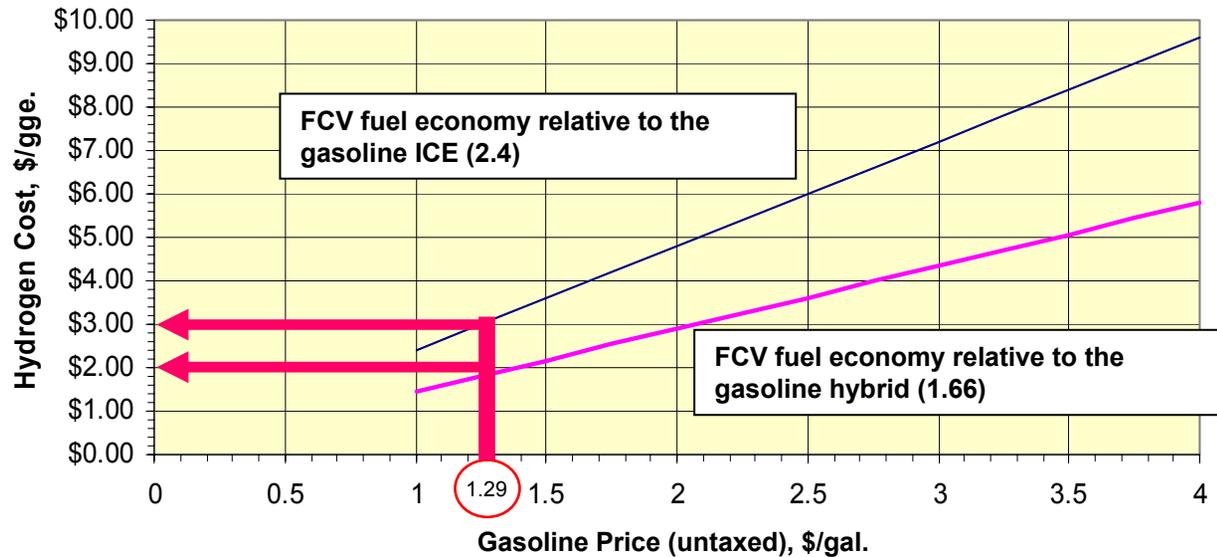
- Electric propulsion system with a 15-year life capable of delivering at least 55 kilowatts (kW) for 18 seconds, and 30 kW continuous at a system cost of \$12/kW peak
- 60% peak energy-efficient, durable fuel cell power system (including hydrogen storage) that achieves a 325 watts per kilogram (W/kg) power density and 220 watts per liter (W/L) operating on hydrogen. Cost targets are at \$45/kW by 2010 (\$30/kW by 2015)
- Internal combustion engine powertrain systems costing \$30/kW, having a peak brake engine efficiency of 45%, and that meet or exceed emissions standards
- Demonstrated hydrogen refueling with developed commercial codes and standards and diverse renewable and nonrenewable energy sources. Goal: Cost of energy from hydrogen equivalent to gasoline at market price, assumed to be \$2-\$3/gge produced and delivered to the consumer independent of pathway by 2015.
- Onboard hydrogen storage systems demonstrating specific energy of 2.0 kWh/kg (6 weight percent hydrogen), and energy density of 1.5 kWh/liter at a cost of \$4/kWh by 2010 and specific energy of 3.0 kWh/kg (9 weight percent hydrogen), 2.7 kWh/liter, and \$2.00/kWh by 2015
- Internal combustion engine powertrain systems operating on hydrogen with a cost target of \$45/kW by 2010 and \$30/kW in 2015, having a peak brake engine efficiency of 45%, and that meet or exceed emissions standards.
- Material and manufacturing technologies for high-volume production vehicles that enable or support the simultaneous attainment of:
 - 50% reduction in weight of vehicle structure and subsystems
 - Affordability, and
 - Increased use of recyclable/renewable materials.

Hydrogen Cost



Hydrogen Cost Goal Logic

(Equivalent \$/mi. for consumer)



