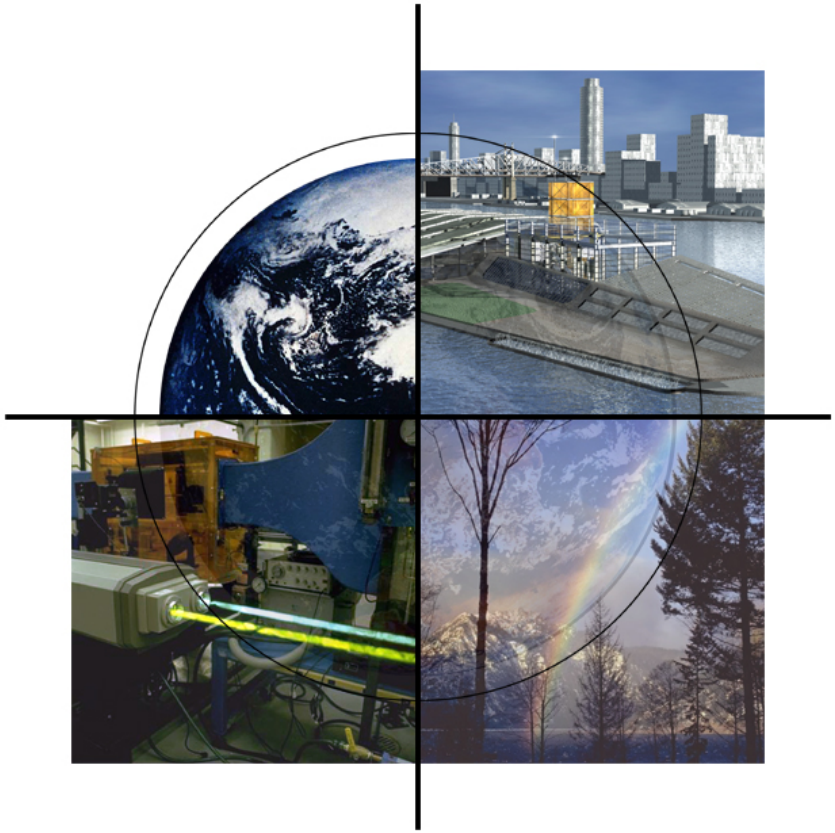
Hydrogen from Coal



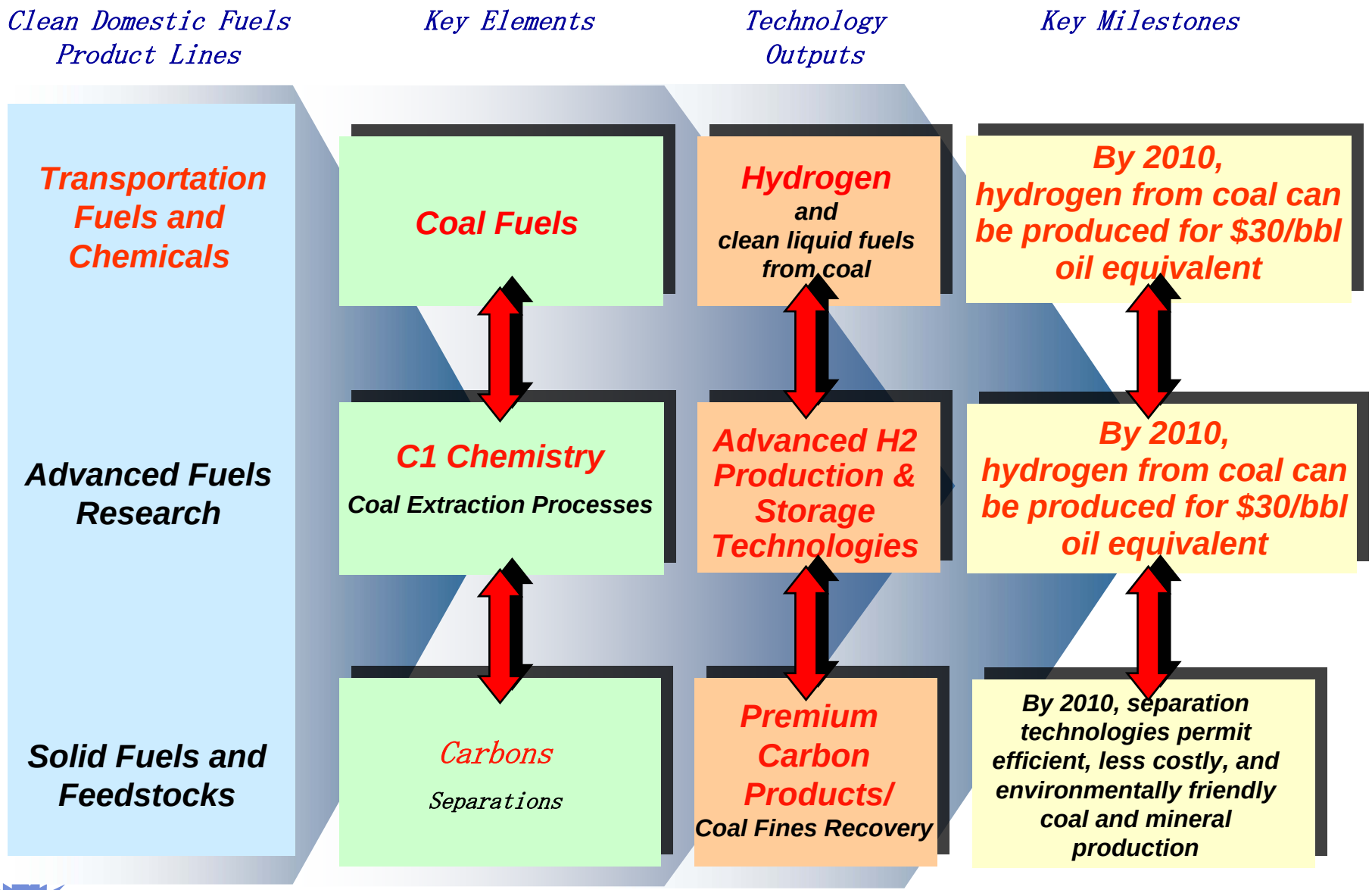
Presentation to:

