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Presented by John C. Winslow, National Energy Technology Center, at the Coal Utilization Technologies Workshop on September 22, 2004 at the National Research Center for Coal & Energy, Morgantown, WV. This meeting was part of the Energy Roadmap Workshop Series commissioned by West Virginia Governor Bob Wise.

Coal-Derived Hydrogen and Liquid Fuels… to Help Meet a Growing Demand

West Virginia Energy Roadmap Workshop

September 22, 2004
West Virginia NRCCE
Morgantown, WV

John C. Winslow
Technology Manager, Coal Fuels

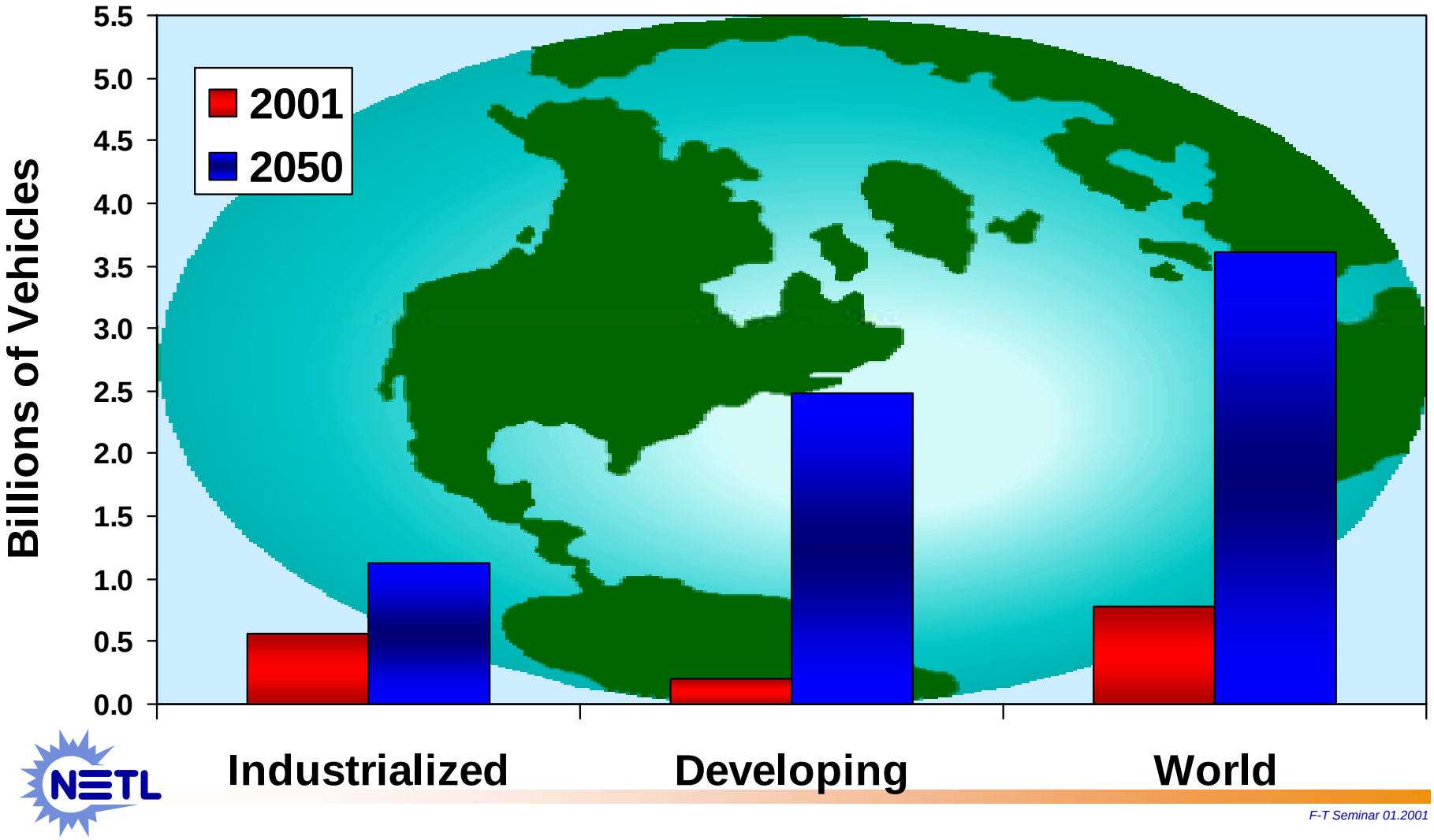
Transportation Fuels: A Likely Scenario

- Fossil fuels will continue to be the preferred option for transportation needs
- Urban and regional environmental pollution concerns will continue to intensify
- Demand for transportation fuels will continue to grow, and because of environmental concerns, the demand for ultra-clean fuels will significantly increase
- Global climate change will continue to be an issue, requiring high end-use efficiencies in all applications including transportation
- The U.S.'s steadily increasing reliance on imported oil (crude and finished products*) will create pressure to diversify our fuel resources

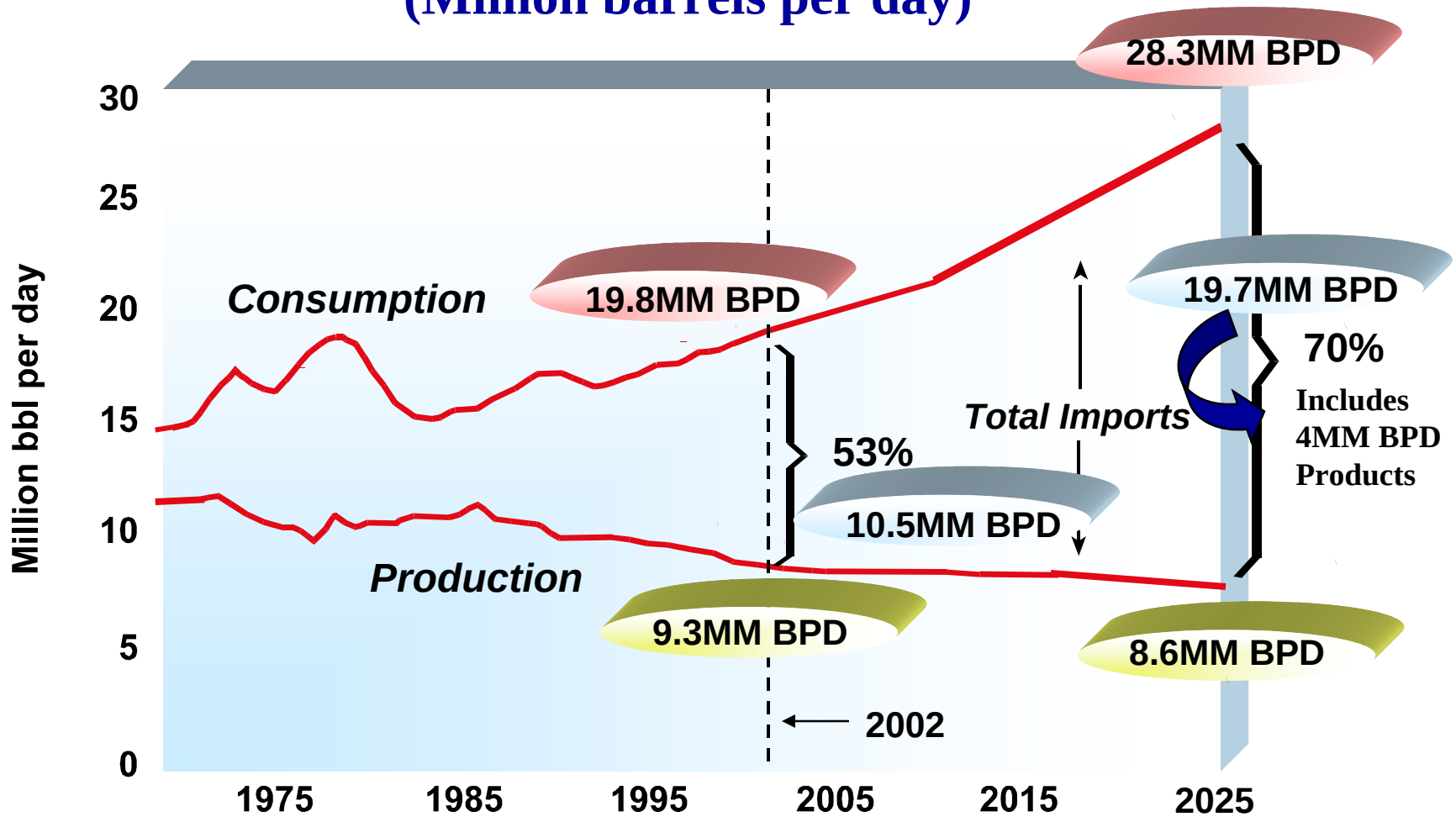
By 2025, expenditures more than double to $194 billion

