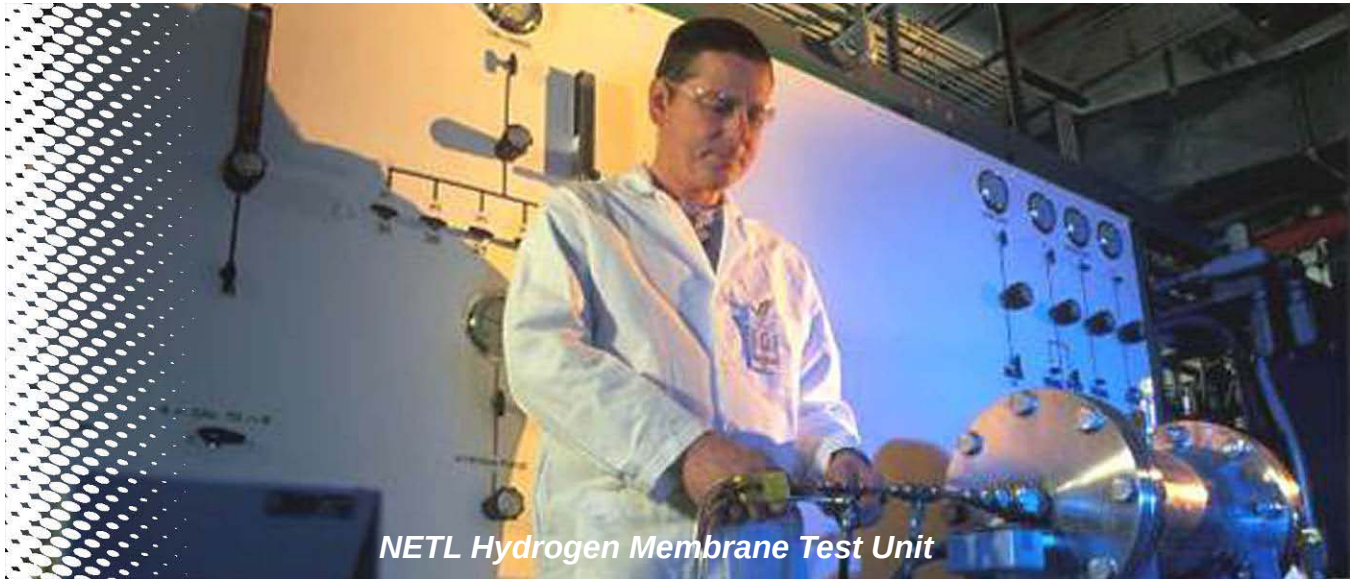
NATIONAL ENERGY TECHNOLOGY LABORATORY

Where energy challenges converge and energy solutions emerge



Generation, Fuels & Environment Membership Advisory Group
Fuels Program Overview
June 15, 2010

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U.S. DEPARTMENT OF ENERGY

Prior Fuels - Hydrogen from Coal Program Elements

H_2 Production Central Pathway

2016 target = Prove feasibility of coal fueled H_2 & power co-production with CO_2 storage, at 25% H_2 cost reduction, 60% system efficiency

Primary Thrusts

- Hydrogen Separation
- Process Intensification
- Advanced Concepts

Alternate Production Pathway

2014 target = alternate pathway that can use current infrastructure

Primary Thrusts

- Liquid Fuels and Synthetic Natural Gas (SNG) Production
- Fuels Reforming
- Polygeneration of High Value Carbon-Based Materials

Other Supported Research Trusts

Utilization

- Advanced Engines

Delivery/Infrastructure

- H_2 & H_2/NG Mixtures
- H_2 RDT&E Platform

Computational Science & Modeling / Systems Analysis / Supporting Sciences

Current Fuels Program Goals

- **2016: prove the feasibility of an efficient, near-zero emissions, coal-fueled hydrogen and power co-production facility that reduces the cost of hydrogen by 25% compared to current coal-based technology.**
- **2012: gasifier products will be characterized to assess the impact of contaminants on gas cleanup systems in order to identify the best product mix and environmental mitigation strategy. (Coal and biomass R&D)**

Current Fuels Program Focus:

- **Focus on co-production/polygeneration and potential benefits for power applications through reduced cost of electricity, improved efficiency, and reduced cost of carbon capture and storage**
- **Improve alignment and coordination with other program offices**

Fuels Program Overview

Research Area	Technical Challenges
Hydrogen production, separation, and purification	• Membrane durability • Contaminant sensitivity • Process intensification • Integration
Coal and biomass	• Handling/pre-processing of coal-biomass mixtures • Feed system reliability • Impacts on downstream processes
Liquid fuels and SNG	• Catalyst and reactor optimization • Range of products and product quality

Benefits

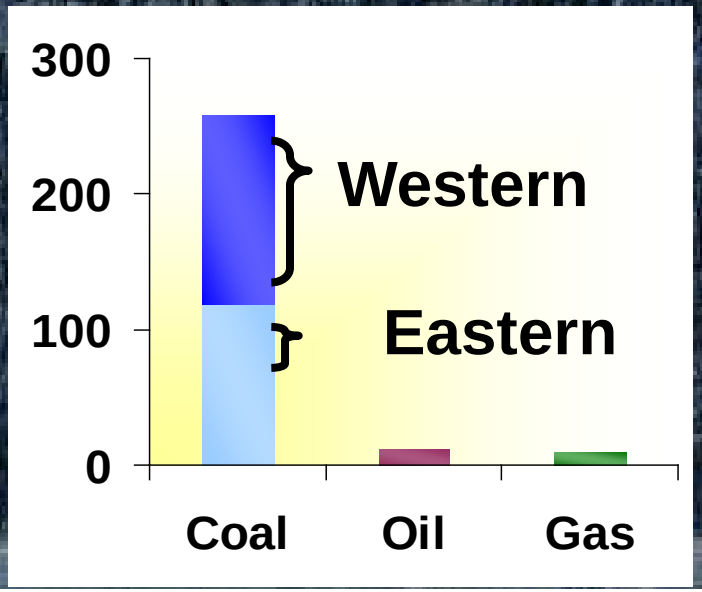
- Address energy security issues
- Can help lower cost of electricity in co-production/polygeneration concepts
- Technologies typically have low incremental cost for CCS

Why Coal?