EIA projected gasoline price in 2015 based on HIGH "A" case

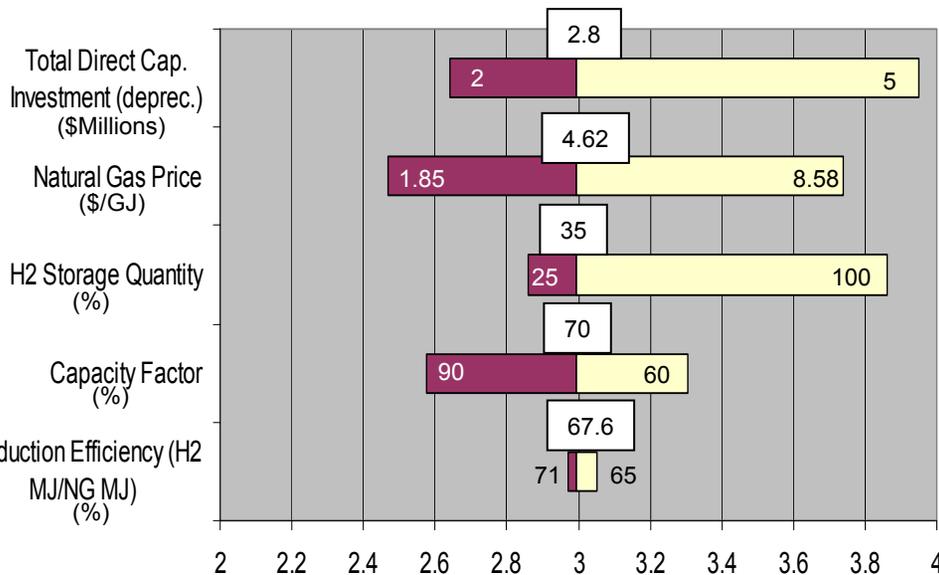
Note: The fuel economy ratios from NRC report

Hydrogen Cost

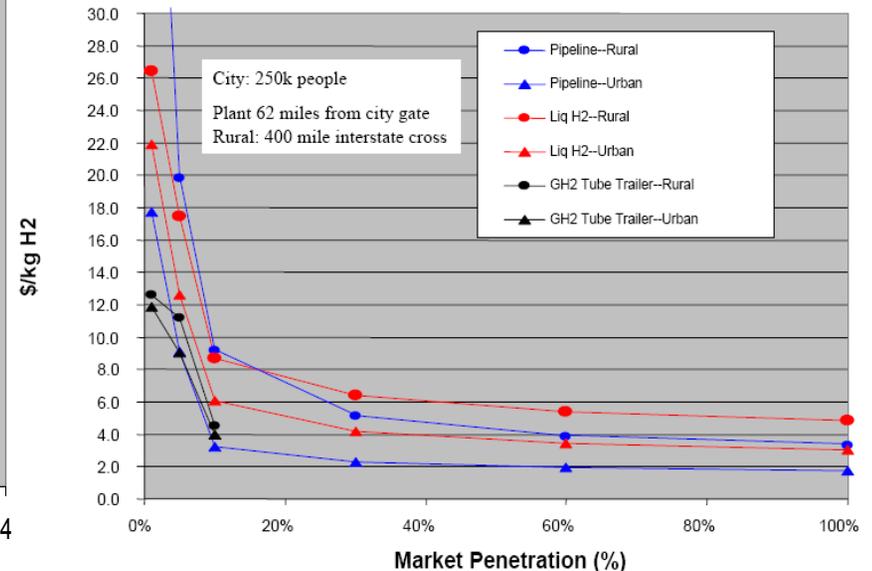


- H2A Model bringing consistency and transparency to hydrogen analysis at the system, technology or component level in terms of cost, performance, benefit and risk impact.

H2 Cost (\$/gge) Sensitivity for Distributed NG



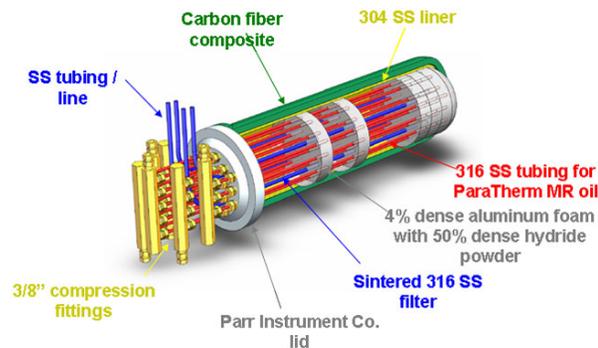
Delivery Costs (\$/gge) vs. Market Penetration



Recent Technical Success (Hydrogen Storage)

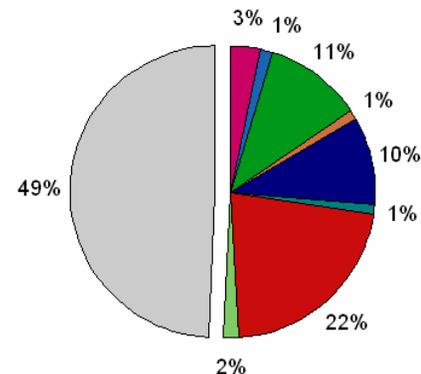


1st Gen System Prototype



- Preliminary 1-kg hydrogen system prototype developed based on sodium alanate
- With composite vessel, ~50% of system is balance of plant