AEO 2004

Ever More Vehicles



U.S. Production, Consumption, and Total Imports of Petroleum, 1970-2025
(Million barrels per day)



Source: EIA (AEO 2004); Reference Case Scenario

What The Experts Are Saying

Why Higher Oil Prices are Inevitable This year, Rest of Decade

"Regardless of global economic growth and the demand for energy, additional oil supplies require massive and urgent investments with supportive national policies within OPEC and major non-OPEC oil exporting countries. There is no evidence that these policies and hence the investments are occurring on the required scale anywhere in the world."

Sadad I. al-Husseini, Saudi Aramco (retired)
Oil & Gas Journal, August 2, 2004, p. 16

What The Experts Are Saying, Cont'd

"Deepwater (Nigeria, Angola, Brazil, Gulf of Mexico) oil discovery rate may have peaked; production peak may follow in 10 years"

Ivan Sandrea, Merrill Lynch – London;
Oil & Gas Journal, July 26, 2004, p. 18

Diverse Resources and Fuel Options Will be Needed to Meet Future Transportation Needs

- *Resources*
  - Conventional petroleum crude
  - Coal/natural gas/petroleum Coke
  - Oil sands
  - Shale oil
  - Biomass
  - Water ?

- *Fuels/Blendstocks*
  - Petroleum-derived fuels
  - **Fischer-Tropsch-derived fuels**
  - CNG, LPG
  - Oxygenates, e.g. dimethyl ether (DME), methanol, ethanol
  - Additives, e.g., octane and cetaner improvers
  - **Hydrogen**
  - Electricity

Coal Liquid Fuels Can Help in the Transition

- Coal-derived liquid fuels are infrastructure compatible -- and – can provide “breathing space” until sustainable future fuels are available
- They are produced from our largest domestic hydrocarbon resource
- They can be used in existing and advanced vehicle systems
- They make petroleum fuels cleaner
- The oil and coal industries won’t do it alone
- Coproducing fuels and electricity is likely to be the market entry strategy; can realistically achieve

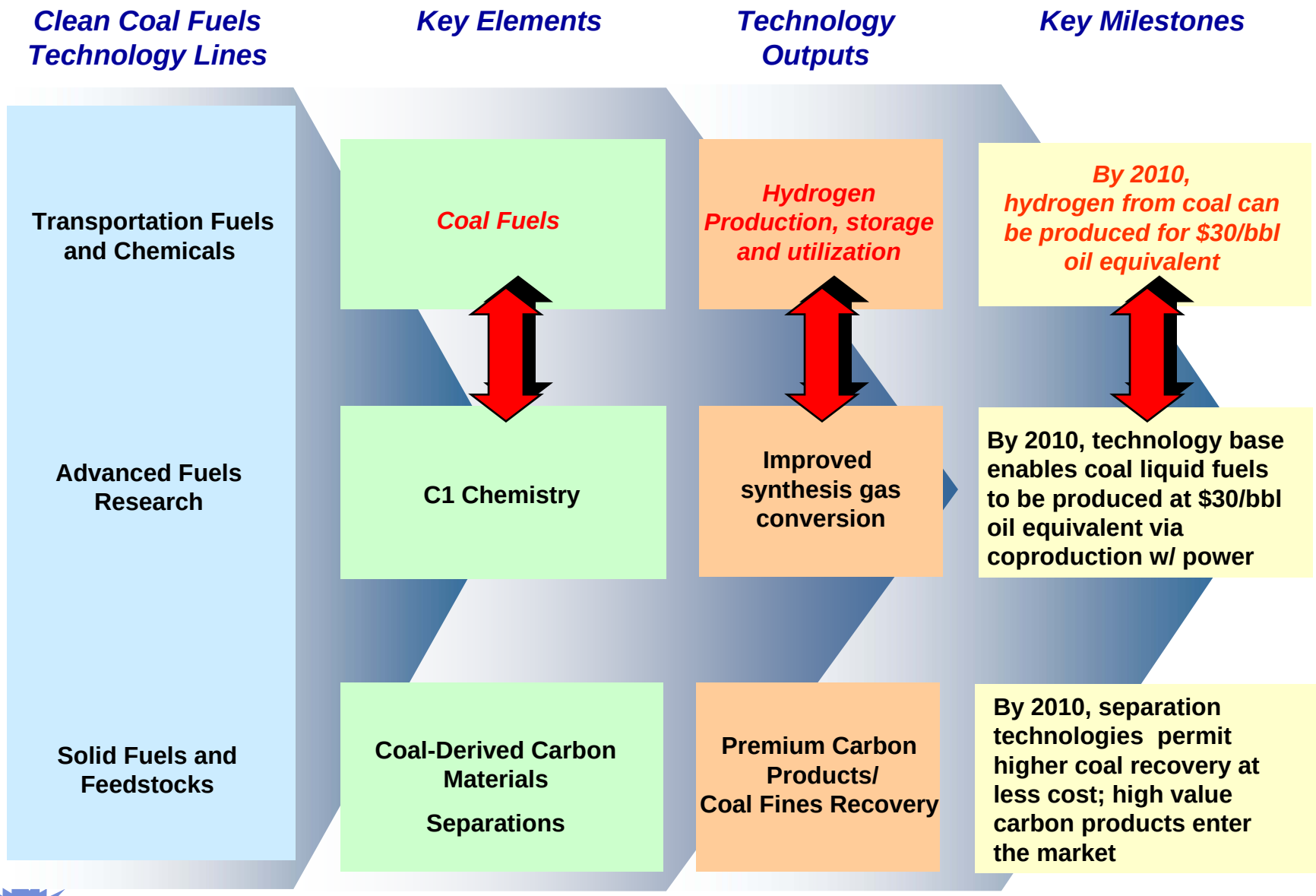
  $30 - $35/barrel COE

As We Transition to the Hydrogen Economy… How important is Coal?