Coal Reserves are Abundant

- Provides over half Nation's electricity
- Abundant domestic reserves
- Low, relatively stable prices

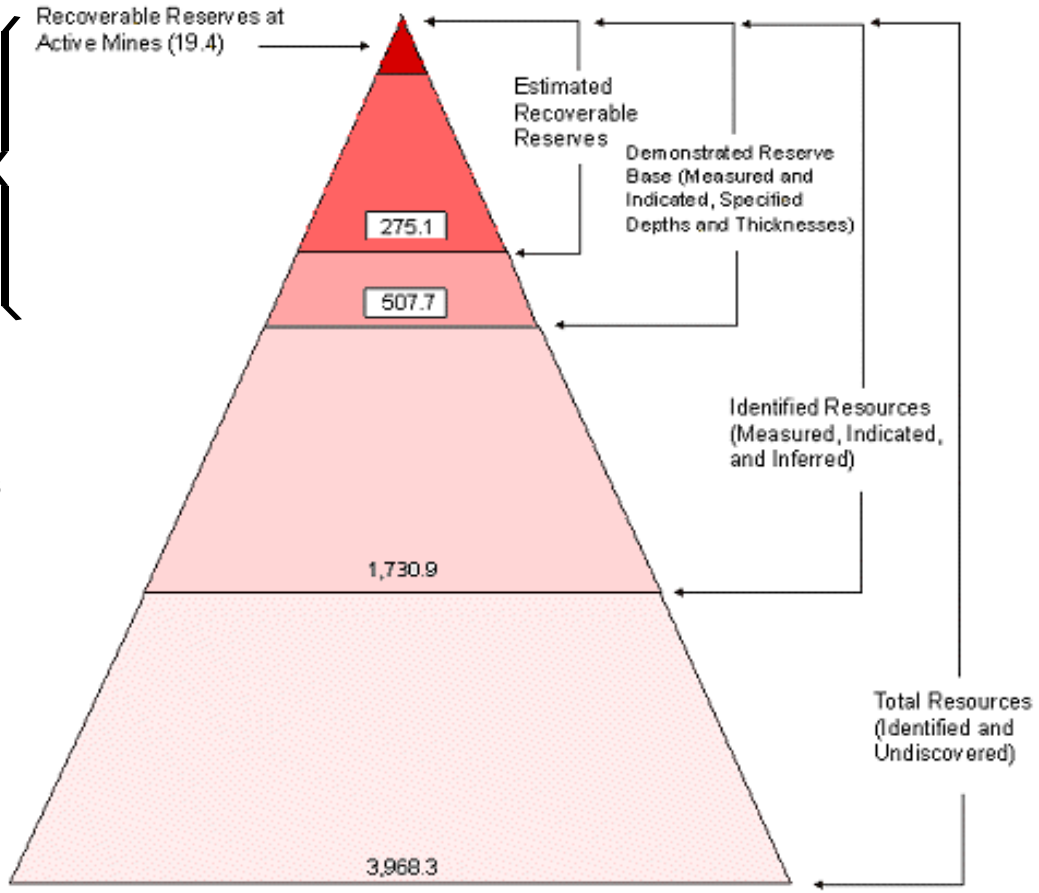
Years Supply at Current Production Rates



Delineation of U.S. Coal Resources and Reserves

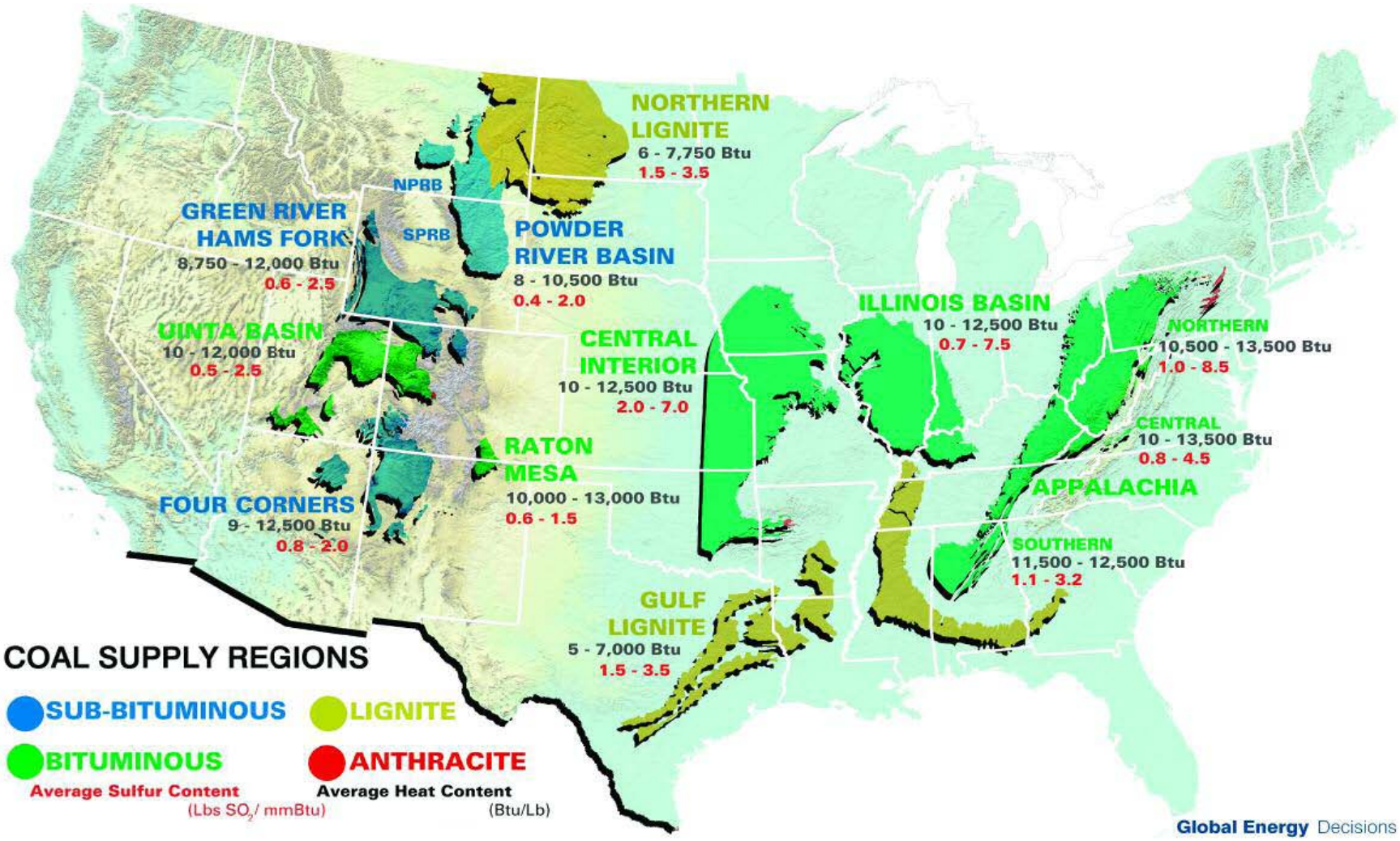
Sufficient reserve to meet projected demand for electricity and up to 4MMBPD CTL industry for over 100 years

