What is Gasification?

Gasification Workshop
September 11-13, 2001
Indianapolis, Indiana
Introduction

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(for Dave Heaven)
Market Drivers

- Rising prices for natural gas
- Increasing demand for electricity
- Decreasing prices for petroleum residuals
- Compliance with stringent environmental regulations: NO$_x$, SO$_2$, CO$_2$
- Need for Hydrogen
  - Heavier Feedstocks
  - “Clean Fuels” Requirement
- (Hazardous) Waste Disposal Costs
Technology Overview
Gasification Process Concept

- Objective: Convert carbon-containing solid or liquid to a simple gas mixture of higher economic value
- Carbon conversion in a reducing atmosphere at 400-1200 psig and 2300 - 2700°F
- Feedstocks: Coal, Petroleum Coke, Heavy Resid., any carbon containing compound
- Synthesis Gas (Syngas) is primarily CO and H₂
- Sulfur is recovered in conventional AGR and Claus Units (as a saleable by-product)
IGCC Feedstocks

- Vacuum resid
- Visbreaker bottoms
- Deasphalter bottoms
- Petroleum Coke
- Refinery and petrochemical residuals
- Coal / lignite
- Oil emulsion (Orimulsion)
- Municipal sewage sludge
- Any carbon-containing material
## Typical Gasifier Operation

<table>
<thead>
<tr>
<th>Feed</th>
<th>Oxygen</th>
<th>Steam</th>
<th>Raw Syngas</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>5905.0 kg-moles/hr</td>
<td>4174.1</td>
<td>4890.8</td>
</tr>
<tr>
<td>H₂</td>
<td>4174.1</td>
<td></td>
<td>82.3</td>
</tr>
<tr>
<td>S</td>
<td></td>
<td>50.0</td>
<td>5477.0</td>
</tr>
<tr>
<td>N₂</td>
<td>17.7</td>
<td>50.0</td>
<td>66.6</td>
</tr>
<tr>
<td>CO</td>
<td></td>
<td></td>
<td>33.0</td>
</tr>
<tr>
<td>CH₄</td>
<td></td>
<td></td>
<td>349.3</td>
</tr>
<tr>
<td>CO₂</td>
<td></td>
<td></td>
<td>79.4</td>
</tr>
<tr>
<td>H₂S</td>
<td></td>
<td></td>
<td>2.9</td>
</tr>
<tr>
<td>COS</td>
<td></td>
<td></td>
<td>0.6</td>
</tr>
<tr>
<td>HCN</td>
<td>NH₃</td>
<td></td>
<td>2.3</td>
</tr>
<tr>
<td>O₂</td>
<td>2659.0</td>
<td></td>
<td>0.0</td>
</tr>
<tr>
<td>Ar</td>
<td>90.0</td>
<td></td>
<td>89.6</td>
</tr>
<tr>
<td>H₂O</td>
<td>1605.0</td>
<td></td>
<td>743.6</td>
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</tbody>
</table>
## Typical Syngas Composition

<table>
<thead>
<tr>
<th>Component</th>
<th>Heavy Oil Feed</th>
<th>Coke Feed</th>
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</thead>
<tbody>
<tr>
<td>CO</td>
<td>45.6</td>
<td>47.7</td>
</tr>
<tr>
<td>H₂</td>
<td>43.3</td>
<td>30.3</td>
</tr>
<tr>
<td>CO₂</td>
<td>8.2</td>
<td>17.9</td>
</tr>
<tr>
<td>H₂O</td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td>CH₄</td>
<td>0.4</td>
<td>0.01</td>
</tr>
<tr>
<td>Ar</td>
<td>1.0</td>
<td>0.8</td>
</tr>
<tr>
<td>N₂</td>
<td>0.5</td>
<td>1.3</td>
</tr>
<tr>
<td>H₂S</td>
<td>0.7</td>
<td>1.8</td>
</tr>
<tr>
<td>COS</td>
<td>0.0</td>
<td>0.02</td>
</tr>
</tbody>
</table>

- Composition also depends on gasifier licensor
IGCC Simplified Block Flow Diagram