- Prototype gravimetric & volumetric capacity reinforce need for high-capacity materials
- Thermal management, and reaction kinetics strongly impact weight & volume



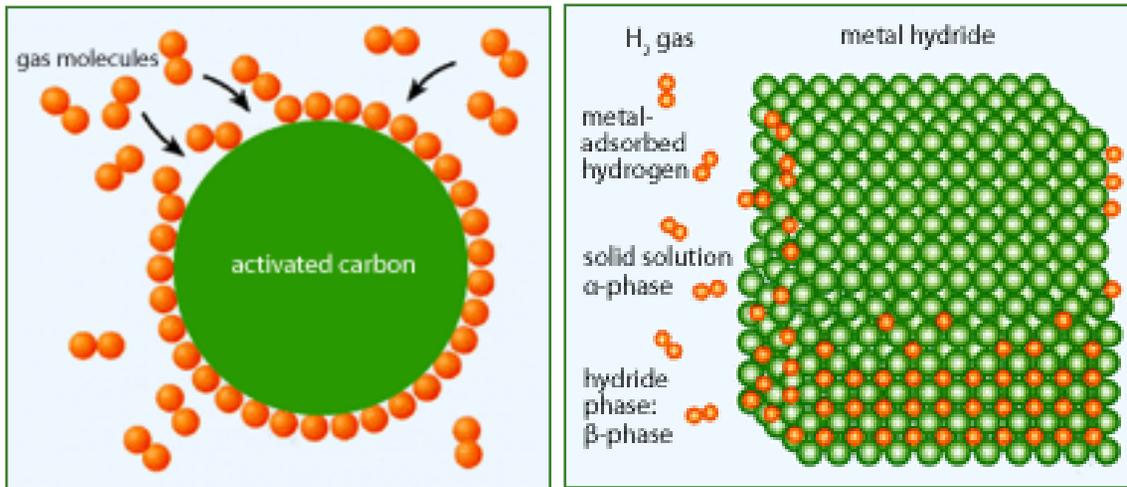
660 Wh / kg
530 Wh / L

Anton, Moser et al, UTRC

Hydrogen Storage



Hydrogen storage system must allow a 300+ mile driving range without compromising vehicle weight or occupant/storage space



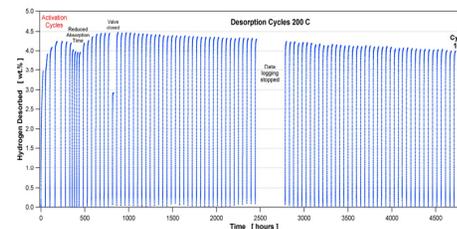
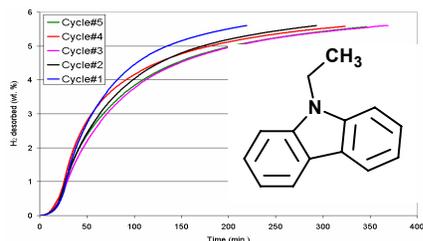
Materials-based storage may make it possible to store larger quantities of hydrogen in smaller volumes at low pressure and near room temperature. Hydrogen can be stored in materials via *adsorption* (far left), *absorption* (center), or *chemical reaction*.

Recent Technical Success (Hydrogen Storage)



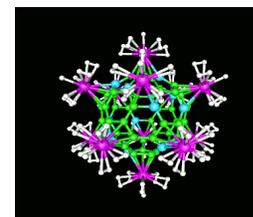
High Capacity Materials > 5 wt%

- Mg modified Li-amides: 5 wt% reversible (material) capacity, with potential to 10 wt%. Absorption demonstrated down to 180C, >100 cycles demonstrated (**Luo, Wang, Gross et al, SNL**)



- Identified chemical hydride with 5.5 - 7 wt% materials storage capacity (**Cooper, Pez et al, APCi**)

- Optimum compounds predicted for potential storage materials ~ 6 to 8 wt% material (**Heben, Dillon et al NREL**)



Recent Technical Successes (Hydrogen Production)



Distributed Natural Gas Reforming

Approaching R & D target of \$3/gge for distributed natural gas reforming at 5000 psi.