1 ton of coal produces 2 barrels of liquid



Source: EIA Coal Reserves Data 1997
http://www.eia.doe.gov/cneaf/coal/reserves/chapter1.html#chapter1a.html

U. S. Coal Resources Are Widely Distributed



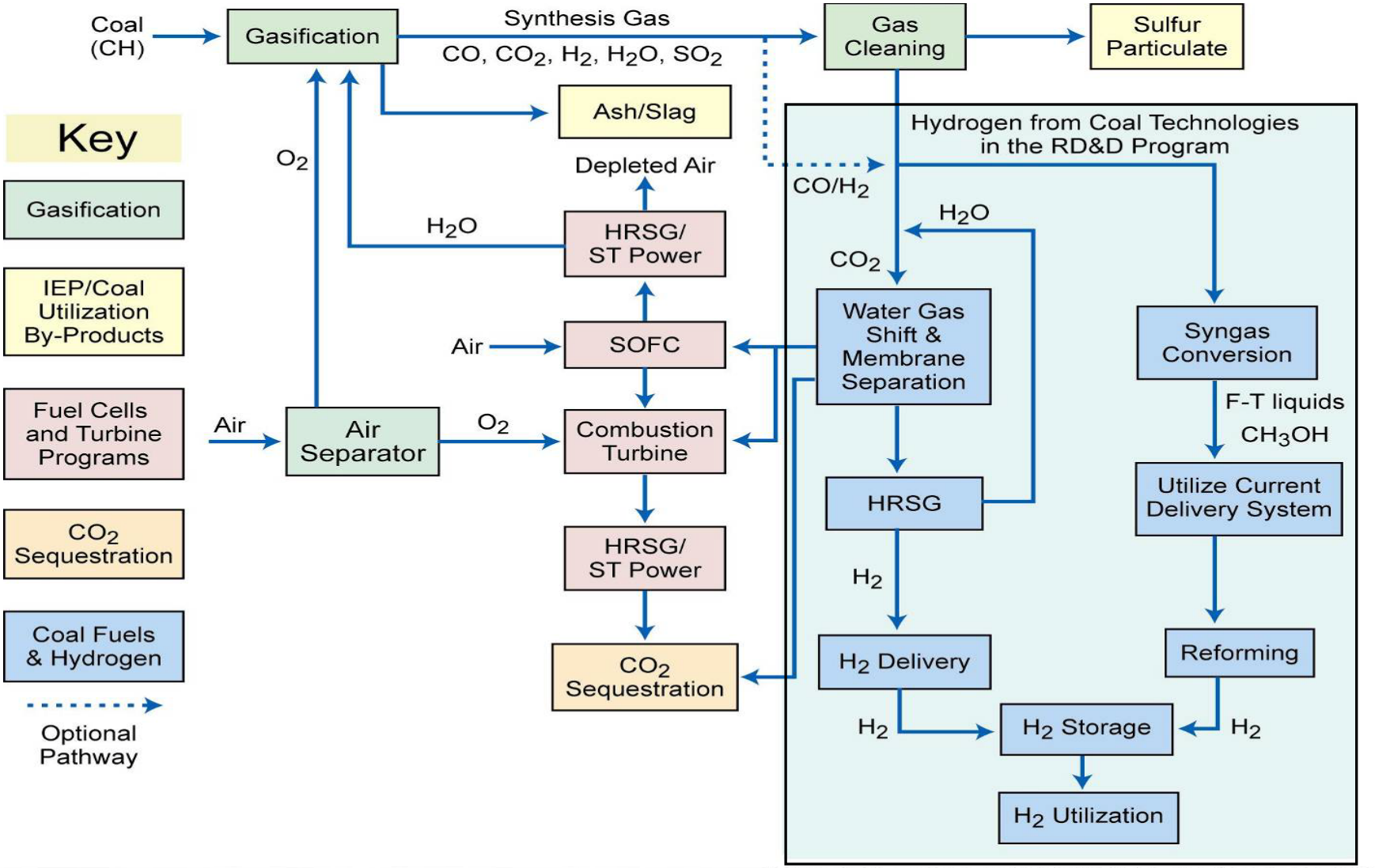
Cumulative Cost and Performance Impact of R&D for Gasification-Based Power Generation

Case Title	Efficiency (% HHV)	Delta* Efficiency (% points)	TPC** ($/kW)	Delta* TPC** ($/kW)	20-yr Levelized COE (¢/kWh)	Delta* COE (¢/kWh)
Reference IGCC	30.4	0	2,718	0	11.48	0
Adv "F" Turbine	31.7	1.3	2,472	-246	10.64	-0.84
Coal Feed Pump	32.5	0.8	2,465	-7	10.54	-0.10
85% CF	32.5	0.0	2,465	0	10.14	-0.40
WGCU/Selexol	33.3	0.8	2,425	-40	10.00	-0.14
WGCU/H_2Membrane	36.2	2.9	2,047	-378	8.80	-1.20
AHT-1 Turbine	38.0	1.8	1,855	-192	8.14	-0.66
ITM	38.3	0.3	1,724	-131	7.74	-0.40
AHT-2 Turbine	40.0	1.7	1,683	-41	7.61	-0.13
90% CF	40.0	0.0	1,683	0	7.36	-0.25
IGCC Pathway		+9.6%pts (+32%)		-1,035 (-38%)		-4.12 (-36%)
Advanced IGFC	56.3	+26%pts +85%	1,759	-959 (-35%)	7.45	-4.03 (-35%)