- **Air**
- **Oxygen Plant**
- **Nitrogen**
- **Gasification**
- **Feed**
- **Oxygen**
- **Recovered Metals**
- **Heat Recovery; Sulfur Removal**
- **Clean Fuel Gas**
- **H2S**
- **Sulfur Plant**
- **Sulfur**
- **Combustion Turbine Generator**
- **Electricity**
- **Steam**
- **Heat Recovery Steam Generators**
- **Steam Gas**
- **Flue Gas**
- **Off-gas**
- **H2 Product**
- **Hydrogen Separation**
- **Electricity**
- **Steam**
Gasification Products

Feed → Gasification Facility → Syngas → Combined Cycle

Slag for Construction Materials

Chemical Production

Fischer Tropsch Synthesis

Argon, Nitrogen, & Oxygen
Carbon Dioxide
Sulfur / Sulfuric Acid
Steam
Hot Water
Electricity
Hydrogen
Carbon Monoxide
Ammonia-based Fertilizer
Synthetic Natural Gas
Industrial Chemicals
Methanol / Ethanol
Naphtha
High Cetane Diesel
Jet Fuel
Wax
IGCC Configuration Options

- **Gasifier**
  - Technology:
    - Texaco
    - Shell
    - E-Gas
    - BGL
    - Nöell
    - Others
  - Pressure/Fuel Gas Expander
  - Sparing
  - Soot Recovery
  - Slurry Preheat
  - Alternative Fuels

- **Raw Gas Cooling**
  - Radiant + Convective
  - Convective
  - Quench
  - Fire Tube
  - No Gas Cooling (Hot GCU)

- **Sulfur Removal & Recovery**
  - Licensor
  - Chemical Solvent
  - Physical Solvent
  - Tail Gas Recycle
  - Hot Gas Clean Up
  - COS Hydrolysis
  - $O_2$-blown Claus

- **Air Separation Unit**
  - Over-the-fence or not
  - Standard LP vs. HP ASU
  - Integration:
    - Partial Integrated
    - Fully Integrated
  - $N_2$ Return
  - LOx/GOx Storage
  - $O_2$ to Sulfur Plant

- **Combustion Turbines**
  - Vendor
  - Conventional vs Advanced
  - NOx Control:
    - Steam Injection
    - Fuel Saturation
    - Nitrogen Dilution
  - SCR
  - Fuel Gas Heating

- **Steam Cycle**
  - Reheat
  - Condensing Temp.
  - No. of Steam Turbines
  - Integration with Gasification
  - Export to Refinery
  - Pressure Levels

- **Utility Systems**
  - Cooling System Type
  - Utility Integration with Refinery
IGCC Plant Efficiencies

- Efficiency is greater than competing combustion technologies for all feedstocks.
- Plant efficiency depends on feedstock carbon conversion, heat recovery, gas turbine choice, and degree of integration.
- A well-integrated heavy oil gasification plant using the latest advanced turbines will approach 47% thermal efficiency (LHV), including oxygen plant requirements.
- An efficiency of 50% will be achievable in the near future using technologies currently being tested.
IGCC Availability

- Availability includes planned and unplanned down time
- Typical power availability is 80-90% from primary feed (depending upon feed type), 94-96% with auxiliary fuel
- All rotating equipment (other than air separation unit compressors, combustion turbine and steam turbine) are spared
- Critical elements are gasifier and combustion turbine
- Availability of power and hydrogen can be improved to 100% by spare trains based on economic analysis
Emissions

- Environmental performance bests competing combustion technologies for all feedstocks
  - Sulfur recovery to >> 99%
  - NO\textsubscript{x} levels controllable to < 10 ppm
  - CO\textsubscript{2} level lower due to higher efficiency, CO\textsubscript{2} recoverable for sales/sequestration
  - Particulate emissions < 10 ppm
  - Feedstock metals/minerals produced as salable concentrate or non-leachable slag
GE Advanced Gas Turbine Syngas and Natural Gas Performance Comparison