EPSCoR

Radisson

Morgantown, WV
June 15, 2005

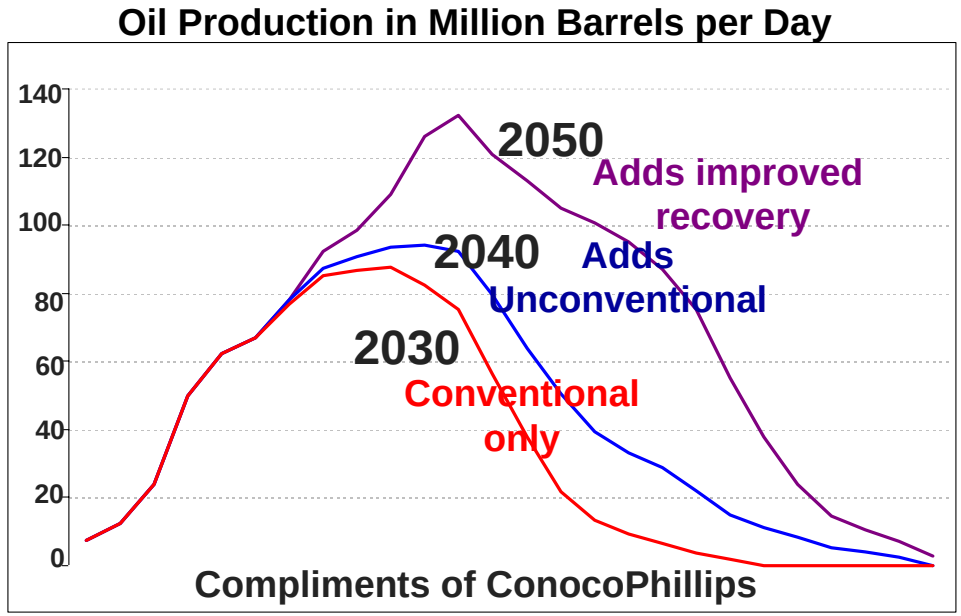
John C. Winslow, Technology Manager
National Energy Technology Laboratory


Clean Domestic Fuels Product Lines
Key Elements
Technology Outputs
Key Milestones
Transportation Fuels and Chemicals
Advanced Fuels Research
Solid Fuels and Feedstocks
Coal Fuels
C1 Chemistry
Coal Extraction Processes
Carbons
Separations
Hydrogen and clean liquid fuels from coal
Advanced H2 Production & Storage Technologies
Premium Carbon Products/ Coal Fines Recovery
By 2010, hydrogen from coal can be produced for $30/bbl oil equivalent
By 2010, hydrogen from coal can be produced for $30/bbl oil equivalent
By 2010, separation technologies permit efficient, less costly, and environmentally friendly coal and mineral production

Key Drivers for a Hydrogen Economy

Under President's Hydrogen Fuel Initiative

- ***Energy security***
  - *Growing energy consumption*
  - *Reliance on foreign supplies*
- ***Environmental quality***
  - *Criteria pollutants*
  - *Greenhouse gas emissions*
- ***International Competitiveness***



Sources:
USGS Estimates of Total Recoverable Resources: 1981 – 2000
Peter R. Odell, Erasmus University Rotterdam; COP estimate

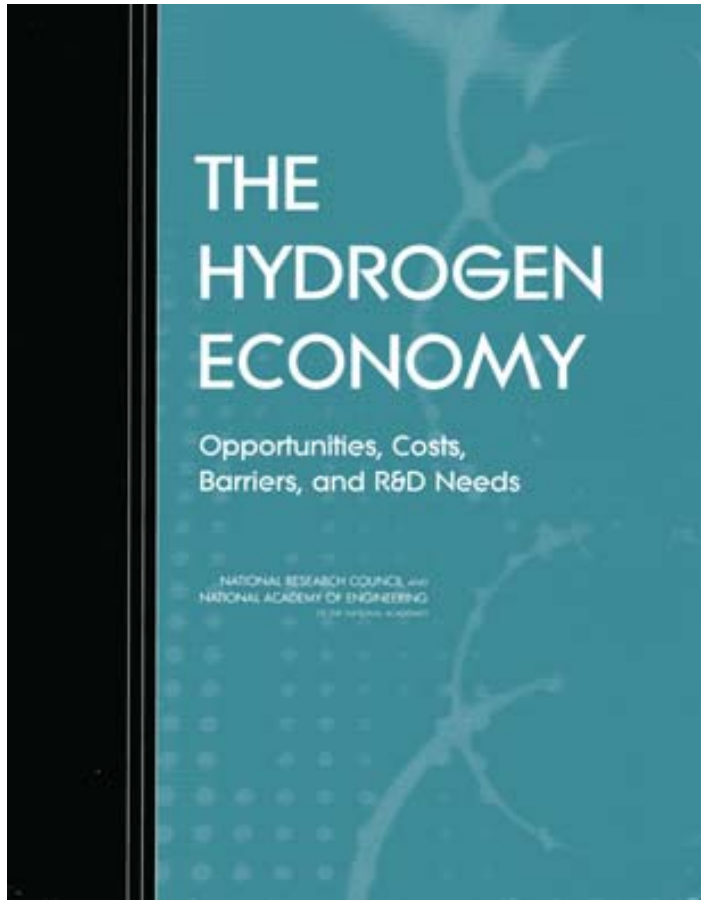
Strategic Goal #1: ***Dramatically Reduce or Even End Dependence on Foreign Oil***