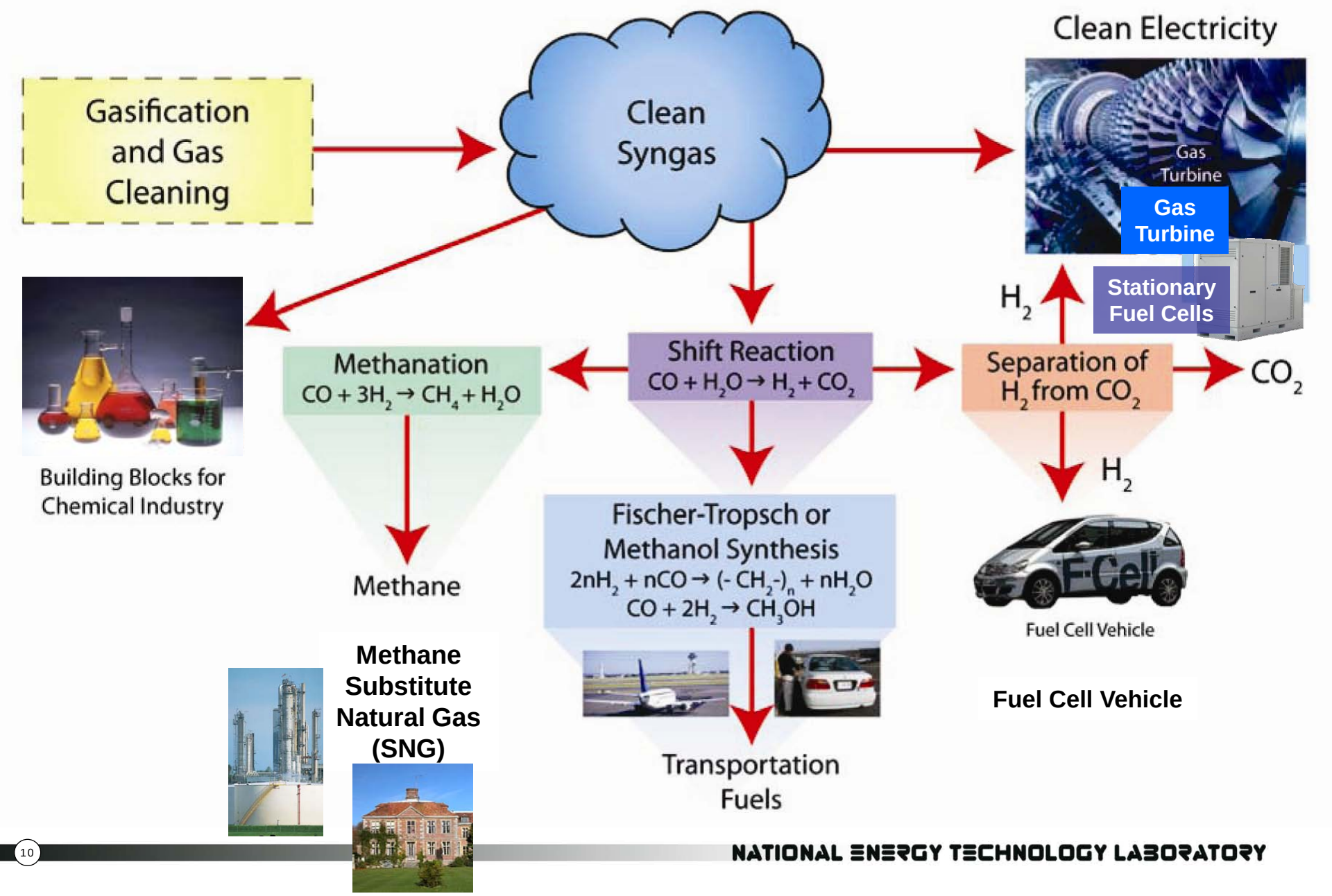
* Delta shown is the incremental change as each new technology is added to previous case configuration

** TPC is reported in January 2007 dollars and excludes owner's costs

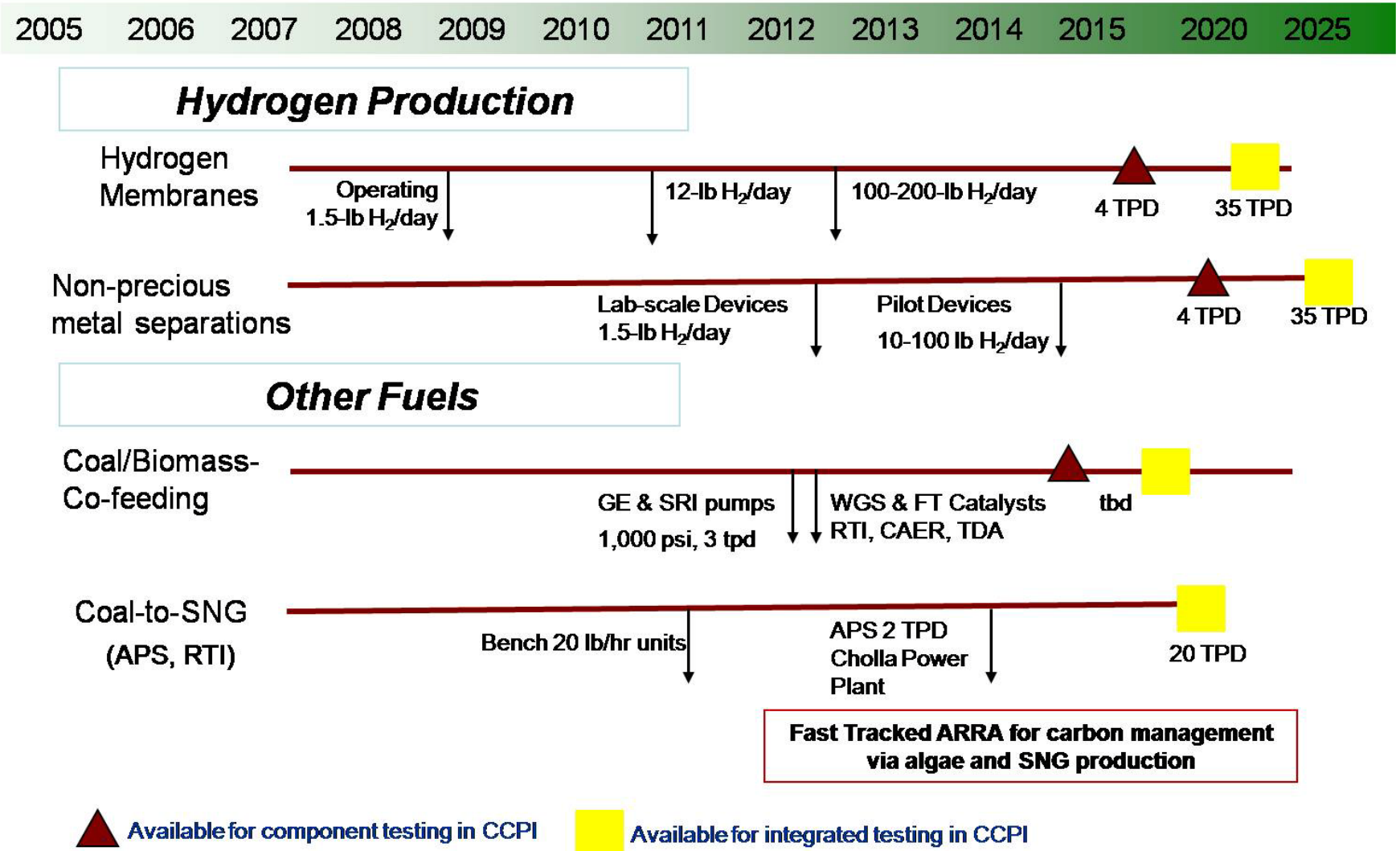
Technology Focus of the Hydrogen from Coal Program



