Gasification Technologies

Clean, Secure and Affordable Energy Systems

IGCC and Clean Coal Technologies Conference
Tampa, FL
June 28, 2005

Gary J. Stiegel, Technology Manager - Gasification
National Energy Technology Laboratory, US Department of Energy
Presentation Outline

- History
- What is Gasification
- Gasification vs. Combustion
- Types of Gasifiers
- Status of Commercialization
- Environmental Benefits
  - Comparison of Gasification vs. Conventional Plants
- Technology Issues and Developments
  - Gasification
  - $O_2$ Separation
  - Gas Cleanup
  - Hydrogen Production and Separation
- FutureGen
- Summary
History of Gasification

Town Gas

Town gas, a gaseous product manufactured from coal, supplies lighting and heating for America and Europe. Town gas is approximately 50% hydrogen, with the rest comprised of mostly methane and carbon dioxide, with 3% to 6% carbon monoxide.

- First practical use of town gas in modern times was for street lighting
- The first public street lighting with gas took place in Pall Mall, London on January 28, 1807
- Baltimore, Maryland began the first commercial gas lighting of residences, streets, and businesses in 1816
History of Gasification

- Used during World War II to convert coal into transportation fuels (Fischer – Tropsch)
- Used extensively in the last 50+ years to convert coal and heavy oil into hydrogen – for the production of ammonia/urea-based fertilizer
- Chemical industry (1960’s)
- Refinery industry (1980’s)
- Global power industry (Today)
What is Gasification?

Oxygen

Coal

Water

Extreme Conditions:
- 1,000 psig or more
- 2,600 °F
- Corrosive slag and H₂S gas

Products (syngas)
- CO (Carbon Monoxide)
- H₂ (Hydrogen)
[CO/H₂ ratio can be adjusted]

By-products
- H₂S (Hydrogen Sulfide)
- CO₂ (Carbon Dioxide)
- Slag (Minerals from Coal)

Gas Clean-Up Before Product Use

Clean-Up

Before Product Use
Gasification Chemistry

Coal → Gasification with Oxygen
C + \( \frac{1}{2} \)O\(_2\) ⇌ CO

Combustion with Oxygen
C + O\(_2\) ⇌ CO\(_2\)

Gasification with Carbon Dioxide
C + CO\(_2\) ⇌ 2CO

Gasification with Steam
C + H\(_2\)O ⇌ CO + H\(_2\)

Gasification with Hydrogen
C + 2H\(_2\) ⇌ CH\(_4\)

Water-Gas Shift
CO + H\(_2\)O ⇌ H\(_2\) + CO\(_2\)

Methanation
CO + 3H\(_2\) ⇌ CH\(_4\) + H\(_2\)O

Oxygen → Gasification with Oxygen
C + \( \frac{1}{2} \)O\(_2\) ⇌ CO

Combustion with Oxygen
C + O\(_2\) ⇌ CO\(_2\)

Steam → Gasification with Steam
C + H\(_2\)O ⇌ CO + H\(_2\)

Gasifier Gas Composition (Vol %)

- H\(_2\) 25 - 30
- CO 30 - 60
- CO\(_2\) 5 - 15
- H\(_2\)O 2 - 30
- CH\(_4\) 0 - 5
- H\(_2\)S 0.2 - 1
- COS 0 - 0.1
- N\(_2\) 0.5 - 4
- Ar 0.2 - 1
- NH\(_3\) + HCN 0 - 0.3
- Ash/Slag/PM
Combustion Chemistry

Coal + Air → Combustion with Oxygen

\[ \text{C} + \frac{1}{2} \text{O}_2 \rightarrow \text{CO}_2 \]

\[ \frac{1}{2} \text{O}_2 + \text{H}_2 \rightarrow \text{H}_2\text{O} \]

Combustion Gas Composition (Vol %)

- \text{CO}_2: 13.5
- \text{H}_2\text{O}: 9.8
- \text{SO}_2: 0.4
- \text{N}_2: 73.2
- \text{O}_2: 3.2

Ash/Slag/PM
Gasification Phase Diagram
(Coal: Illinois #6 Dry Feed)
So what can you do with CO and H₂?

- Syngas
  - Building Blocks for Chemical Industry
  - Transportation Fuels (Hydrogen)
  - Clean Electricity
Chemicals from Coal - Final Products

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

Coal → Acetic Anhydride → Acetic Acid

Courtesy: Eastman Chemical
Gasification-Based Energy Production System Concepts

- Particulate Removal
- Gas Cleanup
- Shift Reactor
- Synthesis Gas Conversion
  - Hydrogen Separation
  - Carbon Dioxide Sequestration
  - Fuel Cells
  - Gas Turbine
  - Generator
  - Electric Power
  - Electric Power
  - Stack

- Gaseous Constituents
- Air Separator
- Oxygen
- compressed Air
- Air
- Heat Recovery Steam Generator
- Steam
- Steam Turbine
- Generator
- Electric Power

- Solids
- Coal, Petroleum coke, Biomass, Waste, etc.