Success Factor: ***By 2030, affordable hydrogen vehicle technology options are widely available for Americans***

Hydrogen and Coal…

- ***Hydrogen could fundamentally transform U.S. energy system***
- ***Fossil Fuels will be one of the principal sources of hydrogen …but carbon capture and storage technologies will be required***
- ***If energy security is primary driver, coal must be a significant component of R&D aimed at making very large amounts of hydrogen***

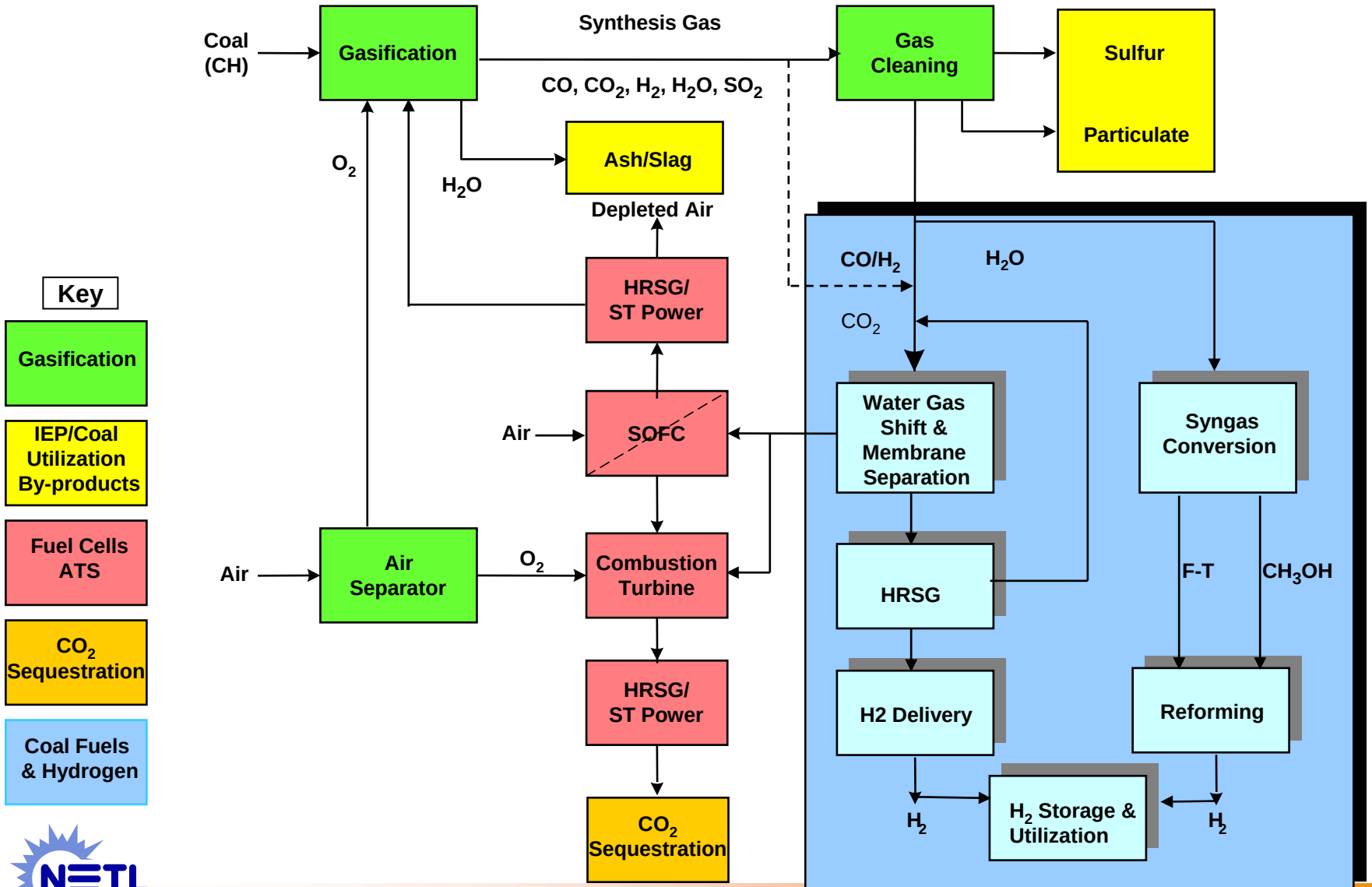
National Academy of Engineering Study



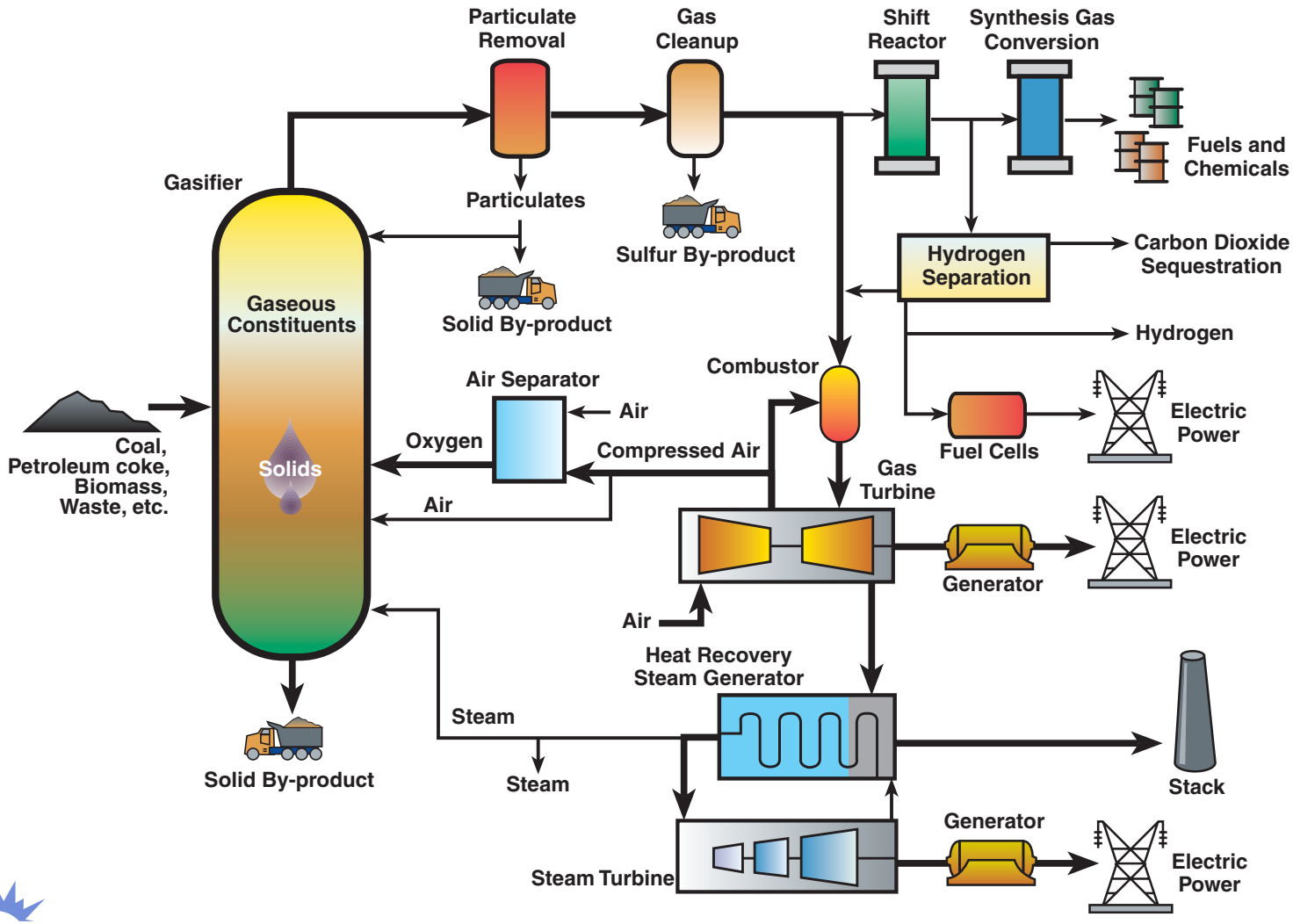
http://books.nap.edu/catalog/10922.html?onpi_newsdoc02042004