Products from Coal-Derived Syngas

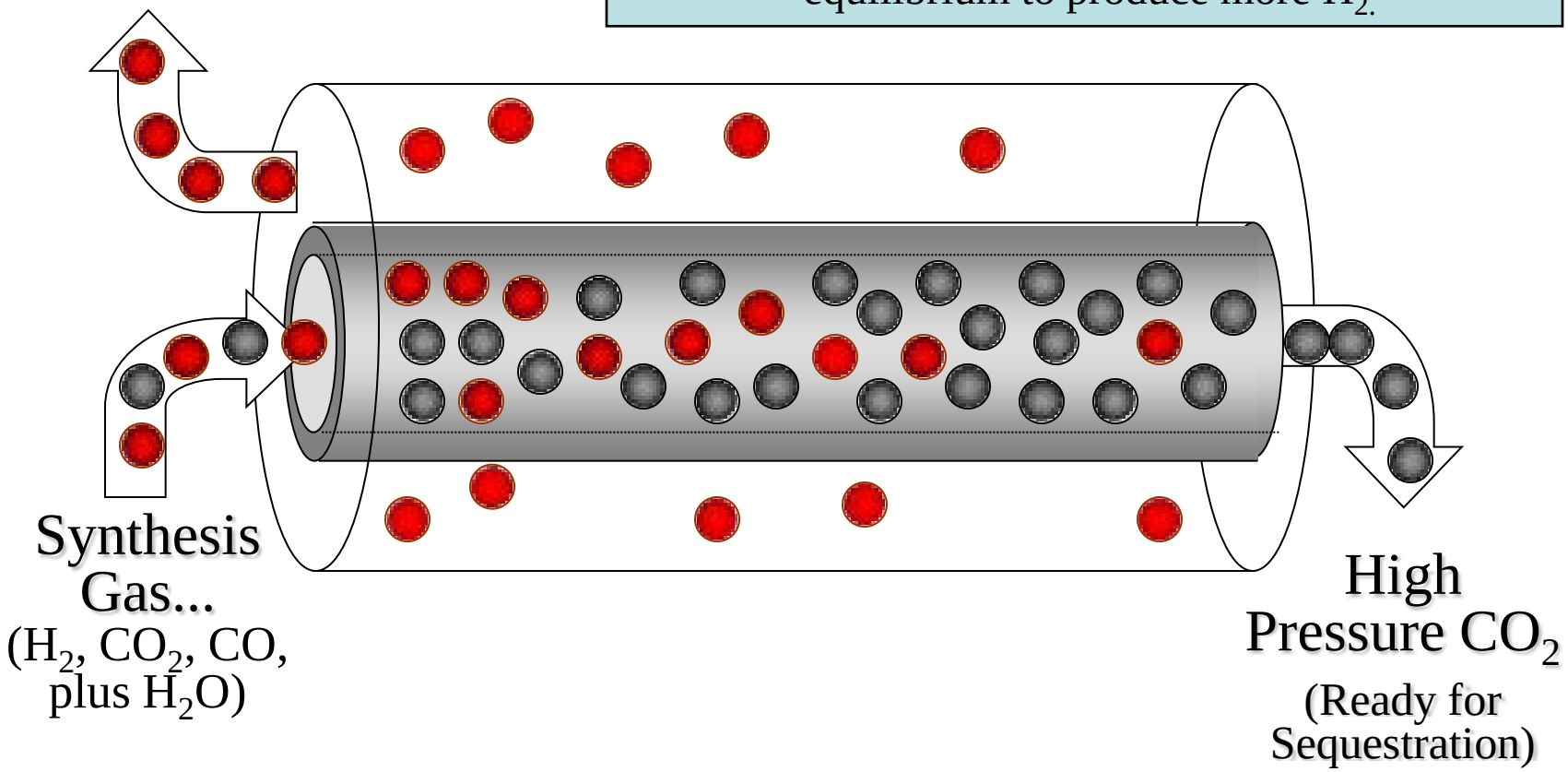


Fuels Program Targets



Hydrogen Separation Membrane

- WGS Reaction: $CO + H_2O \leftrightarrow CO_2 + H_2$
- High-T operation for favorable kinetics
- Membrane removes H_2 to "shift" unfavorable equilibrium to produce more H_2.

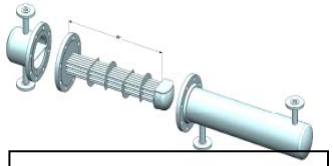


Membrane Development Status

- **Developers Achieving Targets**
- **Eltron tests under water-gas shift feed streams initiated; best alloy membrane has demonstrated a H_2 flux rate of 411 scfh/ft^2**
  - Lifetime testing reactor operated several tests to 600 hours; initial baseline membrane testing in H_2/N_2 feed streams show stable performance at 200 scfh/ft^2.
  - down-selected catalyst tested in streams with 20 ppm H_2S. Stable H_2 flux observed for 160 hours.

- **WPI achieved 359 scfh/ft^2 H_2 flux with 3-5 µm Pd/Inconel membrane at 442°C and 100 psi ΔP.**
  - Built engineering-scale prototype membrane (2"OD, 6"length, 8.8 µm).
  - Total test 63 days at 450°C, 15 psi ΔP, 80 scfh/ft^2 H_2 flux, 99.99% purity (calculates to 340 scfh/ft^2 H_2 flux)