- Fly Ash By-Product
- Sulfur By-Product
- Fly Ash By-Product
- Sulfur By-Product
- Slag By-Product

- Particulates
- Gas Turbine
- Generator
- Electric Power

- Dyes and Chemicals

- IGCC and Clean Coal Technologies Conference, Tampa, FL / GJS / June 28, 2005
Conventional Coal Plant

100 MW

85 MW

40 MW

45 MW

15 MW

40 % Efficiency

Courtesy: EPRI
Gas Turbine “simple cycle”

100 MW → 62 MW

38 MW

38% Efficiency

Courtesy: EPRI
Coal-Based IGCC Power Plant

Net Coal to Power: 30 + 22 – 9 = 43%

100MW

9MW

5MW

18MW

22MW

25MW

47MW

15MW

50MW

80MW

30MW

Cooling Loss

Oxygen Plant

Entrained-Flow Gasifier

Second Stage Coal

Water

Syngas

Char

Particulate Removal

Steam

Steam

Liquid Sulfur By-Product

Sulfur Removal & Recovery

Fuel-Gas Preheat

Char

Steam

Slag

First Stage Slag

Syngas Cooler

Water

Slag Quench

Entrained-Flow Gasifier

Second Stage Coal

Water

Char

Particulate Removal

Steam

Steam

Liquid Sulfur By-Product

Sulfur Removal & Recovery

Fuel-Gas Preheat

Char

Steam

Net Coal to Power: 30 + 22 – 9 = 43%

Courtesy: EPRI

Net Coal to Energy: 30 + 22 – 9 = 43%

Cooling Loss
### Gasifier Types

<table>
<thead>
<tr>
<th>Flow Regime</th>
<th>Moving (or &quot;Fixed&quot;) Bed</th>
<th>Fluidized Bed</th>
<th>Entrained Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combustion Analogy</td>
<td>grate fired combustors</td>
<td>fluidized bed combustors</td>
<td>pulverized coal combustors</td>
</tr>
<tr>
<td>Fuel Type</td>
<td>solids only</td>
<td>solids only</td>
<td>solids or liquids</td>
</tr>
<tr>
<td>Fuel Size</td>
<td>5 - 50 mm</td>
<td>0.5 - 5 mm</td>
<td>&lt; 500 microns</td>
</tr>
<tr>
<td>Residence Time</td>
<td>15 - 30 minutes</td>
<td>5 - 50 seconds</td>
<td>1 - 10 seconds</td>
</tr>
<tr>
<td>Oxidant</td>
<td>air- or oxygen-blown</td>
<td>air- or oxygen-blown</td>
<td>almost always oxygen-blown</td>
</tr>
<tr>
<td>Gas Outlet Temp.</td>
<td>400 - 500 °C</td>
<td>700 – 900 °C</td>
<td>900 – 1400 °C</td>
</tr>
<tr>
<td>Ash Handling</td>
<td>slagging and non-slagging</td>
<td>non-slagging</td>
<td>always slagging</td>
</tr>
<tr>
<td>Commercial Examples</td>
<td>Lurgi dry-ash (non-slagging), BGL (slagging)</td>
<td>GTI U-Gas, HT Winkler, KRW</td>
<td>GE Energy, Shell, Prenflo, ConocoPhillips, Noell</td>
</tr>
<tr>
<td>Comments</td>
<td>&quot;moving&quot; beds are mechanically stirred, fixed beds are not</td>
<td>bed temperature below ash fusion point to prevent agglomeration</td>
<td>not preferred for high-ash fuels due to energy penalty of ash-melting</td>
</tr>
<tr>
<td></td>
<td>gas and solid flows are always countercurrent in moving bed gasifiers</td>
<td>preferred for high-ash feedstocks and waste fuels</td>
<td>unsuitable for fuels that are hard to atomize or pulverize</td>
</tr>
</tbody>
</table>

Note: The "transport" gasifier flow regime is between fluidized and entrained and can be air- or oxygen-blown.
Cumulative Worldwide Gasification Capacity and Growth

MWth Syngas

- Planned
- Operating

Gasification by Technology

MWtH Syngas

Planned
Operating

Shell
Sasol Lurgi
GE
Other
ConocoPhillips
Gasification by Product

MWth Syngas

FT liquids
Chemicals
Power
Gaseous fuels
Not specified

Planned
Operating
Gasification by Primary Feedstock

MWth Syngas

Planned

Operating

Coal

Petroleum

Gas

Petcoke

Biomass/Waste

0

5,000

10,000

15,000

20,000

25,000

30,000

35,000
Gasification by Region

Planned
Operating

MWth Syngas

Africa/ME
Asia/Aust.
Europe
No. Amer.
Cent/So. Amer

0
5,000
10,000
15,000
20,000
25,000
30,000
Commercial-Scale Coal-Based IGCC Power Plants