Hydrogen From Coal

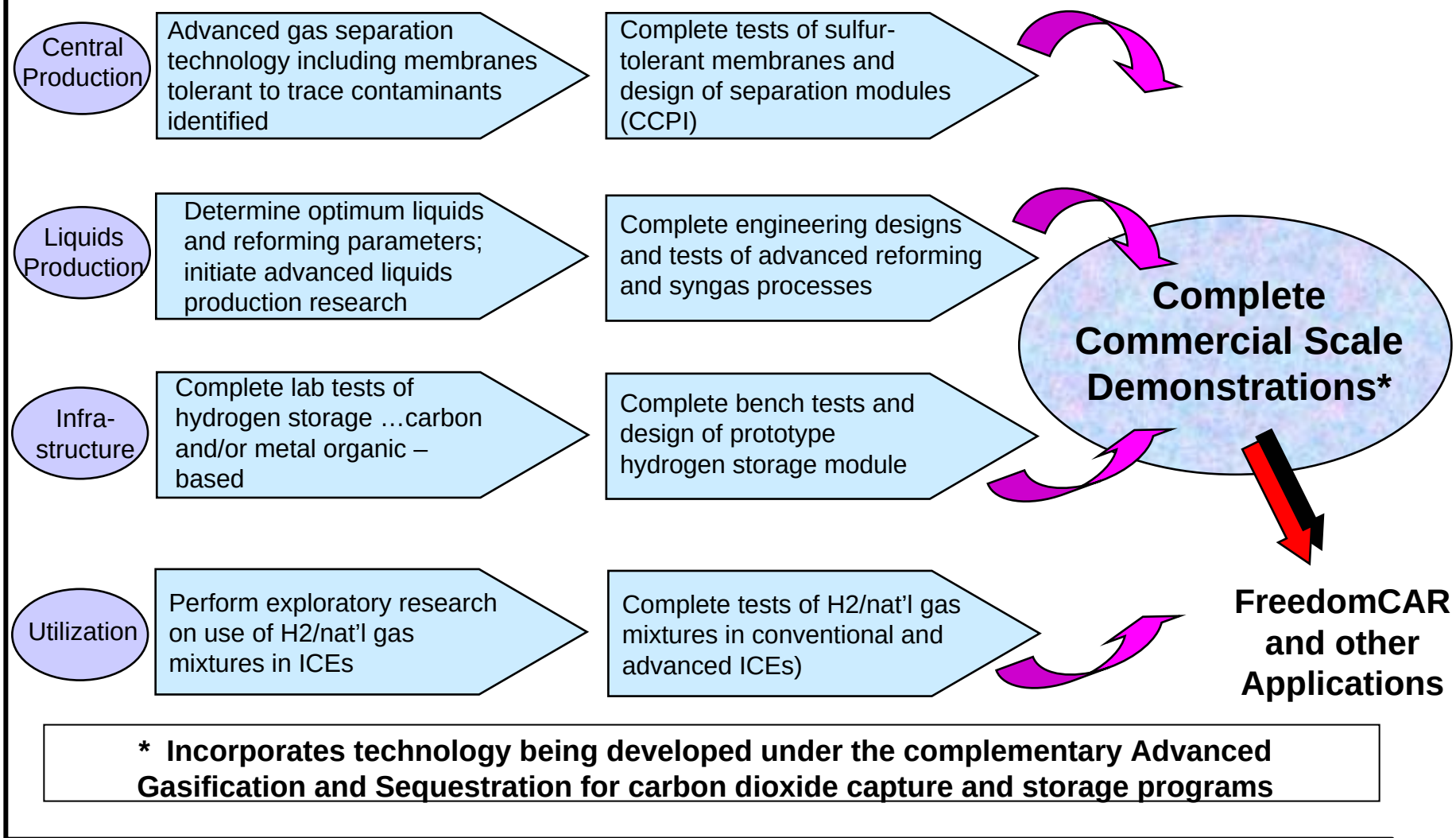
Program Components --- Technology Areas



Gasification-Based Energy Production System Concepts



Hydrogen from Coal Program Roadmap



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

FY05 Hydrogen from Coal Activities

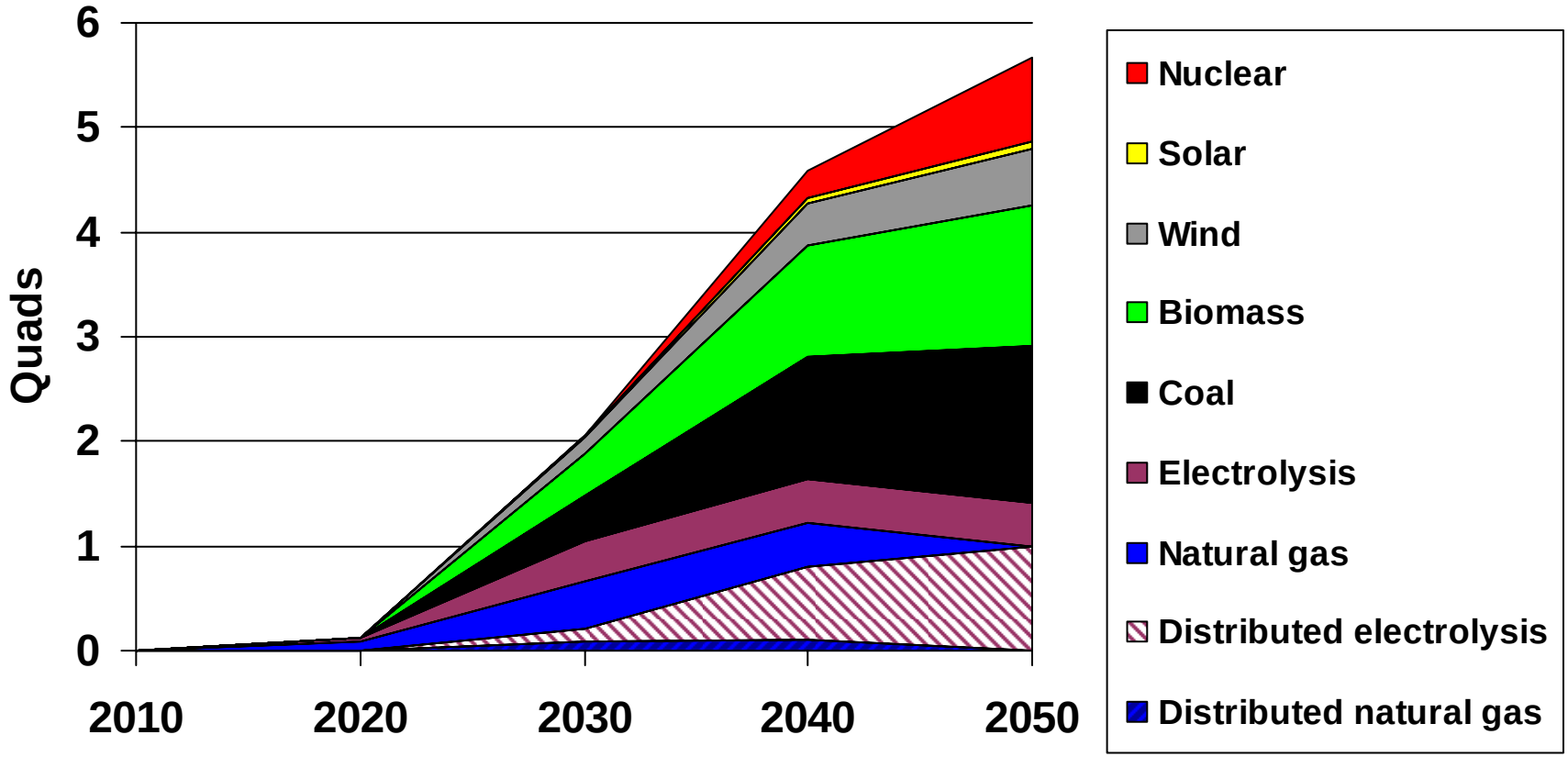
- **Central Production**
  - Complete conceptual design of a hydrogen separation membrane gasifier configuration (**GTI)**
  - Complete design and initiate scale-up of hydrogen separation modules **(Eltron, ORNL)**
  - Evaluate hydrogen separation membrane material before and after exposure to atmospheres that are typical of a coal-based gasifier (**ANL, Media & Process Tech., NETL, ORNL, Ohio State, REB, SWRI)**
    - Separations research progressing from “lessons learned” laboratory and computational research to making and testing next generation of membranes
  - New Awards **(GTI, GE, Aspen Products, UTC, U. of WY/WRI, Lehigh)**
    - Research will focus on advanced water-gas shift membrane reactors; process intensification – single component for multiple separations; and novel sorbent-based separation