The National Academy of Engineering recently completed a year long study of: "The Hydrogen Economy: Opportunities, Costs, Barriers and R&D Needs"

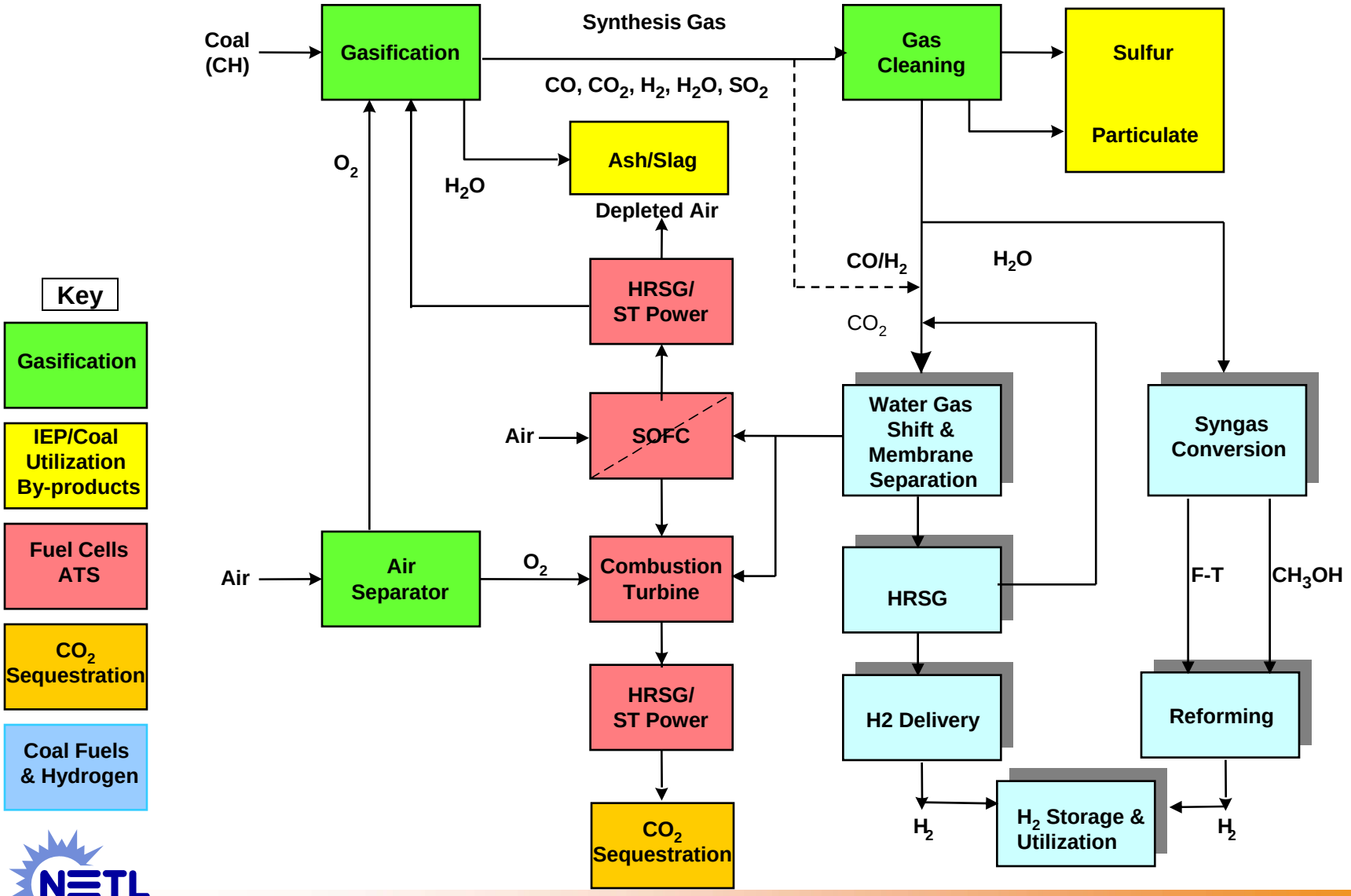
Key Findings…General and those specific to coal

- **Hydrogen could fundamentally transform the U.S. energy system; therefore a robust, ongoing hydrogen program is important**
- **Fossil Fuels will be one of the principal sources of hydrogen for the hydrogen economy…but carbon capture and storage technologies will be required**
- **The U.S. has vast coal resources…hydrogen from coal can be inexpensive…and…coal must be a significant component of R&D aimed at making very large amounts of hydrogen.**


Clean Coal Fuels Technology Lines
Key Elements
Technology Outputs
Key Milestones
Transportation Fuels and Chemicals
Advanced Fuels Research
Solid Fuels and Feedstocks
Coal Fuels
C1 Chemistry
Coal-Derived Carbon Materials
Separations
Hydrogen Production, storage and utilization
Improved synthesis gas conversion
Premium Carbon Products/ Coal Fines Recovery
By 2010, hydrogen from coal can be produced for $30/bbl oil equivalent
By 2010, technology base enables coal liquid fuels to be produced at $30/bbl oil equivalent via coproduction w/ power
By 2010, separation technologies permit higher coal recovery at less cost; high value carbon products enter the market

Hydrogen From Coal

Program Components --- Technology Areas



The Six Major Direct Uses of Synthesis Gas

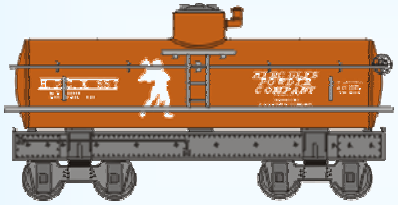
	Primary Product
• Methanol Synthesis (commercial)	Methanol
• F-T and Related Reactions (commercial)	Fuels and Specialty Chemicals
• Isosynthesis (not commercial)	Branched Paraffins
• Combustion (commercial)	Electricity/Heat
• Methanation (one commercial plant in U.S.)	Synthetic Natural Gas (SNG)
• Hydrogen Production	Gasoline/Ammonia

Wender, 1996

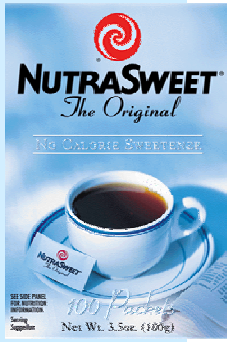
Chemicals from Coal - Final Products

It is likely you have a product in your home based on coal gasification.

