Coal Gasification
and the Meaning of Life

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Outline of Talk

• What is coal gasification?
• How does it work?
• Why the interest?
• Where does it stand?
• Where is it headed?
What is Coal?

<table>
<thead>
<tr>
<th></th>
<th>Bituminous (Ill.#6)</th>
<th>Subbituminous (PRB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon (wt%)</td>
<td>61.2</td>
<td>47.9</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>4.20</td>
<td>3.40</td>
</tr>
<tr>
<td>Oxygen</td>
<td>6.02</td>
<td>10.8</td>
</tr>
<tr>
<td>Sulfur</td>
<td>3.25</td>
<td>0.48</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>1.16</td>
<td>0.62</td>
</tr>
<tr>
<td>Chlorine</td>
<td>0.17</td>
<td>0.03</td>
</tr>
<tr>
<td>Ash</td>
<td>11.0</td>
<td>6.40</td>
</tr>
<tr>
<td>Moisture</td>
<td>13.0</td>
<td>30.4</td>
</tr>
<tr>
<td>Mercury (ppm,dry)</td>
<td>0.12</td>
<td>0.10</td>
</tr>
<tr>
<td>HHV (Btu/lb)</td>
<td>10,900</td>
<td>8,335</td>
</tr>
</tbody>
</table>
Coal vs. Other Fossil Fuels

**COAL**  \( \text{C:H} \sim 1:1 \)  \( C \) \( H \) + \( H \) = *synthetic oil*

+ \( H \) \( H \) = *synthetic NG*

**PETROLEUM**  \( \text{C:H} \sim 1:2 \)  \( C \) \( H \) \( H \)

**NATURAL GAS**  \( \text{C:H} \sim 1:4 \)  \( C \) \( H \) \( H \) \( H \)
What Is Gasification?

- Gasification is a process that converts carbonaceous materials, such as fossil fuels and biomass, into mixtures of hydrogen and carbon monoxide (called synthesis gas, or syngas).
- Other gaseous species also are formed in varying amounts, depending on the fuel composition and process conditions.
- The syngas can be burned as a fuel, or processed to produce chemicals and other fuels.
- While the focus of this talk is on coal gasification, an important attraction of this technology is that it can process other materials besides coal.
Gasification Basics

- Coal gasification must be carried out at high temperature (and pressure, usually) to first decompose the coal then create new products (via addition of hydrogen)
- The source of heat for these reactions is the *partial oxidation* (combustion) of the coal (requiring some addition of oxygen)
- The most abundant source of hydrogen is water (H₂O), added either as a liquid or vapor (steam)
- The source of oxygen is either air or nearly-pure oxygen (supplied by an air separation unit)
A Typical Coal Gasifier

Coal
- %C, H, S, O, N, Cl
- %Ash

Hydrogen
- H₂O

Oxygen
- Air or O₂

Syngas (raw)
- % CO
- % H₂
- % CO₂
- % H₂O
- % CH₄
- % COS
- % H₂S
- % HCl
- % NH₃
- % N₂
- % Ash

Slag
Gasification processes use one or more common reactions:

- **Thermal decomposition**
  \[ HC + \text{heat} = H_2 + C + \text{organics} \]

- **Reaction with oxygen (partial oxidation)**
  \[ HC + O = H_2 + CO + \text{heat} \]

- **Reaction with steam (reforming)**
  \[ HC + H_2O + \text{heat} = 3/2H_2 + CO \]

- **Reaction with hydrogen (hydrogasification)**
  \[ HC + H_2 = CH_4 + \text{heat} \]
Uses of Syngas

After cleanup for removal of impurities, syngas can be used for:

- Electric power generation
- Steam generation
- Process heat
- Chemicals production
- Liquid fuels production
- All of the above
Texaco Gasification Process

**Feeds**
- Oxygen

**Gasification**
- Alternatives:
  - Natural Gas
  - Any Oil
  - Tar/Asphalt
  - Petroleum Coke
  - Coal
  - Wastes/by-Products
  - Biomass
- Syngas
- Gasification
- Sulfur Recovery
- Co-products:
  - Hydrogen
  - Chemicals
  - Ammonia
  - Fuel Cells
  - Fischer-Tropsch

**Gas Refining**
- CO₂
- Syngas
- Gas Separation
- Sulfur Recovery
- HRSG
- Steam
- Electricity
- Combustion Turbine

**End-products**
- Sulfur
- Solids
- Natural Gas
- Any Oil
- Tar/Asphalt
- Petroleum Coke
- Coal
- Wastes/by-Products
- Biomass
Chemicals and Fuels from Syngas