FY05 Hydrogen from Coal Activities

- **Liquids Production/Reforming**
  - Complete tests (and data collection) of advanced steam reforming of methanol **(UC-Davis)**
  - New Awards **(HTI, Syntroleum)**
    - Production of barrel/day quantities of F-T
- **Infrastructure (Storage)**
  - Complete research on carbon – based storage material; initiate evaluation of metal – organic frameworks **(NETL)**
  - New Awards **(Adv. Materials Corp, U. of Michigan)**
    - **Research to complement NETL's metal-organic framework activity**
- **Utilization**
  - Complete engine modifications needed to evaluate performance on hydrogen and/or mixtures of hydrogen and methane **(GTI, KSU, NETL, PSU, TIAX)**
    - Hydrogen utilization in modified ICEs may act as interim technology until fuel cells are advanced to commercial reality.

BACK-UP

U.S. H2 Production by Feedstock Varies Over Time



M. Singh, Argonne Nat'l Lab; 1-10-05

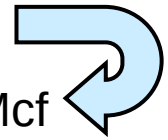
Membrane Separation: A Strategy for Hydrogen Cost Reduction

1. Central Hydrogen Production

- *Membrane Separation (current technology)*

  - Gasification/Shift/PSA w/Seq [1,2/] = $8/Mcf

  - Gasification/Shift/**Membrane** w/Seq [2/] = $7.20/Mcf



10% Reduction

- *Long-term target (2015+)*

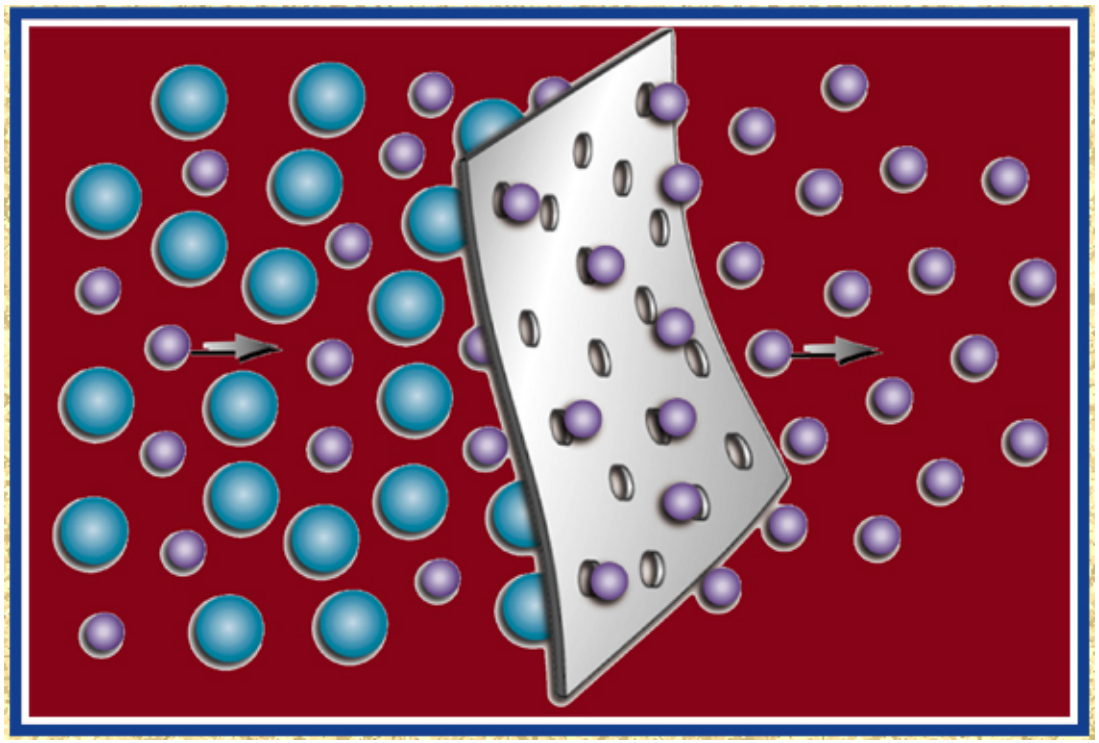
  - Co-Production/Adv. Gasification/Shift/**Membrane** w/Seq [1/] = $4.00/Mcf

  - ***On the path toward this long term target, system advances (including membrane technologies), will be made such that the 2010 target of $5.50/Mcf can be realized***

1/ Hydrogen from Coal; Mitretek, July, 2002
2/ Coal to Hydrogen: Potential Impact of Membrane Separation on Baseline Plants; Mitretek, January 7, 2003