• U.S.
  – Southern California Edison's 100 MWe Cool Water Coal Gasification Plant (1984-1988)
  – SG Solutions Gasification Plant (50-50 owned by Wabash River Energy Ltd & Wabash Valley Power Assoc.) supplying syngas fuel to Cinergy’s 262 MWe Wabash River Generating Station (1995 - present) and currently using primary fuel of petcoke after completing the coal demonstration
  – Tampa Electric's 250 MWe Polk Power Station (1996-present)

• Foreign
  – NUON/Demkolec’s 253 MWe Buggenum Plant (1994-present)
  – ELCOGAS 298 MWe Puertollano Plant (1998-present)
IGCC Technology in Early Commercialization

U.S. Coal-Fueled Plants

- **Wabash River**
  - 1996 Powerplant of the Year Award*
  - Achieved 77% availability **

- **Tampa Electric**
  - 1997 Powerplant of the Year Award*
  - First dispatch power generator
  - Achieved 90% availability **

Nation’s first commercial-scale IGCC plants, each achieving
> 97% sulfur removal
> 90% NO\textsubscript{x} reduction

*Power Magazine ** Gasification Power Block
Environmental Benefits
### Environmental Contrasts

<table>
<thead>
<tr>
<th></th>
<th>Combustion</th>
<th>Gasification</th>
</tr>
</thead>
<tbody>
<tr>
<td>sulfur converted to</td>
<td>SO$_2$</td>
<td>H$_2$S</td>
</tr>
<tr>
<td>sulfur capture</td>
<td>flue gas scrubbers, boiler</td>
<td>absorbed in physical or</td>
</tr>
<tr>
<td></td>
<td>limestone injection</td>
<td>chemical solvents</td>
</tr>
<tr>
<td>sulfur disposal</td>
<td>gypsum sold for wallboard</td>
<td>sold as H$_2$SO$_4$ or elemental S</td>
</tr>
<tr>
<td>nitrogen converted</td>
<td>NO$_x$</td>
<td>traces of NH$_3$ in syngas</td>
</tr>
<tr>
<td>to</td>
<td>(syngas combustion produces</td>
<td>(syngas combustion produces</td>
</tr>
<tr>
<td></td>
<td>low levels of NO$_x$)</td>
<td>low levels of NO$_x$)</td>
</tr>
<tr>
<td>NO$_x$ control</td>
<td>required</td>
<td>currently not needed for IGCC</td>
</tr>
<tr>
<td></td>
<td>(e.g., low-NO$_x$ burners,</td>
<td>(but tighter regs could require</td>
</tr>
<tr>
<td></td>
<td>staged combustion, SCR/SNCR)</td>
<td>SCR)</td>
</tr>
<tr>
<td>C is converted to</td>
<td>CO$_2$</td>
<td>mostly CO in syngas</td>
</tr>
<tr>
<td>CO$_2$ control</td>
<td>post-combustion removal from</td>
<td>pre-combustion removal from</td>
</tr>
<tr>
<td></td>
<td>diluted stream</td>
<td>concentrated stream</td>
</tr>
<tr>
<td>water requirements</td>
<td>much more steam cycle</td>
<td>some water needed for slurry,</td>
</tr>
<tr>
<td></td>
<td>cooling water needed</td>
<td>steam cycle and process needs</td>
</tr>
</tbody>
</table>
The Wabash River Plant in Terre Haute, Indiana, was repowered with gasification technology.
Tampa Electric (TECO) Clean Coal Project
A Case Study for Cleaner Air

TECO's coal-to-gas plant in Polk County, FL, is the pioneer of a new type of clean coal plant.

<table>
<thead>
<tr>
<th>Emissions (Pounds per Million Btus)</th>
<th>Older Coal Plant</th>
<th>Fleet Avg.</th>
<th>TECO CCT Plant</th>
<th>Older Coal Plant</th>
<th>Fleet Avg.</th>
<th>TECO CCT Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO\textsubscript{2}</td>
<td>2.07</td>
<td>1.2</td>
<td>0.1</td>
<td>0.6 to 1.2</td>
<td>0.47</td>
<td>0.07 (15ppm)</td>
</tr>
<tr>
<td>NO\textsubscript{x}</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Comparison of Environmental Factors
Pulverized Coal-Fired, NGCC, and IGCC Plants

- SO2 (lb/MWh)
- NOx (lb/MWh)
- PM10 (lb/MWh)
- CO2 (lb/1000 MWh)
- Total Solids (lb/100 MWh)
- Water Usage (gal/1000 MWh)