**GE High-Pressure
Autothermal Cyclic
Reforming Reactor**

Electrolysis

Developed new system designs with 40-50% part count reduction. Novel stack design for alkaline system on track for achieving a hydrogen production cost \$2.85/gge by 2010



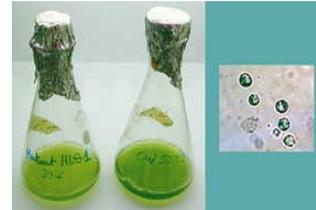
**Teledyne HP TITAN™
HP generator**

Recent Technical Successes (Hydrogen Production)



Biological

40-50% increase in oxygen tolerance achieved



Measuring
photosynthetic
productivity of
micro-algae
(NREL)

Photolytic Energy Conversion

Projected 1000 hours durability with new
gallium phosphide nitride material based on
accelerated testing



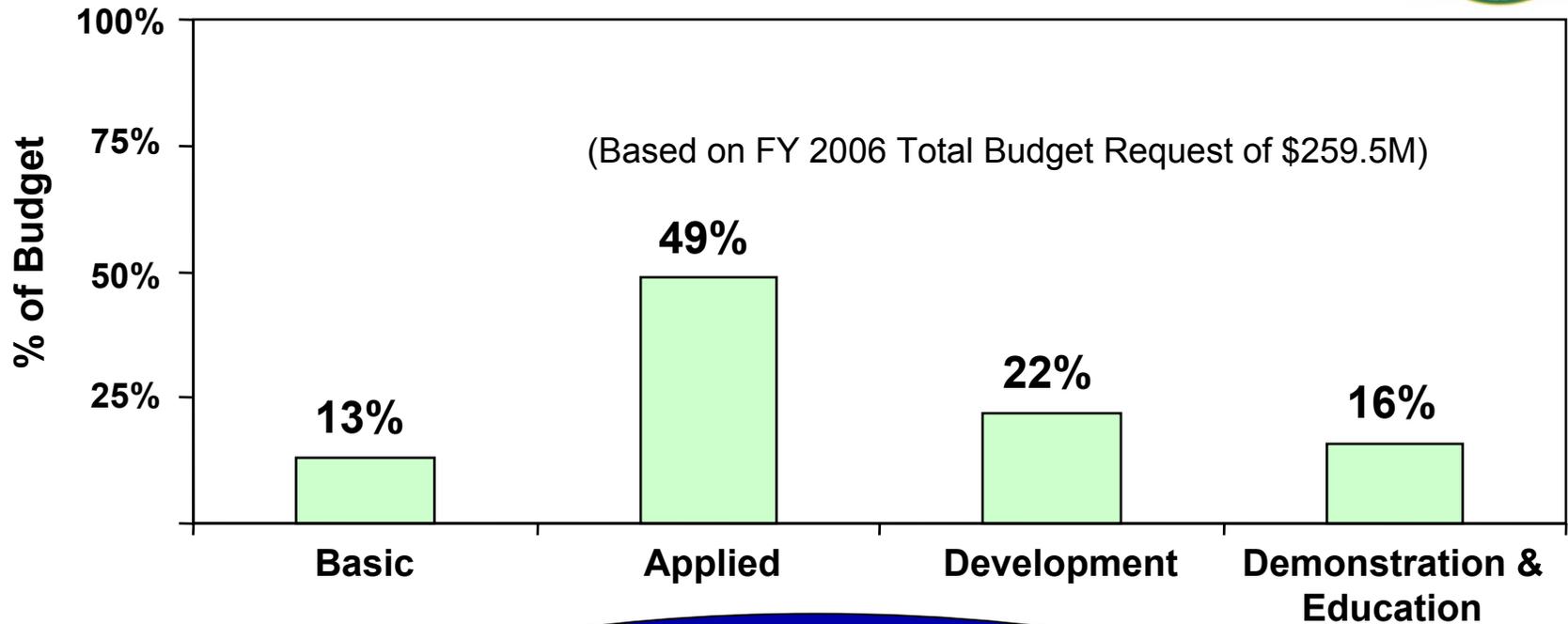
Lab scale testing of
semiconductors
(NREL)