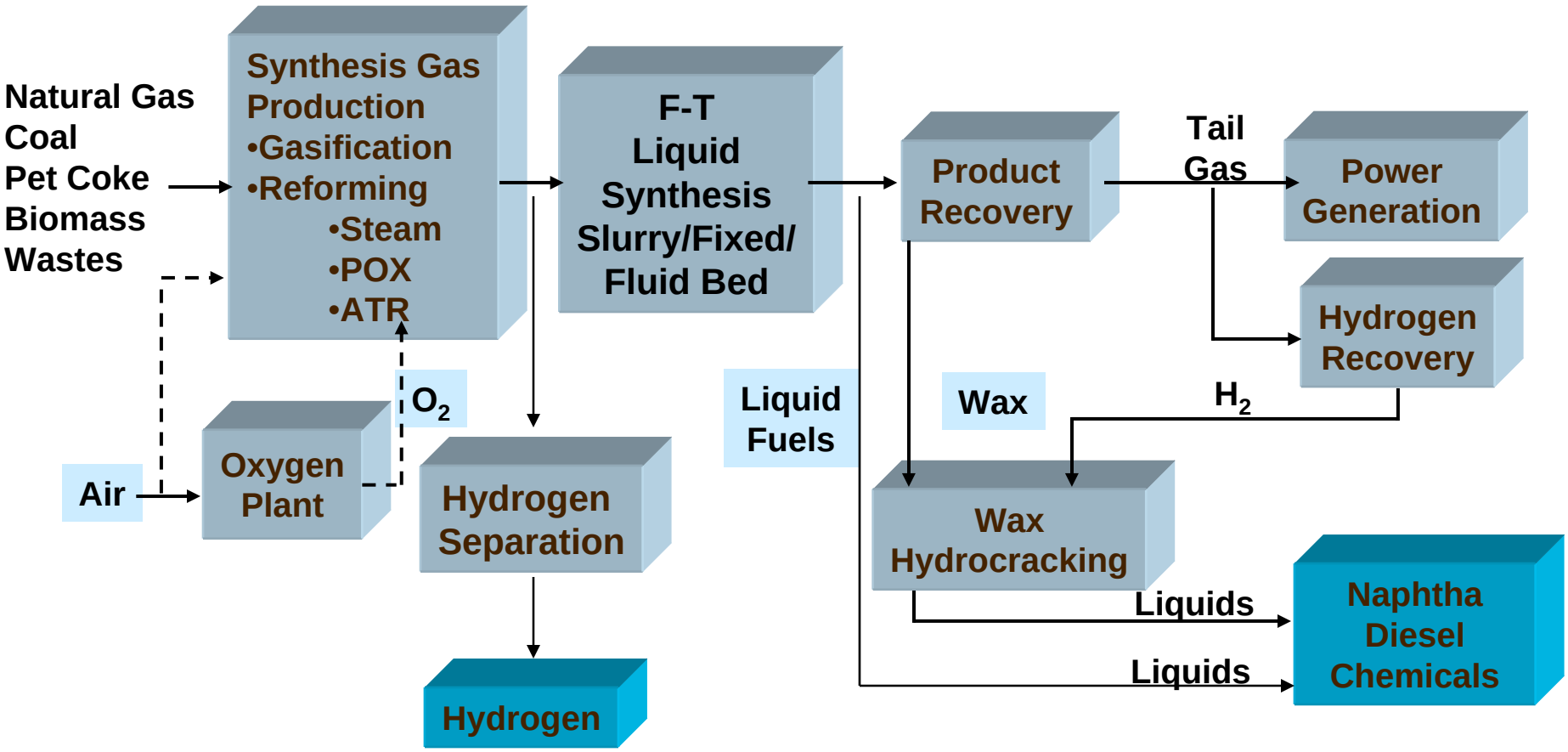
Coal



Acetic Anhydride
Acetic Acid



The Co-Production Strategy Provides Options



Current Military Needs --- Petroleum

Service	Percentage	BPD	BPY	Estimated Cost/FY01
Army	*6%*	*18,500*	*6.7 MM*	*296 MM*
Air Force	*55%*	*166,000*	*60.8 MM*	*2693 MM*
Navy	*38%*	*114,000*	*41.8 MM*	*1853 MM*
Marines	*1%*	*1,500*	*0.7 MM*	*34 MM*
Total	*100%*	*300,000*	*110.0 MM*	*4876 MM*

Note 1: Estimates based on DESC FY01 sales information
Note 2: 75% domestic ~225,000BPD, 25% Overseas ~75,000BPD

Source: Defense Energy Supply Center, 2002

And Another Option:
Strategic Petroleum Reserve

- Prompted by the 1973-74 oil embargo
- Capacity: 700 million barrels…over 30 days supply; world's largest supply of emergency crude
- $20 billion national investment

Hurdles to Deploying Coal Fuels Plants

- **Technical:**
  -Integrated operations of advanced coal fuels technologies have never been demonstrated

- **Economic:**
  -Capital and operations costs must be reduced

- **Environmental:**
  -Coal fuels facilities must show small environmental footprint
  -expansion of coal production

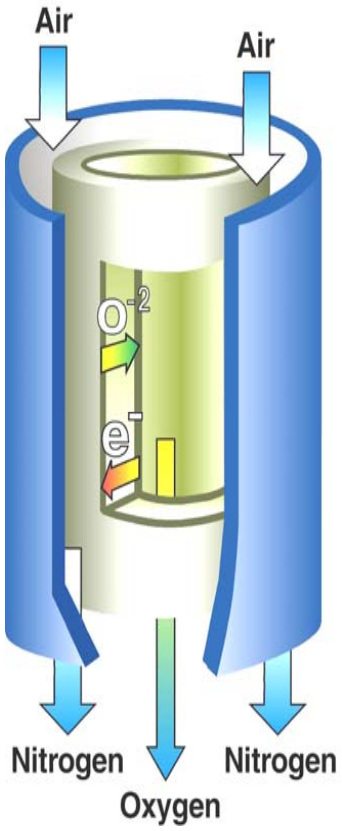
- **Commercial Deployment:**
  -who would take the lead in commercial deployment?