WPI Pd/Inconel H_2 Separation Membranes

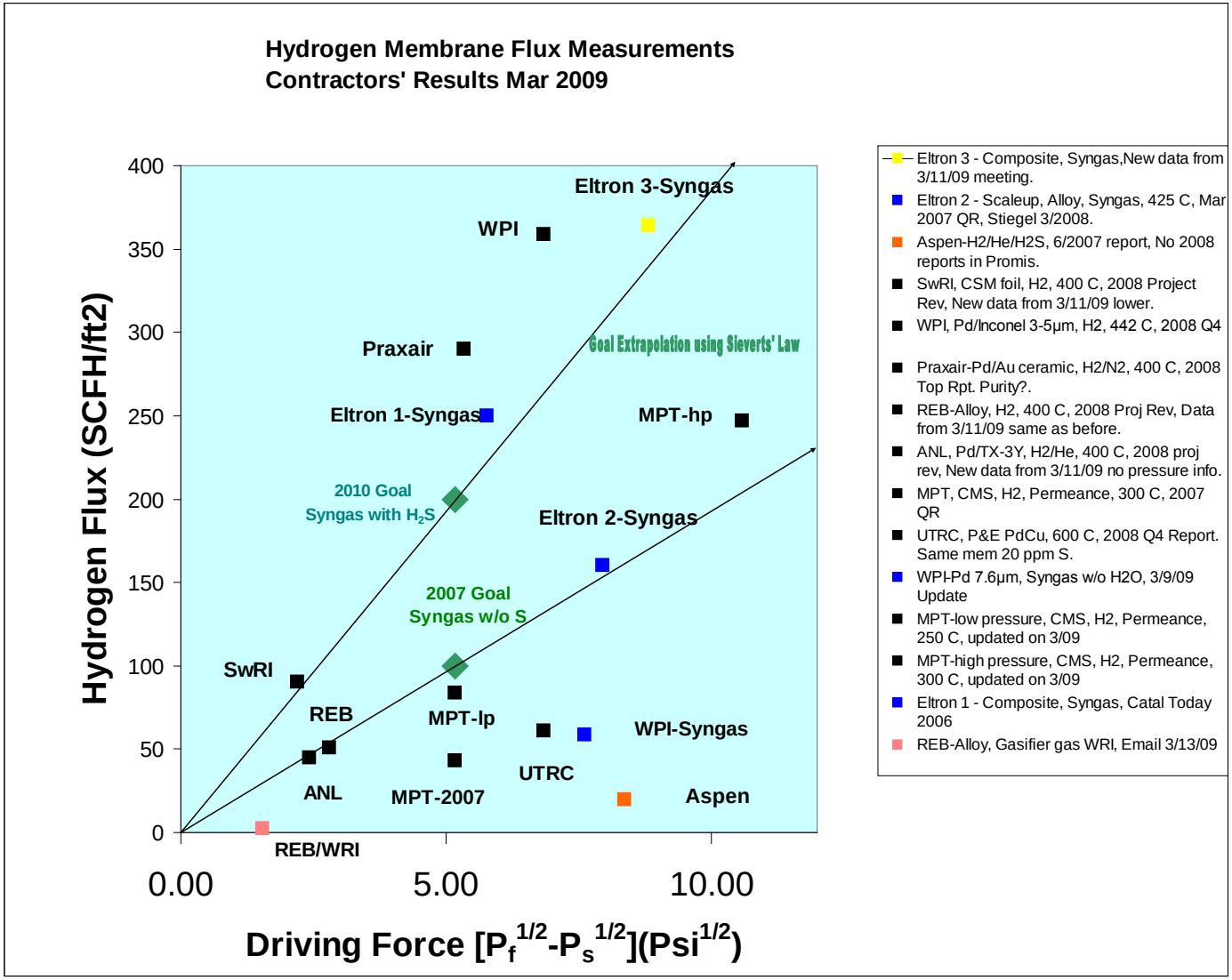


Prototype PDU Membrane Module Configuration

Image of H_2 Separator

- **UTRC tested five separators using PdCuTM alloy which showed increased surface stability in bench-scale tests**
  - Colloidal Pd/Nano Oxide membrane bundles show good hydrogen flux
- **Unbiased verification testing (NETL)**

Experimental Hydrogen Flux



Fuels Program FOA

- **Engineering Design of Advanced H_2 – CO_2 Separation Membranes**
  - Issued: March 30, 2010
  - Closing Date: May 17, 2010
  - Estimated Value: $25 million (20% cost share)
  - Project Duration: 4 years
  - Testing required with coal-derived syngas at target levels
  - Final deliverable to include an engineering design for scale-up to a 4 ton per day unit

Membrane Development Research Needs and Issues

- **Demonstration at Larger Scales**
  - Moderate scale-up is planned
  - Costs for demonstrations are high (equipment costs)
  - Limited facilities for testing with coal derived syngas streams and conditions (P,T) not representative
  - Effect of contaminants in real derived syngas may have a severe impact on membrane performance and/or lifetime
    - Sulfur effects have been examined and seem to be moderate and reversible

Alternative Membrane Approaches

Background:

- **Comprehensive assessment of precious metal production showed:**
  - Current membranes based on Pd – high metal costs
  - Global deposits quite limited to South Africa and Russia
  - Less than 10 significant mining companies in the world; declining production
  - Mining practices and refining have significant CO_2 footprint
  - Commercial deployment using precious metals have potentially global economic and environmental impacts
  - Could see undue influence and therefore restrain the ability to deliver centrally produced hydrogen via membrane separation technologies

Recent FOA: **Non-Precious Metals H_2 Separation Membrane Lab-scale Research**

Total Award Value: **$5,000,000 (cost share 20%)**

Non-Precious Metal Membrane Development Projects

- **Six New Efforts**
  - Ceramatec: Ceramic Membranes
  - Worcester Polytechnic Institute: Molten Metal Membranes
  - University of Nevada: Amorphous Alloy Membranes
  - Colorado School of Mines: Nanoporous Metal Carbide Membranes
  - Southwest Research Institute: Thin Film Amorphous Alloy Membranes
  - University of Texas-Dallas: Mixed Matrix Membranes

NETL CBTL Research Initiatives
Funding / Timeline

Areas of Interest

1. Feeding Coal/Biomass Mixtures Across a Pressure Gradient
2. Characterization of the Products from Gasifying Coal/Biomass Mixtures
3. Determine Contaminate Effects on FT and WGS Processes