* Based on 1998 Parson study for DOE: “Market-Based Advanced Coal Power Systems”
# Coal-Fired Power Plant Emissions – Recent Permits

<table>
<thead>
<tr>
<th>Emissions</th>
<th>WePower SCPC</th>
<th>WePower PC</th>
<th>Indeck CFB</th>
<th>WePower IGCC</th>
<th>Wabash IGCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO2</td>
<td>0.15</td>
<td>0.18</td>
<td>0.15</td>
<td>0.03</td>
<td>0.133³</td>
</tr>
<tr>
<td>NOx</td>
<td>0.07</td>
<td>0.08</td>
<td>0.08</td>
<td>0.03</td>
<td>0.103</td>
</tr>
<tr>
<td>VOC</td>
<td>0.004</td>
<td>0.004</td>
<td>0.004</td>
<td>0.004</td>
<td>0.002</td>
</tr>
<tr>
<td>CO</td>
<td>0.12</td>
<td>0.12</td>
<td>0.11</td>
<td>0.03</td>
<td>0.045</td>
</tr>
<tr>
<td>PM/PM10</td>
<td>0.018</td>
<td>0.015</td>
<td>0.015</td>
<td>0.011</td>
<td>0.011</td>
</tr>
<tr>
<td>Hg (lb/10¹²Btu)</td>
<td>1.12</td>
<td>~ 2</td>
<td>4.0</td>
<td>0.5</td>
<td>3.24⁴</td>
</tr>
</tbody>
</table>

1. WePower SCPC and IGCC information from April 2003 Draft Environmental Impact Statement, Elm Road Generating Station, Volume 1, Public Service Commission of Wisconsin & Department of Natural Resources, Table 7-11, p. 157 (Pittsburgh 8 coal)
2. Wabash River Repowering Project, 1997 and 1998 average reported to IDNR, including fuel oil (Illinois 6 coal)
3. Wabash River has demonstrated 0.03 lb/MMBtu SOx, but operates nearer the 0.20 lb/MMBtu permit for economic reasons
4. Electric Utility Steam Generating Unit Mercury Test Program, USEPA, October 1999 (no controls)
5. "Project Summary for a Construction Permit Application from the Prairie State Generating Company, LLC", Illinois Environmental Protection Agency. BOILER STACK ONLY
7. "Analysis and Preliminary Determination for the construction and Operation Permits for the proposed Construction of an Electric Generation Facility for Elm Road Generating Station", October 2, 2003, Wisconsin Department of Natural Resources

*Source: ConocoPhillips*
Gasification Technologies Program

Clean, Affordable Energy Systems

Feedstocks
Flexibility

Gasification

Products/Byproducts Utilization

Gas Stream Cleanup

Gas Cleaning

H₂/CO₂ Separation

H₂

CO₂

Fuels/Chemicals

Fuel Cell

High Efficiency Turbine

Fuel

Electricity

Liquids Conversion

Co-Production
(co-funded activities)

Oxygen Membrane

Air Separation

Coal, biomass, pet. coke

Power

Process Heat/Steam

Fuels/Chemicals

Electricity
Major Technology Issues

**Oxygen Membrane**
- Durability of the Membrane
- Integration with Overall Process
- Low-rank Coal
- Injector Reliability
- Single Train Availability
- Durability of Refractory Material
- Durability and Accuracy of Monitoring Devices
- Alternative Feedstocks
- Feed System Reliability
- Heat Removal
- Temperature Measurement & Control

**Gas Cleaning**
- Cost-Effective Multi-Contaminant Control to Ultra-Clean Specifications
- Moderate Temperature
- Hg Removal at Elevated Temperatures
- Integrated Specifications with Downstream Process Requirements
- Integration with NOx Reduction Processes

**Gasification**
- Oxygen
- Fuel Gas
- CO₂
- H₂ – CO₂ Gas Separation
- Water-Gas Shift

**Fuel System Reliability**
- Heat Removal
- Temperature Measurement & Control

**Durability and Accuracy of Monitoring Devices**
Gasification Systems

Southern Company
- EPRI
- Kellogg, Brown & Root
- Siemens Westinghouse Power
- Southern Research (SRI)
- Rolls Royce – Allison Engine
- Lignite Energy Council
- Peabody Coal
- BNSF Railway

Development and demonstration of modular industrial scale gasification-based processes and components at Power Systems Development Facility (PSDF)
Gasification Systems

**PSDF & UND EERC TRDU**
Development and testing of transport gasification reactor
- Air-blown and O₂-blown
- Bituminous and low-rank coals

**Rocketdyne**
Develop and test technology for a novel plug flow gasifier with:
- Rapid mix injectors
- Actively cooled wall liner
- Dry feed system

**Stamet Pump**
Development of dry feed system

**Alstom**
Hybrid combustion-gasification using high temp chemical and thermal looping
- Solids transfer media
- Multiple reactors for oxidation, reduction, carbonation, and calcination of calcium compounds

**GE Global Research**
- California Energy Commission
Development of advanced gasification process for CO₂ separation and H₂ production

**NETL**
Oxygen Separations
Why Oxygen Separation Membrane Technology is Important

- In an IGCC plant, the air separation unit
  - Accounts for ~15% of the plant capital cost
  - Consumes ~ 10% of the gross power output

- Reducing capital cost and increasing efficiency of ASU
  - Improve economic viability of IGCC,
  - Stimulate commercial deployment.