- **Social:**
  -Public resistance to coal use must always be addresed

Example Scenario: Oxygen Separation

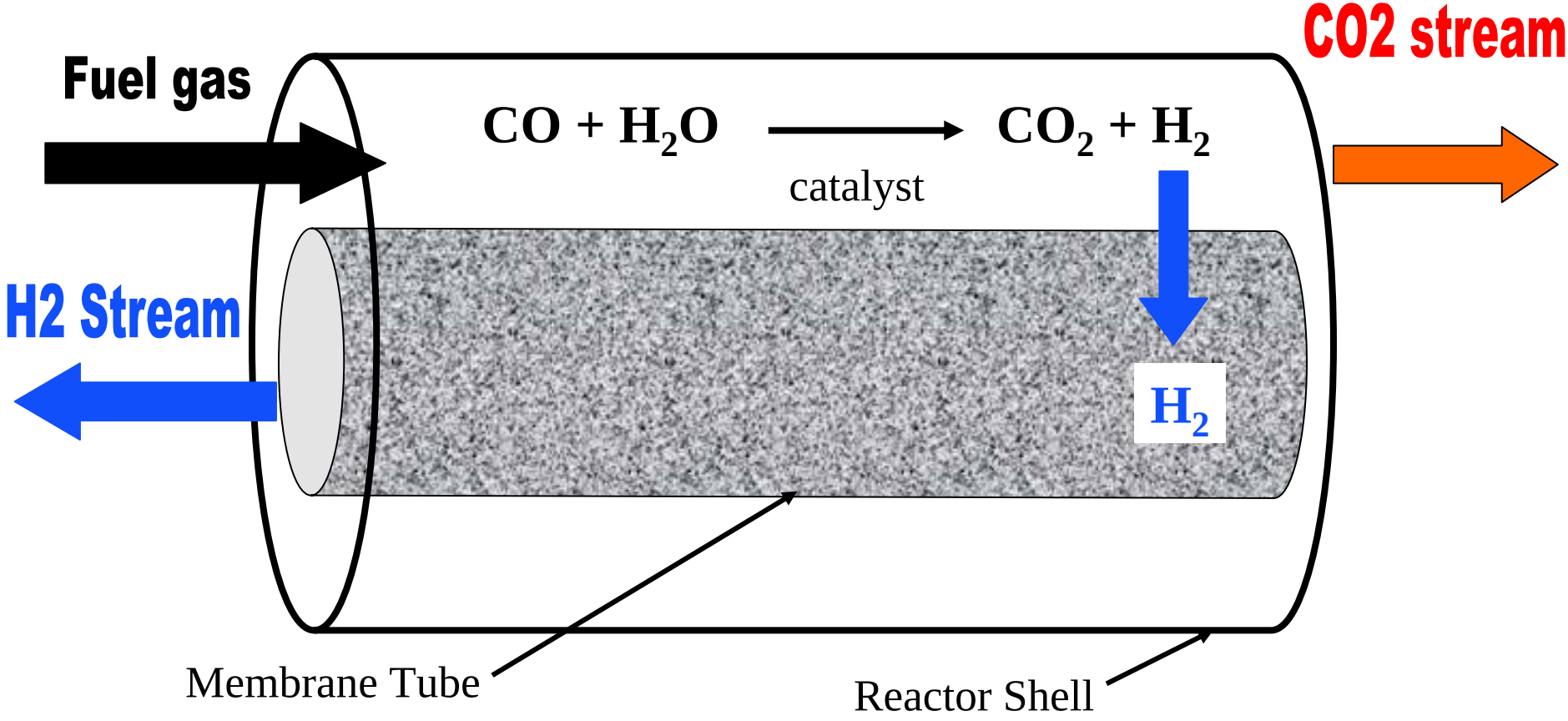
- **Benefits of Oxygen Separation Membranes**
  1. **Lower capital cost than cryogenic oxygen systems**
     - **$20,000 → $13,000/tpd O_2 (35% decrease)[1]**
  2. **Lower auxiliary power**
     - **235 kWh/ton O_2 → 147 kWh/ton O_2 (37% decrease)[1]**
  3. **Simplify CO_2 capture system… remove H_2O and compress flue gas**

$$\text{Coal} + 3/2\ O_2 \Longrightarrow CO_2 + H_2O$$



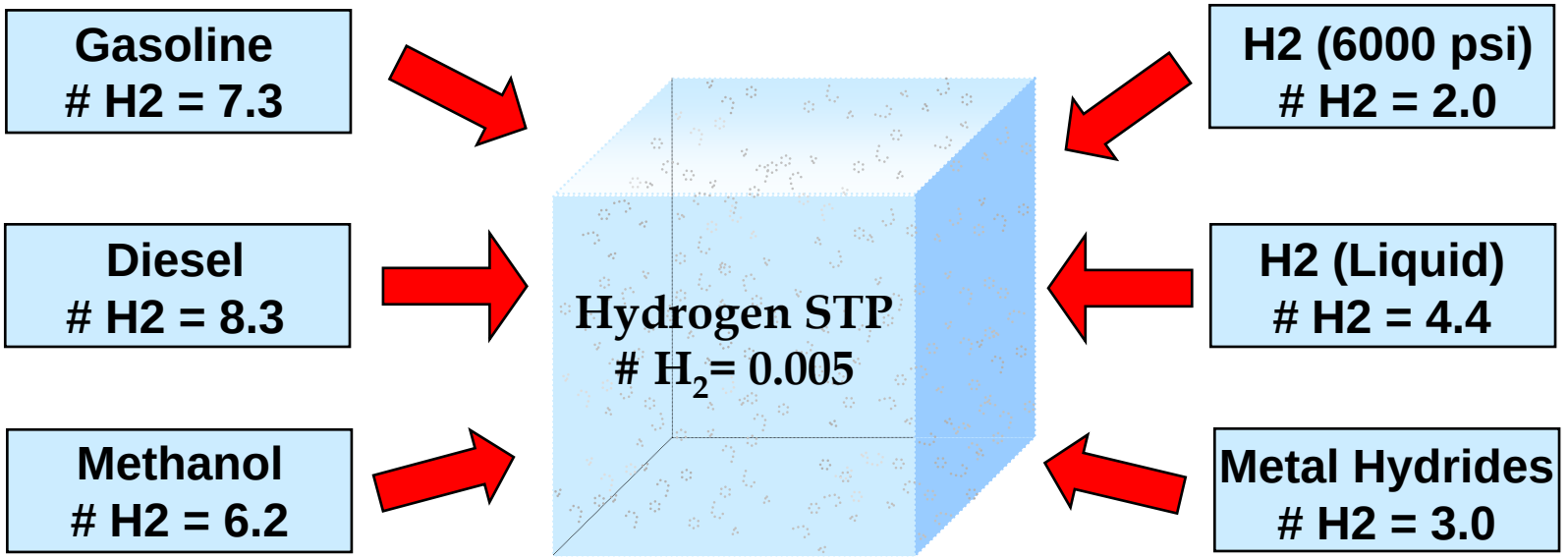
Source: 1. Air Products and Chemicals, Inc. 2002

Water Gas Shift - Hydrogen Separation Membrane Reactor



- Removal of hydrogen drives reaction to completion
- Carbon dioxide stream at high pressure, ready for sequestration
- Hydrogen available as a clean energy source