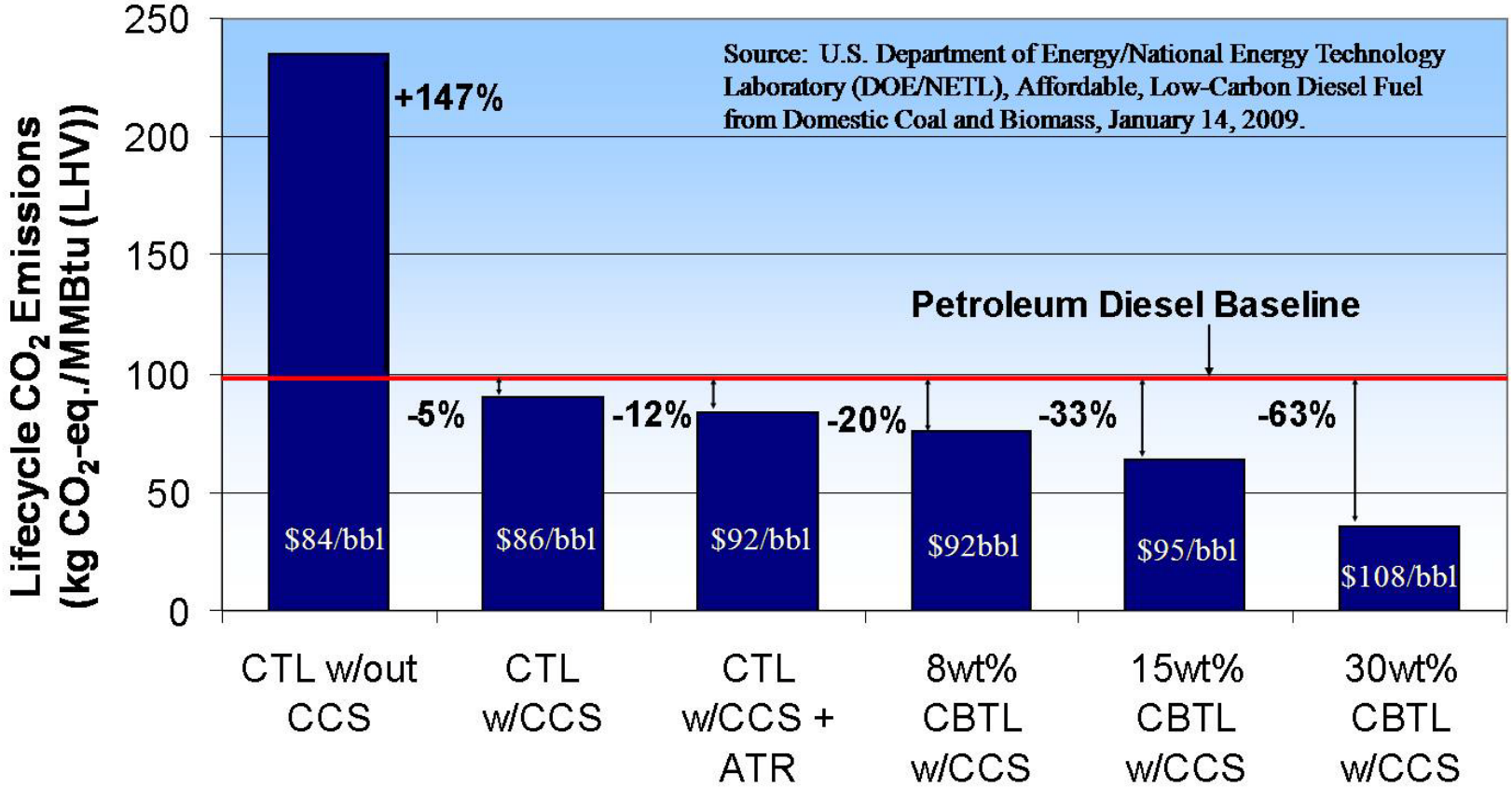
Total Award Value

- $7,200,000 (cost share varied 20% to 35%).

Awards made to:

- Feeding Pumps:
  - **Southern Research Institute, and GE**
- Products of CB Gasifier:
  - **GE**
- Contaminate Effects:
  - **Research Triangle Institute, TDA, and University of Kentucky**

CBTL Emission Benefits



- **Lowers carbon footprint from coal by using renewable resource**
- **Allows biomass to take advantage of economies of scale associated with coal**
- **Applicable for stand-alone and/or polygeneration/co-production**
- **Produces "drop-in" fuels**

Current CBTL FOA

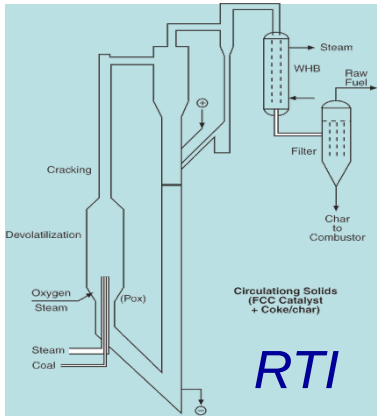
- **Co-Production of Power, Fuels and Chemicals via Coal/Biomass Mixtures**
  - Issued: April 27, 2010
  - Closing Date: May 28, 2010
  - Estimated Value: $5 million (20% cost share)
  - Project Duration: 1 – 3 years
- **Three areas**
  - Pre-processing and Conditioning of CB Mixtures for Simultaneous Feed
  - Reactive Properties of CB Mixed Fuels
  - Design Concepts for Co-Production

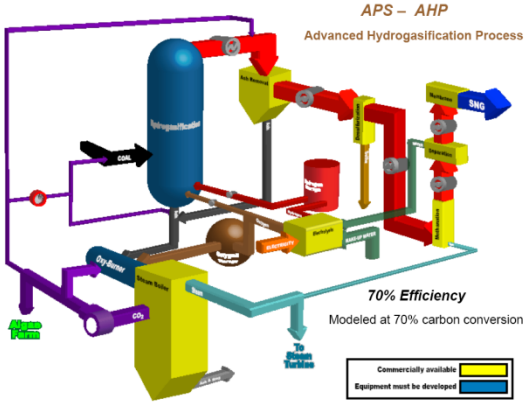
Additional Fuels Program Projects

- **Coal to SNG projects at bench-scale; initial testing of reactor systems begun.**

- **Indirect CTL conversion; conducting systems and life-cycle analyses; lab-scale advanced catalysis science testing being conducted (ICRC, UKY).**

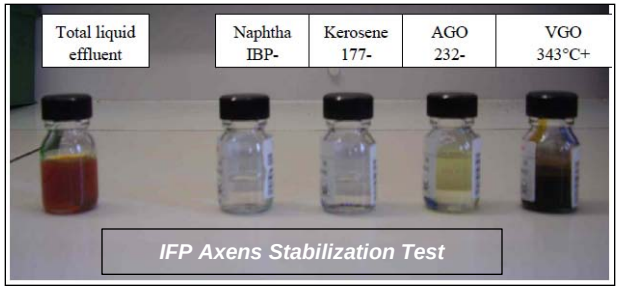
- **Direct CTL conversion; upgrading and characterization of raw DCL liquids; Conduct an engineering assessment of carbon emission, water use and preliminary economics of a moderate scale DCL facility**





Arizona Public Services

Nikiski AK FT Plant



NETL Studies and Systems Analyses

1. **NETL Report "Baseline Technical and Economic Assessment of a Fischer-Tropsch Liquids Facility**
   a. **Small Scale 10,000 bpd facility;**
      Stand-alone and Co-sited with IGCC system
   b. **Commercial 50,000 bpd facility;** Baseline

2. **Coal/Biomass-to-Liquids (CBTL);**
   Done with US Air Force

3. **Affordable Low-Carbon Diesel Fuel from Coal & Biomass**
   Finds CTL fuel is compatible with current fuel distribution infrastructure, used directly in existing diesel vehicles, & economically competitive with petroleum-derived diesel when crude price equal to or above $86 /bbl.