- Systems studies of membrane technologies have shown significant potential
  - Increased net MWe
  - IGCC plant efficiency
  - Major decreased cost of oxygen production,
  - Overall decrease in Cost of Electricity (COE)
## Oxygen Production Technologies Comparison

<table>
<thead>
<tr>
<th></th>
<th>DELIVERED LIQUID OXYGEN</th>
<th>VPSA</th>
<th>CRYOGENIC</th>
<th>CERAMIC MEMBRANES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capacity Range</strong></td>
<td>&lt; 30 tpd</td>
<td>200 tpd</td>
<td>20 – 3500 tpd</td>
<td>Probably larger sizes &gt; 150 tpd</td>
</tr>
<tr>
<td><strong>Oxygen Purity</strong></td>
<td>99.5%+</td>
<td>90-94%</td>
<td>95%-99.9%</td>
<td>99%+</td>
</tr>
<tr>
<td><strong>Co-Products</strong></td>
<td>N/A</td>
<td>Difficult</td>
<td>Nitrogen, Argon, Liquids, etc.</td>
<td>Nitrogen Likely</td>
</tr>
<tr>
<td><strong>Power Consumption</strong>*</td>
<td>Higher</td>
<td>Lower</td>
<td>Base</td>
<td>Lowest</td>
</tr>
<tr>
<td><strong>Capital Cost</strong>*</td>
<td>Lowest</td>
<td>Lower</td>
<td>Base</td>
<td>Lower</td>
</tr>
<tr>
<td><strong>Oxygen Cost</strong>*</td>
<td>Highest</td>
<td>Low</td>
<td>Base</td>
<td>Lowest</td>
</tr>
<tr>
<td><strong>Operating Temperature</strong></td>
<td>-300 F/-184 C</td>
<td>Ambient</td>
<td>-300 F/-184 C</td>
<td>&gt;1100 F/&gt;600 C</td>
</tr>
<tr>
<td><strong>Age of the Technology</strong></td>
<td>75 Years</td>
<td>40 Years</td>
<td>100 Years</td>
<td>15 Years</td>
</tr>
</tbody>
</table>

* Assuming all targets are met

Table provided by Praxir
Mixed-Conducting Oxygen Separation Membranes

- Pressure driven operation
- Mixed ionic-electronic conduction, no external circuit
- Oxygen ion transport through oxide materials
- Infinite $O_2$ selectivity
- High temperature process - 900 °C
Membrane Air Separation Advantages

*Air Products*

<table>
<thead>
<tr>
<th></th>
<th>ITM Oxygen</th>
<th>Cryo ASU</th>
<th>Δ %</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGCC Net Power (MWe)</td>
<td>438</td>
<td>409</td>
<td>+7</td>
</tr>
<tr>
<td>Net IGCC Efficiency (% LHV) (% HHV)</td>
<td>41.8</td>
<td>40.9</td>
<td>+2</td>
</tr>
<tr>
<td>Oxygen Power Req’t (kWh/ton)</td>
<td>147</td>
<td>235</td>
<td>-37</td>
</tr>
<tr>
<td>Oxygen Plant Size (sTPD)</td>
<td>3,200</td>
<td>3,040</td>
<td>+5</td>
</tr>
<tr>
<td>Oxygen Plant Cost ($/sTPD)</td>
<td>13,000</td>
<td>20,132</td>
<td>-35</td>
</tr>
<tr>
<td>Total IGCC Cost ($,000)</td>
<td>447,000</td>
<td>448,000</td>
<td>-----</td>
</tr>
<tr>
<td>IGCC Specific Cost ($/kW)</td>
<td>1,020</td>
<td>1,094</td>
<td>-7</td>
</tr>
</tbody>
</table>

IGCC plant cost reduced 7%, plant efficiency increase 2% with >35% cost and energy savings in oxygen production
APCI Air Separation ITM Modules

- Test membrane modules
  - FY06 – 5 TPD
  - FY08 – 25 TPD

- Offer commercial air separation modules
  - Post- FY09 demos of IGCC and FutureGen
Gas Cleanup
Gas Cleanup