Hydrogen Storage

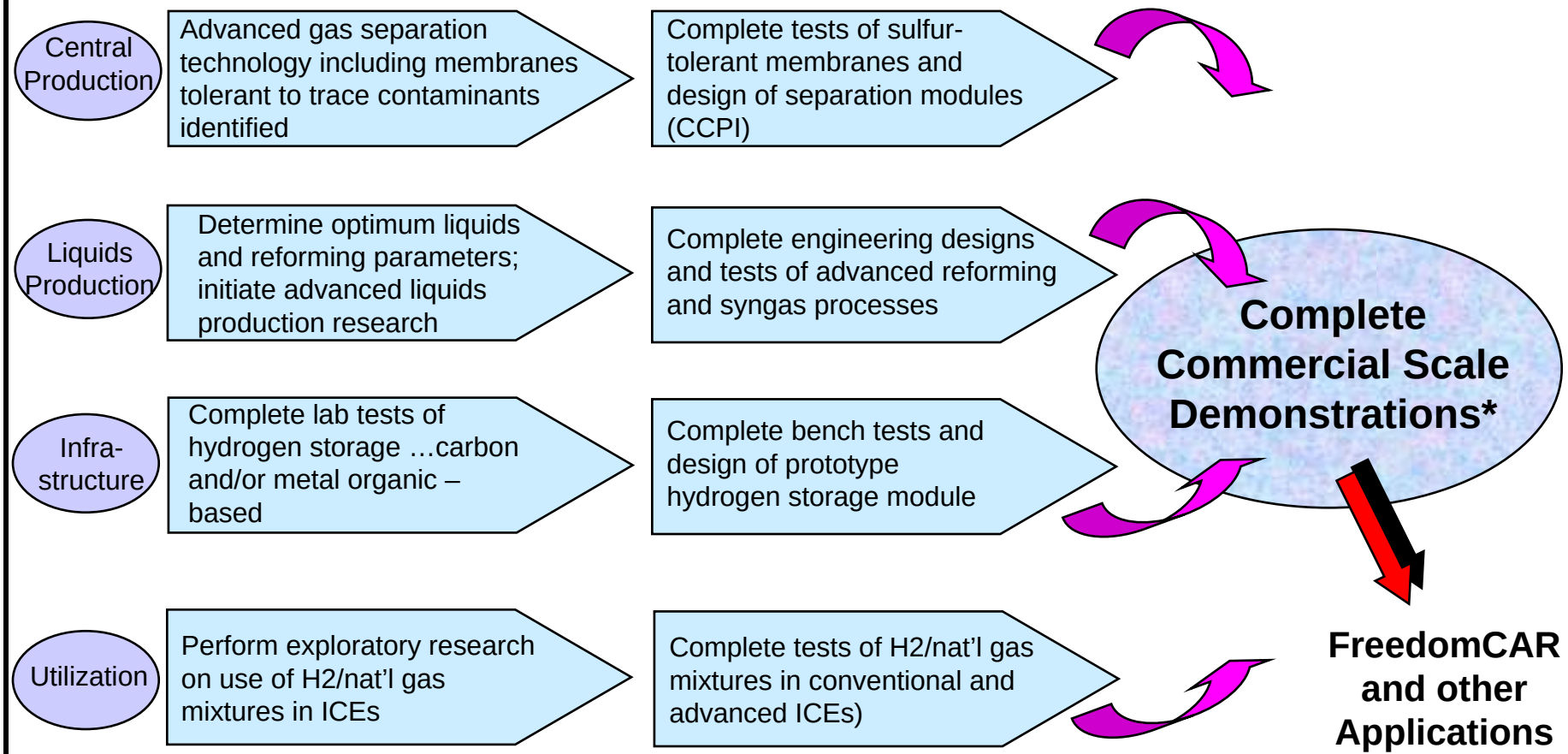


1 Cubic Foot Volume

Potential Deployment Scenario and Benefits for CTL

- **Sixty (60) plants by 2030 (2.4/year) produce 2 MMBPD and 30 GW of power**
- **Compare to EIA forecast of 50 GW needed by 2020 (3.3/year)**
- **Capital cost $136 Billion over 25 years ($5.4 B/Year)**
- **Oil import bill now is $120B in 2020 $195B (if WOP is $30/B)**
- **Thirty-two percent additional coal required**

Hydrogen from Coal Program Roadmap



*** Incorporates technology being developed under the complementary Advanced Gasification and Sequestration for carbon dioxide capture and storage programs**

2005 2010 2015

Coal-Derived Liquid Fuels: Supplementary Material

DOE-Funded F-T / F-T Related Projects

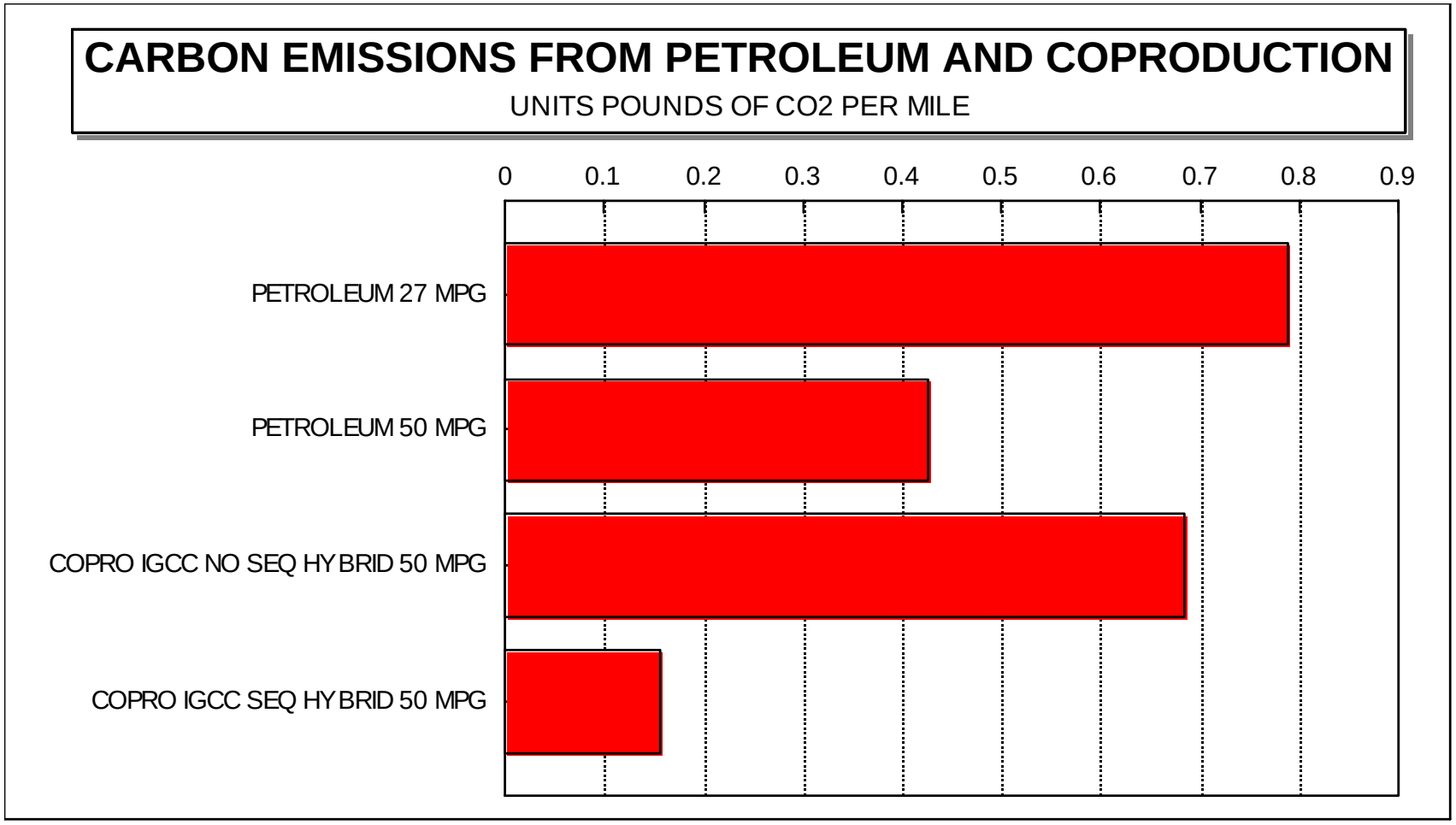
- **C1 Chemistry**
  - Consortium for Fossil Fuel Liquefaction Science
    - Auburn, U. of Ky., U. of Pgh., U. of Utah, WVU
  - National Energy Technology Laboratory….Defense Fuels
- **Iron-Based Catalysts for Slurry-Phase Reactors**
  - Hampton University
  - Research Triangle Institute
  - Texas A&M
  - University of Kentucky (includes cobalt catalysts)
  - University of New Mexico
  - Xavier University
- **Slurry Reactor Development**
  - Air Products & Chemicals, Inc./Sandia National Laboratory/ Washington U./Ohio State
- **Pilot-Scale Process Testing**
  - Air Products & Chemicals, Inc. (~30 bbl/day at LaPorte, TX)…to be dismantled this year