- CO + H2

**Acetic Anhydride**
- Terephthalic Acid
- p-Xylene

**Ethene & Propene**
- VAM
- n-Butyl Acetate
- n-Butylene

**Acetic Acid**
- MTBE
- Isobutylene

**Methanol**
- Formaldehyde
- Aniline
- Phosgene

**Formaldehyde**
- Aniline Phosgene

**Terephthalic Acid**
- MTBE

**Ethene & Propene**
- VAM

**n-Butyl Acetate**
- Terephthalic Acid

**Acetylene**
- Solvents

**Gasoline & Fuels**
- Ethanol & Isobutanol

**Lubricants & Wax**
- Urea

**Ethanol & Isobutanol**
- Ammonium Phosphate & Diammonium Phosphate

**Sulphuric Acid**
- Ammonium Sulphate

**Phosphoric Acid**
- Ammonia

**Ammonia**
- Nitric Acid
- Ammonium Sulphate

**Ammonium Nitrate**
- Nitric Acid

**1,4-Butanediol**
- Acetylene

**Nitric Acid**
- Ammonium Nitrate

**MDI**
- Formaldehyde

**SNG**
- Ammonia

Source: Gunal-Akgol, U.Waterloo
An Old Technology

- Coal gas was first used in London in 1790 for gas lights
- Later used for fuel gas in Europe and North America in the 19th and early 20th century
- Used to produce coal-derived transportation fuels in Germany during WWII
- Many different gasification processes have been proposed, employing different schemes for fuel feed, reactor design, etc.
- Current generation of gasifiers are cleaner and more efficient than earlier designs
A 1942 view of coal gasification

... from John Wayne and friends
Byproduct Coke Plant
(World’s Biggest, ca. 1970)
Why the Current Interest?

• Gasification is already commercially attractive for a variety of refinery and petrochemical processes
• Offers a way to utilize low-value products or wastes as “opportunity fuels” (esp. petroleum coke)
• Can produce multiple products (polygeneration)
Worldwide Gasification Capacity

Source: SFA Pacific /DOE, 2001
Gasification by Global Region

Source: SFA Pacific /DOE, 2001
## Largest Gasification Projects

<table>
<thead>
<tr>
<th>Plants</th>
<th>Location</th>
<th>Gasifiers</th>
<th>$MW_{th}$ syngas</th>
<th>Year</th>
<th>Feedstock/Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sasol-II</td>
<td>S. Africa</td>
<td>Lurgi</td>
<td>5,090</td>
<td>1977</td>
<td>coal / F-T liquids</td>
</tr>
<tr>
<td>Sasol-III</td>
<td>S. Africa</td>
<td>Lurgi</td>
<td>5,090</td>
<td>1982</td>
<td>coal / F-T liquids</td>
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<tr>
<td>Confidential*</td>
<td>USA</td>
<td>Texaco</td>
<td>2,761</td>
<td>2006</td>
<td>coal / electric</td>
</tr>
<tr>
<td>Port Authur*</td>
<td>USA</td>
<td>E-Gas</td>
<td>2,029</td>
<td>2005</td>
<td>coke / electric</td>
</tr>
<tr>
<td>Dakota</td>
<td>USA</td>
<td>Lurgi</td>
<td>1,900</td>
<td>1984</td>
<td>lignite / SNG</td>
</tr>
<tr>
<td>Repsol*</td>
<td>Spain</td>
<td>Texaco</td>
<td>1,654</td>
<td>2005</td>
<td>residue / electric</td>
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<tr>
<td>Lake Charles*</td>
<td>USA</td>
<td>Texaco</td>
<td>1,407</td>
<td>2005</td>
<td>coke / electric</td>
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<tr>
<td>Deer Park*</td>
<td>USA</td>
<td>Texaco</td>
<td>1,400</td>
<td>2006</td>
<td>coke / electric</td>
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<tr>
<td>SARLUX</td>
<td>Italy</td>
<td>Texaco</td>
<td>1,217</td>
<td>2001</td>
<td>residue / electric</td>
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<tr>
<td>Human*</td>
<td>China</td>
<td>Texaco</td>
<td>1,171</td>
<td>2006</td>
<td>coal / syngas chem.</td>
</tr>
</tbody>
</table>

*Source: SFA Pacific /DOE, 2001*
Gasifier Technologies

Source: SFA Pacific /DOE, 2001
Primary Gasification Feedstock

Source: SFA Pacific /DOE, 2001
Gasification Applications

Source: SFA Pacific /DOE, 2001
Pet Coke Gasification to H₂ and CO₂ for Ammonia and Urea

Farmland Industries, Coffeyville, Kansas
Pet Coke Gasification to H₂ and CO₂ for Ammonia and Urea
Farmland Industries, Coffeyville, Kansas
SNG Plant Supplying CO$_2$ for Enhanced Oil Recovery (EOR) and Sequestration

Sources: USDOE; NRDC
Why the Current Interest?