- Particulate Removal
- Mercury Removal
- Shift Conversion
- COS Hydrolysis
- Acid Gas Removal
- Sulfur Recovery
- Tail Gas Treating
- SCOT Process
Synthesis Gas Cleanup – Priorities

- Deep cleaning technologies required to meet future environmental regulations
  - “Meet Rectisol performance at equal or lower cost than amine systems”

- Better definition of contaminants and required levels (particulates, H₂S, COS, CO₂, NH₃, volatile metals, carbonyls)

- Need to operate closer to downstream process requirements (e.g., gas turbine, syngas conversion)

- High cost of particulate and chemical removal (need fewer unit operations)
Synthesis Gas Cleanup Priorities

- **Cold Gas Cleanup (ambient)**
  - Opportunities to improve conventional technologies
  - Removal of heat stable salts
  - Need to develop new approaches

- **Warm Gas Cleanup (300-700 °F)**
  - Develop technologies that operate above the dew point of the gas stream – more efficient operation
  - Development of technologies for multi-contaminant removal (e.g., mercury, arsenic, selenium, ammonia, particulates, etc.)

- **Particulate Filtration**
  - Development of more durable, reliable, and cost effective filters (Useful life - three years)
  - Simpler, cheaper approaches to solids removal
Ultra Gas Cleaning

RTI International
- SRI International
- MEDAL
- Sud Chemie, Inc.
- University of Texas at Austin
- Eastman Chemical
- KBR
Develop processes to reduce H2S and CO2 (membranes), NH3 (sorbents), and HCl (Na2CO3) to ppb levels
Pilot testing at Eastman Chemical

NETL In-House Research
- NETL with CrystaTech
- Selective Catalytic Oxidation of H2S (SCOHS)
Single-step process for converting H2S to elemental sulfur
Development and evaluation of sorbents and solvents

Siemens Westinghouse Power Corporation
- Gas Technology Institute
Develop a two-stage process to reduce H2S, HCl, and particulates to ppb levels

ConocoPhillips
Test cyclone-filter hybrid particle removal system at the Wabash River IGCC Plant
New Projects in Ultra Gas Cleaning
(Clean to Near-Zero at Warm-Gas Temperatures)

TDA Research
Development of single sorbent process for removal of multiple trace metals (Hg, As, Se, Cd)

Gas Technology Institute
- University of California at Berkeley
- ConocoPhillips

Integrated multi-contaminant process removing H$_2$S, NH$_3$, HCl, and heavy metals (Hg, As, Se, Cd) in single process reactor
Includes high pressure conversion of H$_2$S to elemental sulfur

RTI International
- Eastman Chemical
- Nexant
- SRI
- SudChemie
- URS

Bulk removal of H$_2$S, COS, NH$_3$, and HCl in transport reactor to sub-ppm levels followed with fixed bed polishing plus trace heavy metals removal to near-zero

University of North Dakota Energy Environmental Research Center
- Corning

Develop a multi-contaminant control process using a sorbent-impregnated monolith fixed honeycomb structure
## Economic Advantage of Warm Gas Cleaning

<table>
<thead>
<tr>
<th>Capital Cost (in $millions)</th>
<th>Type</th>
<th>Base Case MDEA</th>
<th>RTI HTDS w/DSRP</th>
<th>Rectisol</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cool Gas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Temp Gas Cooling</td>
<td>12.3</td>
<td>0</td>
<td>12.3</td>
<td></td>
</tr>
<tr>
<td>NH\textsubscript{3} + AG Removal</td>
<td>19.3</td>
<td>38.7</td>
<td>49.7</td>
<td></td>
</tr>
<tr>
<td>S Recovery + Tail Gas Treat</td>
<td>32.3</td>
<td>7.4</td>
<td>27.6</td>
<td></td>
</tr>
<tr>
<td>Power Generation / HRSG</td>
<td>150.8</td>
<td>138.6</td>
<td>164.8</td>
<td></td>
</tr>
<tr>
<td>Delta Cost ($ millions)</td>
<td>0</td>
<td>-30.0</td>
<td>+39.6</td>
<td></td>
</tr>
<tr>
<td>Delta Cost (as % of Base)</td>
<td>0 %</td>
<td>-7.9%</td>
<td>+10.5%</td>
<td></td>
</tr>
</tbody>
</table>
Ultra-Clean Warm Gas Cleanup Progress

**RTI Process Development Testing at Eastman Chemical**

**Field Test Objective:**
First integrated evaluation of warm-gas contaminant cleanup technologies with coal-derived gas at a commercial gasification plant

**Preliminary Test Results at ChevronTexaco Montebello Research Center:**
Demonstrated H₂S and COS reduction at 600 to 900 °F from 8300ppmv to below 2 ppmv detection limit