DOE-Funded F-T/F-T Related Projects, Cont'd

- **Liquid Phase Methanol Demonstration**
  - **80,000 gallons/day methanol production**
    - **Air Products/Eastman**

- **Membrane Separation Technologies for:**
  - **Oxygen Production**
    - **Air Products**
    - **Praxair**
  - **Synthesis Gas Production (Natural gas reforming)**
    - **Air Products**
    - **Praxair**

- **Coproduction of Power & F-T Fuels**
  - **WMPI with Sasol and Shell technologies using anthracite waste**


CARBON EMISSIONS FROM PETROLEUM AND COPRODUCTION
UNITS POUNDS OF CO2 PER MILE
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
PETROLEUM 27 MPG
PETROLEUM 50 MPG
COPRO IGCC NO SEQ HYBRID 50 MPG
COPRO IGCC SEQ HYBRID 50 MPG

Potential Deployment Scenario and Benefits for CTL, Cont'd

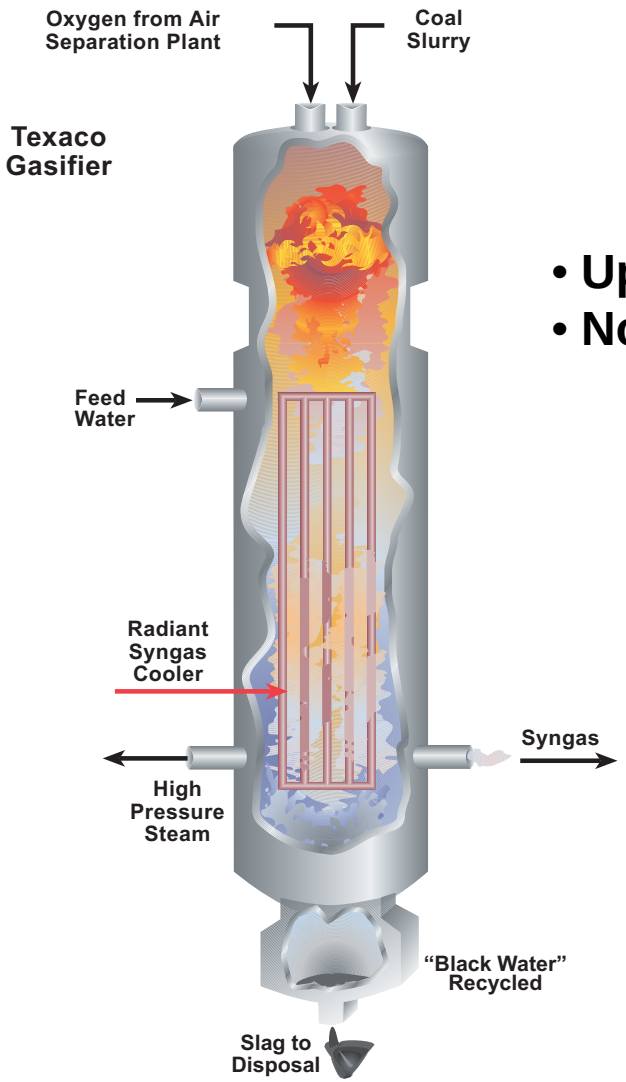
- **U.S. consumer pays no more for CTL product than petroleum fuel ($30/B)**
- **Domestic jobs created (~300,000)**
- **Security of supply from domestic resource (energy security)**
- **Low environmental impact, esp. with CO_2 sequestration**
- **Allows time to transition to the hydrogen economy**

Incentives

- **Government incentives may be required for the first demonstration coproduction plant because of high risk and capital. These could include:**

  - excise tax exemption
  -investment tax credit
  -accelerated depreciation
  -section 29 credit
  -cost share
  -price guarantee
  -purchase guarantee
  -loan guarantee
  -ethanol model