Solar High Temperature Thermochemical

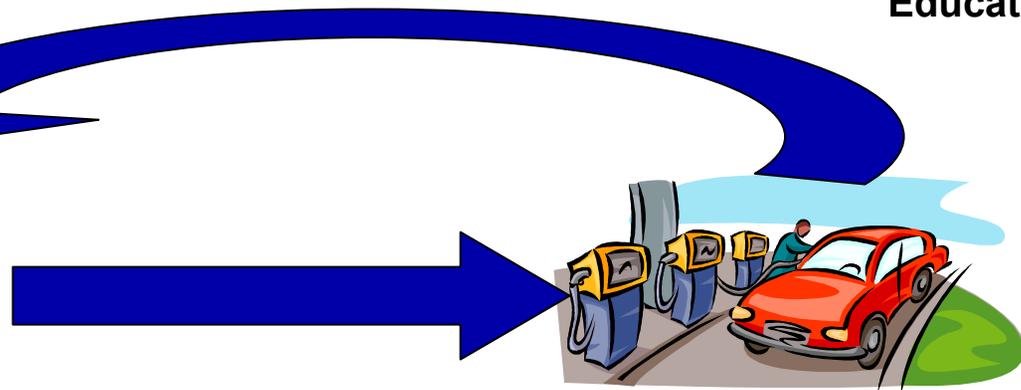
Demonstrated lab feasibility of zinc & manganese cycles
Selected 4 groups of cycles (Volatile metal, metal oxide,
sulfate, sulfuric acid)



Hydrogen



R&D



Tech Validation through
"Learning Demonstrations"

Hydrogen Manufacturing R&D



- Develop low-cost, high-volume fabrication methods for new materials & components
- Establish and refine cost-effective manufacturing techniques while hydrogen products are still evolving
- Adapt laboratory fabrication to low-cost, high-volume production
- Address the diversity and size of industries in both the manufacturing and energy sectors
- Enable development of supplier networks

Manufacturing Roadmap Workshop

July 13-14, 2005

Washington, DC

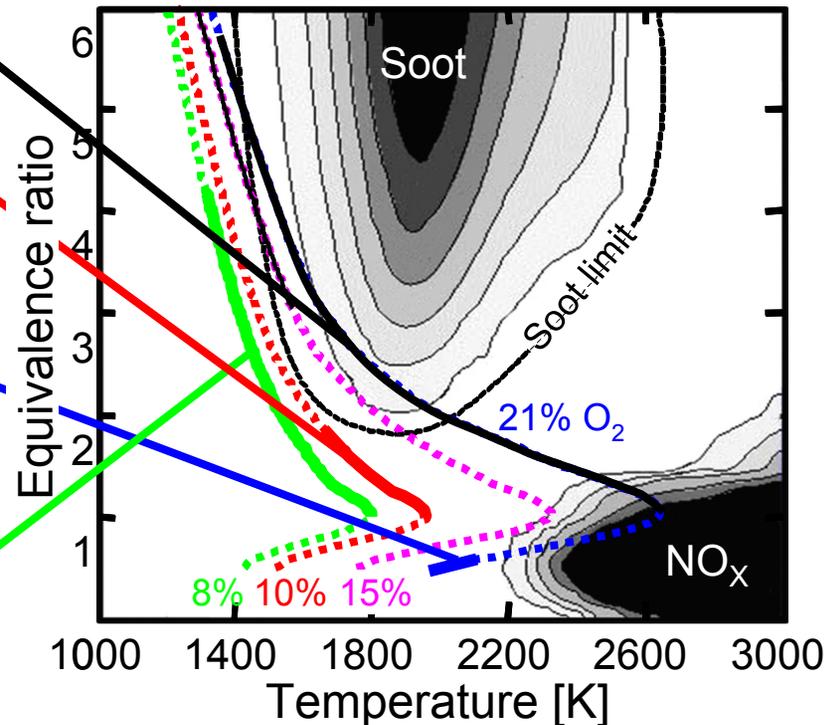
Proceedings at www.eere.energy.gov/hydrogenandfuelcells/wkshp_h2_manufacturing.html

Roadmap available for public comment by February 2006

Recent Technical Successes (Low Temperature Combustion)



- Conventional diesel combustion
- Mixing before combustion prevents soot formation.
 - EGR used to lower NO_x.
- Higher mixing before combustion prevents NO_x & soot formation.
- No EGR (21% O₂).
- Low-temperature rich combustion prevents soot and NO_x formation
- High EGR with less mixing



- New methods for LTC with diesel-like, mixing-controlled heat release have been shown - one approach uses no EGR.
- Since combustion is mixing-controlled, unpredictable heat-release rates in premixed systems are avoided.
- Next steps: Determine the mixing-controlled LTC boundaries of operation and investigate the robustness of mixing-controlled LTC and the feasibility of using in an engine.

Recent Technical Success (Lightweight Materials)



Challenge: To advance Structural Cast Magnesium as a lightweight alternative to heavier alloys

- Required advancements in corrosion mitigation, casting simulation, thermal creep, bolt load retention, and others.
- Successfully applied learned science and technical expertise to produce prototype magnesium castings of a '06 Corvette Engine Cradle with a 35% weight savings (10.3 kg vs. 15.8kg) compared to current cast Aluminum part.
- Will be applicable to other structural parts and chassis components for greater weight savings