**Potential Offered:**
- Achieve ultra-clean syngas
- Reduce total plant capital cost by $80-$100KW
- Improve thermal efficiency by 1-2 points
IGCC with Mercury Removal

COAL SLURRY
OXYGEN
BFW
HP STEAM

SYNGAS COOLER
PARTICULATE REMOVAL
SLAG
FINES

COS HYDROLYSIS

CONDENSER
WATER
MERCURY REMOVAL
ACID GAS REMOVAL

AIR
GAS TURBINE
HRSG

STEAM TURBINE
BFW

NETL
Mercury Removal System Performance and Cost

Estimates for an IGCC Reference Plant based on Tampa Electric Gasification Plant with GE Energy gasifier and sized to 287 MWe net

- Remove greater than 90% of mercury
  - To zero detectability limits

- Stable adsorption of mercury in carbon beds as mercury sulfide
  - Small volume of stabilized solid waste for controlled disposal (17 tons/yr or 0.06 tons/MW-yr)

- Incremental capital costs of $3.34/kW for carbon bed removal system
  - <0.3% of Total Capital Costs of IGCC plant cost of $1200/kW

- Incremental cost of electricity (COE) of $0.254/MWh for O&M and capital repayment
  - <0.6% of COE from IGCC plant of $44/MWh
  - Estimated cost of mercury removal in IGCC compares favorably (<10%) to costs of 90% removal in conventional PC power plant
Separations
Hydrogen and CO₂
# Summary of Hydrogen from Coal Cases

<table>
<thead>
<tr>
<th></th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasifier*</td>
<td>Conventional</td>
<td>Advanced</td>
<td>Advanced</td>
</tr>
<tr>
<td>Separation System</td>
<td>PSA</td>
<td>Membrane</td>
<td>Membrane</td>
</tr>
<tr>
<td>Carbon Sequestration</td>
<td>Yes (87%)</td>
<td>Yes (100%)</td>
<td>Yes (100%)</td>
</tr>
<tr>
<td>Hydrogen Production (MMSCFD)</td>
<td>119</td>
<td>158</td>
<td>153</td>
</tr>
<tr>
<td>Coal (TPD) as received</td>
<td>3000</td>
<td>3000</td>
<td>6000</td>
</tr>
<tr>
<td>Efficiency (%) (HHV basis)</td>
<td>59</td>
<td>75.5</td>
<td>59</td>
</tr>
<tr>
<td>Excess Power (MW)</td>
<td>26.9</td>
<td>25</td>
<td>417</td>
</tr>
<tr>
<td>Capital ($MM)</td>
<td>417</td>
<td>425</td>
<td>950</td>
</tr>
<tr>
<td>RSP of Hydrogen ($/MMBtu) / ($/kg)</td>
<td>8.18 / 1.10</td>
<td>5.89 / 0.79</td>
<td>3.98 / 0.54</td>
</tr>
</tbody>
</table>

* Conventional gasification technology assumes Texaco quench gasification; advanced gasification technology assumes advanced E-gas gasification.

- Membrane RD&D is estimated to reduce the cost of hydrogen from coal by 25%.
- Co-production of hydrogen and electricity can further reduce the cost of hydrogen production by 32%.

Source: Hydrogen from Coal, Mitretek Technical Paper MTR 2002-31, July 2002
Gas Separations - $\text{H}_2$ & $\text{CO}_2$

**NETL OSTA In-House Research**
- Pd and Pd/Cu alloy membranes, characterization, and standard test capabilities

**ANL**
- High-temperature ceramic membrane separating $\text{H}_2$ from syngas and water splitting

**Eltron Research**
- Coors Tek
- Sud Chemie, Inc.
- ANL
- NORAM Engineering & Construction Co.
- WahChang

**ORNL**
- Microporous inorganic membranes development and fabrication

**RTI**
- Alternate membrane materials, polymeric reverse selective membranes

**NETL OSTA In-House Research**
- Fluorinated Hydrocarbon Membranes

**Nexant**
- Simteche
- LANL
- Low-temperature approach to $\text{H}_2$ and $\text{CO}_2$ separation via hydrates
FutureGen: A Presidential Initiative

One-billion-dollar, 10-year demonstration project to create world’s first coal-based, zero-emission electricity and hydrogen plant

*President Bush, February 27, 2003*

- Produce electricity and hydrogen from coal using advanced technology
- Emit virtually no air pollutants
- Capture and permanently sequester CO₂
FutureGen Concept

- Hydrogen Pipeline
- Electricity
- CO₂ Pipeline
- Enhanced Oil Recovery
- Geologic Sequestration

Coal-Fired IGCC

Oil Pipeline
Keys Goals of FutureGen

- Verify effectiveness, safety, and permanence of carbon sequestration
- Establish standardized technologies and protocols for CO\textsubscript{2} measuring, monitoring, and verification
- Gain domestic and global acceptance for FutureGen concept