- Gasification is already commercially attractive for a variety of refinery and petrochemical processes.
- Offers a way to utilize low-value products or wastes as “opportunity fuels” (esp. petroleum coke).
- Can produce multiple products (polygeneration).
- In the U.S., great interest today is in the potential for IGCC power plants to meet stringent air emission standards — especially future CO₂ capture and storage reqmts — at lower cost than combustion-based plants.
Fate of Impurities

Coal Combustion Systems

- Sulfur $\rightarrow$ SO$_2$
- Nitrogen $\rightarrow$ NO + NO$_2$
- Ash $\rightarrow$ (Bottom Ash) + Flyash
PC Plant with CO$_2$ Capture

Combustion Controls
- **Fuel Type**: Coal
- **NOx Control**: None

Post-Combustion Controls
- **NOx Control**: Hot-Side SCR
- **Particulates**: Cold-Side ESP
- **SO2 Control**: Wet FGD
- **Mercury**: None
- **CO2 Capture**: Amine System

Solids Management
- **Disposal**: mixed w/ Landfill

Plant Diagram
IGCC Plant with CO$_2$ Capture

**Configure Plant**

- **Gasification Options**
  - Gasifier: Texaco (Oxygen-blown)
  - Gas Cleanup: Cold-gas
  - CO2 Control: Sour Shift + Selexol

- **Combustion Controls**
  - NOx Control: None

- **Solids Management**
  - Slag: Landfill
  - Sulfur: Sulfur Recovery

**IGCC Base Configuration**

![Diagram of IGCC Plant with CO$_2$ Capture](image-url)
A Modern Gas Turbine
Integrated Coal Gasification Combined Cycle (IGCC) Plant
Wabash River, Indiana

Source: Global Energy, 2002
Polk Power Station
IGCC Plant
(Tampa Electric, 250 MW)
### EPRI Cost and Performance Estimates (without CO$_2$ capture)

<table>
<thead>
<tr>
<th>Technology</th>
<th>SubPC</th>
<th>SuperPC</th>
<th>UltraPC</th>
<th>AFBC</th>
<th>IGCC</th>
<th>NGCC</th>
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<tbody>
<tr>
<td>MW</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>590</td>
<td>506</td>
</tr>
<tr>
<td>Capital ($/kW)</td>
<td>1364</td>
<td>1397</td>
<td>1416</td>
<td>1426</td>
<td>1502</td>
<td>500</td>
</tr>
<tr>
<td>HHV Heat Rate (kJ/kWh)</td>
<td>10,070</td>
<td>9550</td>
<td>9402</td>
<td>10,024</td>
<td>8891</td>
<td>7646</td>
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<tr>
<td>Fuel ($/GJ)</td>
<td>0.948</td>
<td>0.948</td>
<td>0.948</td>
<td>0.948</td>
<td>0.948</td>
<td>2.50/3.71/2.50</td>
</tr>
<tr>
<td>Capacity Factor (%)</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>80/80/40</td>
</tr>
<tr>
<td>COE ($/MWh)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capital</td>
<td>24.0</td>
<td>24.6</td>
<td>24.9</td>
<td>25.1</td>
<td>26.5</td>
<td>8.8</td>
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<tr>
<td>O+M</td>
<td>6.8</td>
<td>6.7</td>
<td>6.7</td>
<td>8.9</td>
<td>7.2</td>
<td>3.2</td>
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<tr>
<td>Fuel</td>
<td>9.5</td>
<td>9.0</td>
<td>8.8</td>
<td>9.7</td>
<td>8.4</td>
<td>19.1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>40.3</strong></td>
<td><strong>40.3</strong></td>
<td><strong>40.5</strong></td>
<td><strong>43.7</strong></td>
<td><strong>42.1</strong></td>
<td><strong>31.1/40.3/41.9</strong></td>
</tr>
</tbody>
</table>

*Note: Hg removal adds ~2-3$/MWh to PC and 0.3$/MWh to IGCC COE.*

*Source: Holt, 2002*
Cost of Alternative Options

- Wind, Biomass
- Coal and Gas Plants with CO₂ Capture
- Nuclear, Hydro
- Natural Gas Combined Cycle
- Coal Plants (combustion, gasification)
- IGCC
- PC

Cost of Electricity ($ / MWh)
CO₂ Emission Rate (kg / MWh)
Gasification vs. Combustion

• *A Chemistry Perspective:*
  Combustion = Oxidizing atmosphere
  Gasification = Reduction atmosphere

• *A Disciplinary Perspective:*
  Combustion = Mechanical Engineering
  Gasification = Chemical Engineering

• *A Technology Perspective:*
  Combustion = Power Plants
  Gasification = Chemical Plants, Refineries, etc.
Where Do We Go from Here?