Texaco Gasifier



- Up to 1,000 psig or more
- Nominal 2,600 Deg F

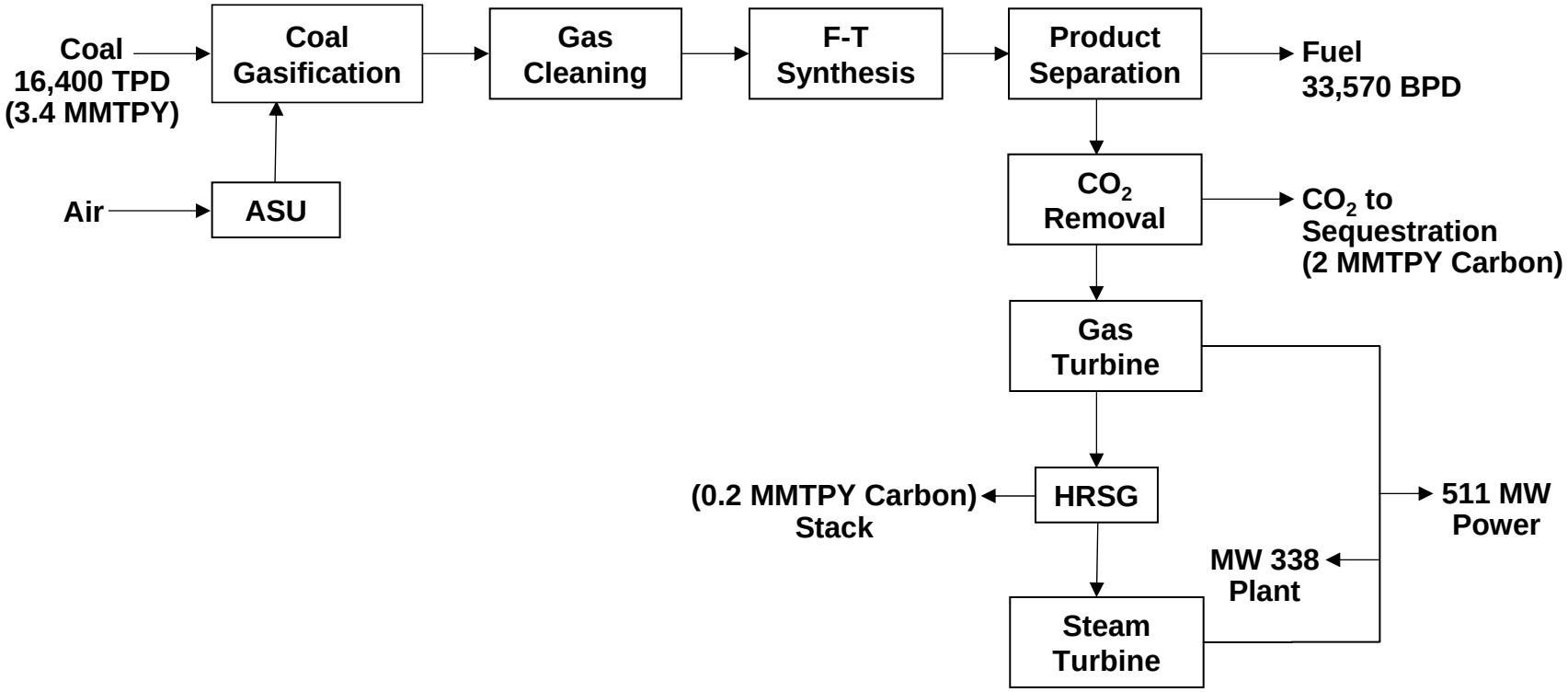
Defense Fuels Research

Research in support of a fuel spec. for a fully synthetic jet fuel

(Cooperative with Army, Air Force and Navy)

- **Study of chemistry related to seal swelling & fuel lubricity**
  - **Compare performance/chemistry of JP-5 with Synthetic S-5 modified with aromatics and oxygenates**
  - **Isolate and characterize oxygenates in jet fuel and relate to fuel lubricity properties.**

Coproduction: One Case To Evaluate Economics



Economics of Previous Configuration

Advanced Coproduction plant with Carbon Sequestration

Capital	$2,244 MM
Coal	156 MM/yr* ($29/ton)
O&M	142 MM/yr

Capital Recovery Factor (CRF) 12.7%
Capacity 90%

Power value assumed $49/MWH (511 MW)
RSP of liquid fuels $35/barrel ($30/bbl crude oil equivalent)

Power value assumed $36/MWH (511 MW)
RSP of liquid fuels $40/barrel ($35/barrel crude oil equivalent)

Basis for CRF:

67% debt/33% equity

8% interest; 16 year debt

15% ROE after taxes; inflation @ 3%; 40% federal tax rate

* includes $10/ton carbon for sequestration

DOE-Funded F-T/F-T Related Projects, Cont'd

- **F-T Fuel Production and Verification**
  - **ConocoPhillips**
    - fuel production (400 bbl/day) and comparative evaluation with conventional and alternative fuels
  - **Envires LLC**
    - novel (molten metal) synthesis gas production
  - **ICRC/Syntroleum**
    - fuel production (70 bbl/day) and evaluation
  - **Praxair**
    - reforming via membrane oxygen separation technology
  - **WMPI (Planned)**
    - Co-production of power and F-T Fuels with Sasol technology using anthracite waste

U.S. Military Challenges

- *Military must be prepared to fight on one or more fronts in the middle east*
- *An oil embargo or major oil-related terrorism,*
  - *world oil shortages develop*
  - *oil prices skyrocket*
- *U.S. economy severely impacted*
- *Military access to fuel threatened*
- *First military recourse: take possession of U.S. fuel supplies*
- *Mitigate military fuels shortage through DOD coal-derived fuels program*

Another Option:
Northeast Home Heating Oil Reserve

Location	Amount, bbl	Distribution Capability, BPD
NY Harbor	*1,000,000*	*100,000*
New Haven, CT	*250,000*	*25,000*
New Haven, CT	*500,000*	*50,000*
Providence, RI	*250,000*	*25,000*
	2,000,000	*200,000**

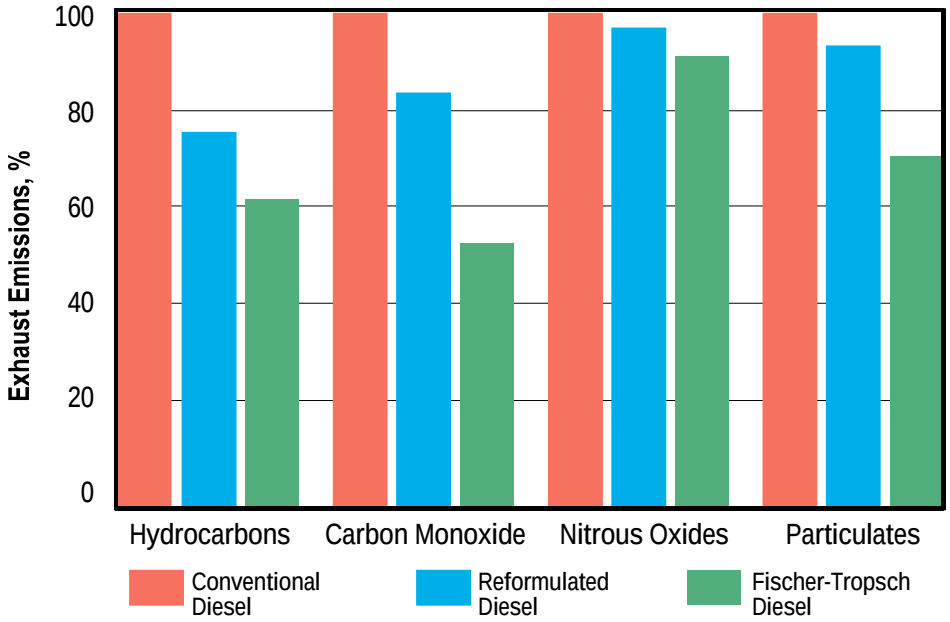
**200,000 BPD would provide 10 days supply*

Other Benefits

- *F-T fuel would be much higher quality than heating oil…reduced emissions*
- *Could lead to dedicated home heating oil market*

Source: FY2004 Congressional Budget

Fischer-Tropsch Diesel Lowers Emissions



- **Emissions are lowered due to low sulfur (<1 ppm), low aromatics (<3%) and high cetane number (>70)**
- **Can be blended with conventional diesel to improve emissions quality**
- **The naphtha is sulfur free and suitable as a feedstock for chemicals production**

Ryan, 1996

Why a Coal Hydrogen Fuel Program?

- **A hydrogen economy offers the potential for:**
  - reduced emissions of greenhouse gases, esp. CO_2
  - significant reductions in criteria pollutants (PM, NOx, SOx)
  - decreased reliance on imported energy
- **The Administration is reorienting the Partnership for a New Generation of Vehicles program to the FreedomCAR program….focused on fuel cell technology….which will require technical developments in the production and utilization of hydrogen**
- **Coal-derived hydrogen technologies can play a major role in the transition to a sustainable hydrogen energy economy…..BUT**
  - hydrogen production, distribution, storage and end-use still face significant technical, cost and infrastructure barriers