- Validate engineering, economic, and environmental viability of coal-based, near-zero emission technologies that by 2020 will—
  - Produce electricity with < 10\% increase in cost compared to non-sequestered systems
  - Produce H\textsubscript{2} at $4/MMBtu wholesale price ($0.48 /gal gasoline eq.) compared to today’s price of $0.70/gal gasoline eq.
## Cost Comparison of Advanced Gas Separation Technologies

<table>
<thead>
<tr>
<th>Resource</th>
<th>Technology</th>
<th>Hydrogen Cost ($/10^6 Btu) / ($/kg)</th>
<th>Year Technology is Available</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas*</td>
<td>Steam Methane Reforming, PSA, No Sequestration</td>
<td>5.54 / 0.75</td>
<td>Current</td>
</tr>
<tr>
<td>Natural Gas*</td>
<td>ITM Syngas Generation, Advanced Membrane Separation, CO₂ capture</td>
<td>4.15 / 0.56</td>
<td>2013</td>
</tr>
<tr>
<td>Coal</td>
<td>Gasification, Shift, PSA, No Sequestration</td>
<td>6.83 / 0.92</td>
<td>Current</td>
</tr>
<tr>
<td>Coal</td>
<td>Advanced Gasification, Membrane Separation, CO₂ Sequestration</td>
<td>5.89 / 0.79</td>
<td>2015+</td>
</tr>
<tr>
<td>Coal**</td>
<td>Advanced Gasification, Membrane Separation, Solid Oxide Fuel Cell for Co-Production of Power, CO₂ Sequestration</td>
<td>2.40 / 0.32</td>
<td>2020+</td>
</tr>
<tr>
<td>Biomass</td>
<td>Pyrolysis to bio-oil followed by steam reforming</td>
<td>(9-16) / (1.21-2.16)</td>
<td>2015+</td>
</tr>
<tr>
<td>Nuclear</td>
<td>Sulfur-Iodine Cycle (Thermochemical Process)</td>
<td>9.70 / 1.31</td>
<td>2020+</td>
</tr>
<tr>
<td>Electrolysis</td>
<td>Electricity Cost at 4 cents/kWh</td>
<td>(19-22) / (2.56-2.97)</td>
<td>Current</td>
</tr>
</tbody>
</table>
Opportunities for Coal Gasification

• Environmentally-preferred coal power generation
  – Near-zero levels of SO$_2$, NOx, PM, Hg achievable and demonstrated
  – Gasification well suited to CO$_2$ capture

• Hydrogen production from coal (FutureGen)
  – Gasification is key element for producing H$_2$–rich syngas

• Chemical and fertilizer industries
  – 2003 trade deficit – loss of jobs, plant closures
  – Replace natural gas with coal and waste gasification

• Production of synthetic natural gas
  – Significant interest because of high natural gas prices
Gasification - What Needs to be Done

- **Attain status of “Technology-of-choice”**
  - Exploit lower emissions potential and attain preferred environmental selection
    - Lower SOx, NOx, PM, Hg, Heavy Metals, Halides, Toxics
    - Address the CO2 issue
- **Achieve economic competitiveness**
  - Reduce capital and O&M costs
  - Transition from FOAK to nth plant (learning curve)
- **Risk reduction and commercial viability**
  - Information exchange on existing experience
  - Additional new plants and demonstrations
- **Technology development**
  - Capitalize on existing commercial experience
  - Improvements to baseline technologies
  - Breakthrough technologies
...the Benefits

**GASIFICATION**
- Stable, affordable, high-efficiency energy supply with a minimal environmental impact
- Feedstock Flexibility/Product Flexibility
- Flexible applications for new power generation, as well as for repowering older coal-fired plants

**BIG PICTURE**
- Energy Security - Maintain coal as a significant component in the US energy mix
- A Cleaner Environment (…reduced emissions of pollutants) -- The most economical technology for CO₂ capture
- Ultra-clean Liquids from Coal -- Early Source of Hydrogen
Visit the Gasification Technology Website at http://www.netl.doe.gov/coal/gasification/index.html

Gasification Technologies can provide a stable, affordable energy supply for the nation. Gasification-based systems provide high efficiency with near zero pollutants. They provide flexibility in the production of a wide range of products including electricity, fuels, chemicals, hydrogen, and steam. And perhaps most important, in a time of electricity- and fuel-price spikes, flexible gasification systems provide for operation on low-cost, widely-available feedstocks.

As you view the various pages of this web site, you will learn about the Gasification Program and its goals, current projects and solicitations, development facilities, system and market studies, and databases. We hope that the information provided will prove to be a valuable resource for you. We welcome any suggestions, comments, or questions about the information contained on this website.