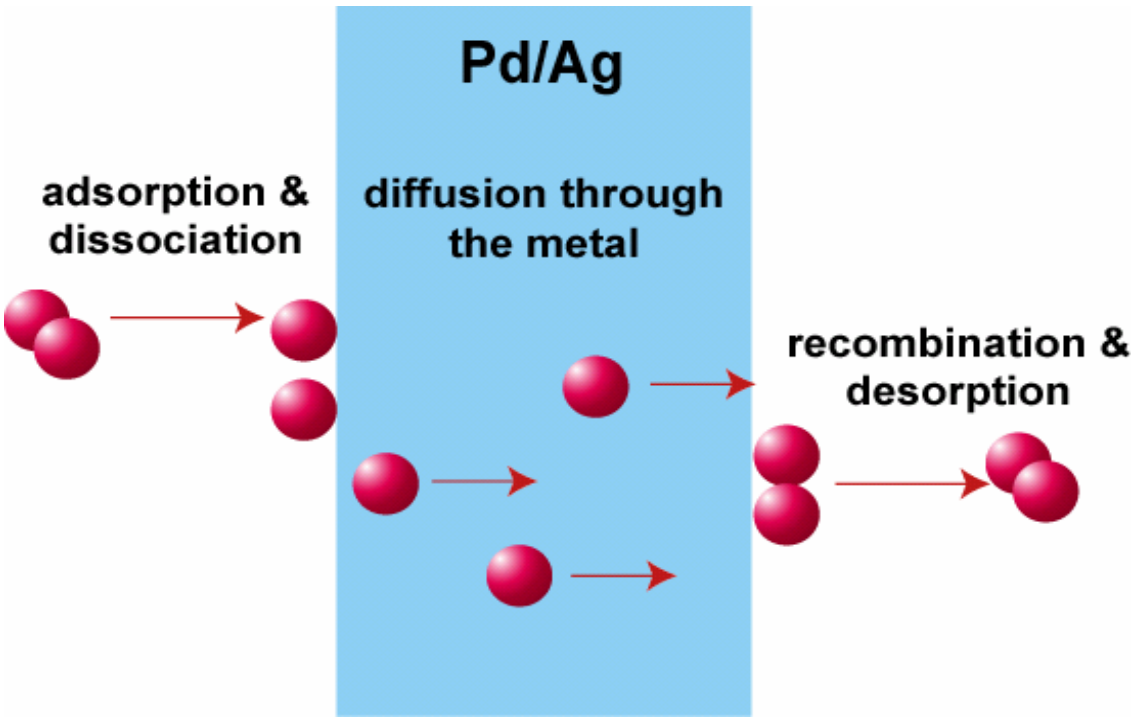
Micro Porous Membranes

Gas Mixture

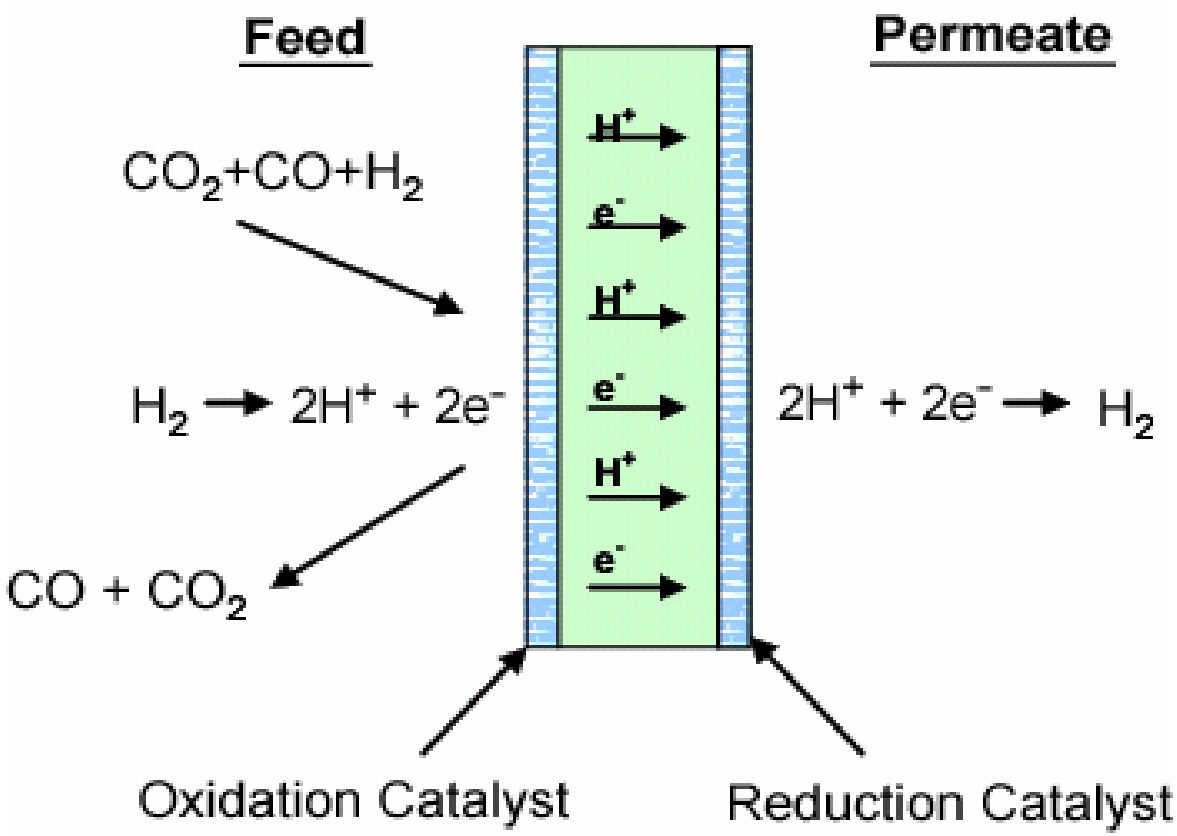


Hydrogen

Dense Metallic Membrane



Dense Ceramic Membrane



DOE Technical Targets

TYPE / YEAR	Micro Porous		Dense Metallic		Dense Ceramic	
	2010	2015	2010	2015	2010	2015
Flux Rate (scfhr/ft2)	200	300	200	300	200	300
Total Cost ($/ft^2)	$200	<$100	$1,000	<$500	$200	<$100
ΔP Capability	400	1000	400	1000	400	1000
H2 Recovery (% of total gas)	>80%	>90%	>80%	>90%	90%	100%
H2 Purity	99.5%	99.99%	>99.95%	99.99%	99.5%	99.99%
Durability (hrs)	26,280	>43,800	26,280	>43,800	26,280	>43,800