CTL Technology – Economics Key Issue

- Conceptual plant designs estimate $5.5–6.95 billion required for initial 50,000-bpd plants (Capital cost = $110–139K/daily barrel)
- Plants may be profitable with crude oil price between $83–92/bbl with carbon storage (carbon storage estimated to account for $4/barrel of the required selling price)

Benefits of CBTL in United States

- Take advantage of carbon uptake benefits of biomass
- Coal can offset variability of biomass supply – coal as a "flywheel"
- Co-feeding allows biomass to take advantage of economies of scale
- Low-cost of coal as a feedstock
- Large coal reserve base; estimates suggest significant biomass reserves may be available
- Liquid fuels via F-T process are zero-sulfur and have environmental benefits

Key Activity/Component Funding

Technology Area/Budget Line Funding ($000's)			
Key Activity /Component	**FY 2009 Enacted**	**FY2010 Enacted**	**FY2011 CBR**
1 Hydrogen-from-Coal			
a. Hydrogen Fuels	15,073	18,000	10,800
b. Coal-Biomass	7,250	4,250	0
2 HQ, SBIR/STTR, DCAA, APP Contractor Support, Outreach, etc.	2,677	2,750	1,200
Total	**25,000**	**25,000**	***12,000***

For Additional Information

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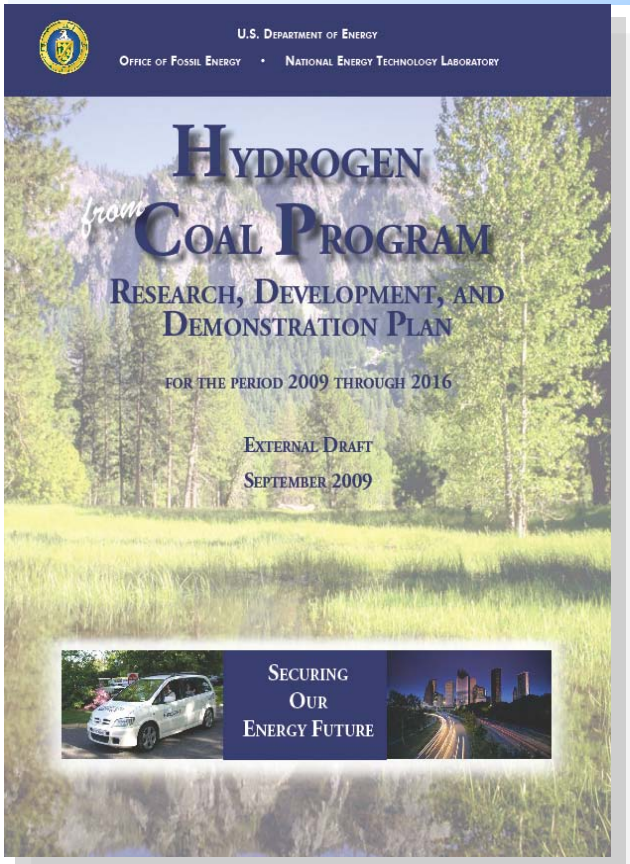

NETL

www.netl.doe.gov

Office of Fossil Energy

www.fe.doe.gov

Additional Slides

Hydrogen Separation Technical Targets

Hydrogen from Coal Multi-Year RD&D Plan

Performance Criteria	Units	2007 Target	2010 Target	2015 Target
Flux [(a)]	$ft^3/hour/ft^2$	100	200	300
Temperature	ºC	400–700	300–600	250–500
S Tolerance	ppmv	----	20	>100
Cost	$\$/ft^2$	150	100	<100
WGS Activity	-	Yes	Yes	Yes
ΔP Operating Capability [(b)]	psi	100	Up to 400	Up to 800 to 1,000
Carbon Monoxide Tolerance	-	Yes	Yes	Yes
Hydrogen Purity	%	95%	99.5%	99.99%
Stability/Durability	years	1	3	5

[a] For 100 psi ΔP (hydrogen partial pressure basis)
[b] ΔP = total pressure differential across the membrane reactor

Barriers to Creation of a Significant U.S. Industry

- ✓ ***Economic Risk*** — ***World oil price volatility is the single greatest impeding the deployment of CTL facilities; petroleum industry capital drawn to higher profit producing crude oil E&P***
- ✓ ***Technical Uncertainty*** — ***Although plant components have been operated at commercial scale, the efficient integration of advanced coal gasification with advanced F-T synthesis technologies poses significant risk***
- ✓ ***Needed Incremental Investment in Infrastructure*** — ***CTL facilities will require the use of large quantities of coal driving a significant expansion of the U.S. coal mining industry; current railroads and railcars are inadequate to handle projected increases coal demand; additional barge capacity will likely be required; mine mouth plants coal-fuel plants will need pipeline connects***
- ✓ ***Ready Availability of Critical Materials, Resources and Skills*** — ***Multiple CTL plants built concurrently worldwide will create competition for critical process equipment, engineering, labor skills and materials which the U.S. does not presently possess***
- ✓ ***Environmental Concerns*** — ***As a carbon-rich fossil fuel, coal releases large quantities of carbon dioxide when converted into fuels and power which must be economically controlled; and NIMBY***

A Path Forward…

- **Build and Operate a few Pioneer Plants**
  - Subsidize the completion of 3 to 5 front-end engineering design studies
  - Facilitate "Early Commercial Learning Experience"
  - Identify barriers to process improvement and cost reduction
  - Develop a greater understanding of the issues surrounding carbon capture, transport, sequestration, monitoring and verification of permanent storage

- **Initiate a Program of Targeted Research**
  - Build a comprehensive R&D plan built on barriers derived from actual operation of pre-commercial sized plants

- **Investigate Financial Incentives**
  - Tax Credits (EPACT 2005 Section 1307)
  - Loan Guarantees
  - Guaranteed Price Floors

- **Formulate and test F-T fuels for early commercial markets**
  - DOD, Clean Cities, Northeast Home Heating Oil Reserve

- **Involve, Coordinate, and Exchange Information with Interested Foreign Governments**