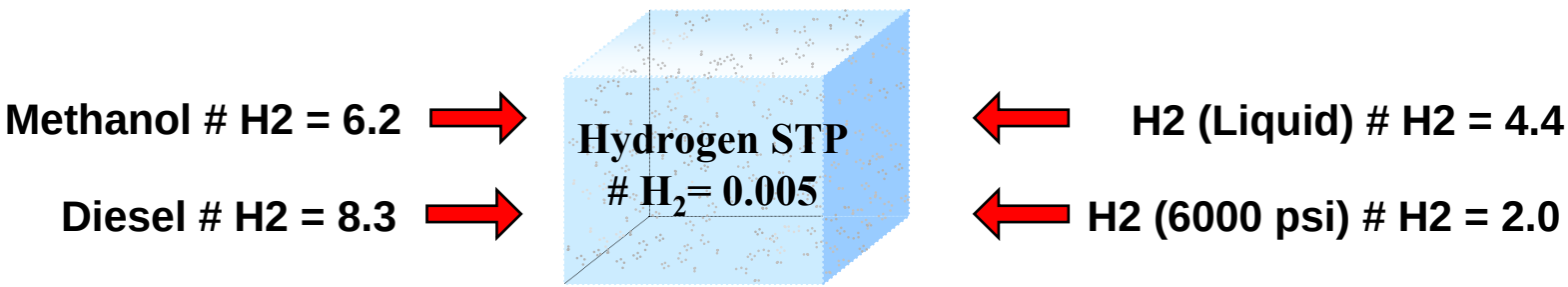
Technology Barriers

- **Membrane materials**
  - Optimum diffusivity, flux, resistance
- **Rapid, reliable screening methods**
  - Computational, experimental
- **Fundamental knowledge base**
  - Mass transport, selectivity, kinetics
- **Membrane fabrication**
  - Defect control and management
  - Large-scale production, cost.
- **Membrane reactors**
  - Seals, synergy versus challenges

Liquid Hydrocarbons: A Strategy for Hydrogen Cost Reduction

2. Liquids Production (F-T/Methanol) for Hydrogen Production

- Definitive systems analyses are planned to compare central station hydrogen production versus distributed reforming of liquid hydrocarbons
  - Liquids can be distributed through existing infrastructure
  - Liquids store significant amounts of hydrogen:



1 Cubic Foot Volume

Near/mid – term benefit of using liquid hydrogen carriers is apparent, but systems analysis needed to determine the benefit more precisely

Substitute Natural Gas: A Strategy for Hydrogen Cost Reduction

3. Substitute Natural Gas (SNG) for Hydrogen Production

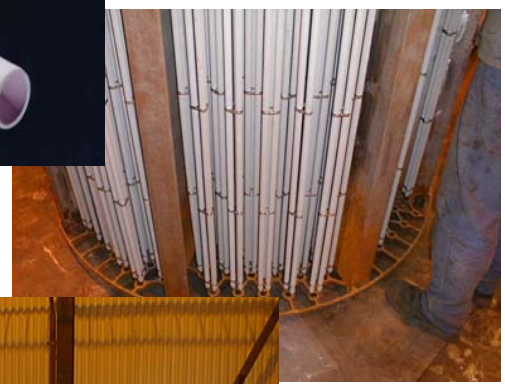
- **Energy security is the top priority for DOE's Hydrogen program; natural gas is major resource for hydrogen production, but:**
  - 12-month avg. spot price is about $6.00/MMBtu ($7.17 as of 3/31/05)
- Mitretek and John Marano examined three cases for co-producing power and SNG from Texas lignite [1/]
  - Results range from $5.00 - $6.90/MMBtu
  - Lowest cost case used:
    - Single-stage, advanced dry-feed quench gasifier
  - RSP of Products:
    - Electricity (244 MW net) @ $35.6/MW
    - SNG (39MMscfd) @ $5.00/MMBtu
    - CO2 (8300 TPD) @ $12/ton

1/ Polygeneration of SNG, Hydrogen, Power and Carbon Dioxide from Texas Lignite; Mitretek and Consultant (John Marano), December, 2004

Follow-on study to evaluate similar systems in ND and WY

NETL R&D Accomplishments

- Commercially-ready micro porous membranes.
- Novel metal alloys and cermets.
- Specialized membrane seals and brazing techniques.
- Bench-scale membrane reactors
- Computational models to develop and predict membrane performance



Hydrogen from Coal
Cost and Performance Targets (2010)

- **Central Production**
  - Hydrogen Separation (Microporous Membrane)
    - Achieve flux of 200 at $100/ft^2
  - Water-Gas Shift
    - Achieve projected durability of at least 7 years with > 15% cost reduction
- **Liquids Production**
  - Achieve 20% reduction in cost of producing/reforming high hydrogen content coal-derived liquids
- **Infrastructure**
  - Develop material(s) capable of storing 6 wt.% H_2 on a kg H_2/kg system mass basis
- **Utilization**
  - Compared to pure CH_4, use mixture of H_2 and CH_4 to reduce, in ICEs, hydrocarbon and criteria pollutant emissions by 50% with equivalent cost and performance