<table>
<thead>
<tr>
<th>Manufacturer Model</th>
<th>General Electric Frame 7FA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel: Type Heating Value (LHV)</td>
<td>Syngas 115 BTU/SCF</td>
</tr>
<tr>
<td>Power Output @ 59°F</td>
<td>197 MW&lt;sub&gt;e&lt;/sub&gt;</td>
</tr>
<tr>
<td>Heat Rate, LHV</td>
<td>8,840 BTU / kW-hr</td>
</tr>
<tr>
<td>Efficiency</td>
<td>37.5%</td>
</tr>
<tr>
<td>Exhaust Temperature</td>
<td>1091°F</td>
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<tr>
<td>NOx Control</td>
<td>Nitrogen Injection</td>
</tr>
<tr>
<td>NOx (@15% O&lt;sub&gt;2&lt;/sub&gt; dry)</td>
<td>9 ppmv</td>
</tr>
<tr>
<td>CO (dry)</td>
<td>25 ppmv</td>
</tr>
</tbody>
</table>
Gas Turbine
NO$_x$ Control Technologies

- Primary control is the addition of inerts to gas turbine flame to reduce flame temperature
  - Steam
  - Water
  - Nitrogen
- Low-NO$_x$ burners for low BTU gas under development to eliminate need to add inerts
- Primary controls reduce NO$_x$ to 9-25 ppm
- Further NO$_x$ reduction to 5-9 ppm possible by selective catalytic reduction (SCR)
Sulfur Control Technologies

- MDEA acid gas removal plus Claus plant and tail gas treating achieves ~ 98% sulfur recovery
- Addition of catalytic conversion of COS to $\text{H}_2\text{S}$ improves MDEA performance and total sulfur recovery > 99.8%
- Other acid gas removal processes are Purisol, Rectisol, Selexol, Sulfinol
- Use of oxygen rather than air reduces size of Claus Plant and improves performance
Gasification Application
IGCC Advantages

- Environmentally clean
  - Low SO$_2$, NOx emissions
  - Low solid waste
- High efficiency
- Feed flexibility
- Low water use
- Low CO$_2$ produced
- Low cost feedstocks
- Wide selection of technologies / equipment
- Co-product flexibility
- Phased construction
- Continuous performance improvement
- Decreasing costs
- Commercially well-proven
IGCC Disadvantages

- Higher capital cost
- Not as well known, especially by utility companies
Favorable Conditions for IGCC Applications

- Low value coal, heavy oil or petroleum coke feedstock
- Favorable demand and sales price for power
- Sales opportunity for byproducts – hydrogen, steam, syngas, oxygen, nitrogen, chemicals, etc.
- Environmental regulations discourage direct combustion of the feedstock
- Alternative combined cycle fuels (natural gas) are expensive or not available
- Existing infrastructure capacity available
- Potential for sale of chemical byproducts to nearby market
- Expensive disposal of solid or liquid wastes
- Large plant size (MW)
## Gasification Plants in Operation, Under Construction, or Under Development Since 1995

<table>
<thead>
<tr>
<th>International Plant Name</th>
<th>Country</th>
<th>Feedstock</th>
<th>Gasifier</th>
<th>Equiv. Capacity, MW</th>
<th>Start-Up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buggenum</td>
<td>Netherlands</td>
<td>Coal</td>
<td>Shell</td>
<td>255</td>
<td>1994</td>
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<tr>
<td>Schwarze Pumpe</td>
<td>Germany</td>
<td>Coal/Wastes</td>
<td>BGL</td>
<td>85</td>
<td>1999</td>
</tr>
<tr>
<td>Pernis</td>
<td>Netherlands</td>
<td>Residual Oil</td>
<td>Shell</td>
<td>350</td>
<td>1997</td>
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<tr>
<td>Puertollano</td>
<td>Spain</td>
<td>Coal/Petcoke</td>
<td>Prenflo</td>
<td>320</td>
<td>1997</td>
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<tr>
<td>BASF</td>
<td>England</td>
<td>Chemical Wastes</td>
<td>Noell</td>
<td>16</td>
<td>2000</td>
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<tr>
<td>IBIL/Sanghi</td>
<td>India</td>
<td>Lignite</td>
<td>Carbona</td>
<td>60</td>
<td>2000</td>
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<tr>
<td>API Energia</td>
<td>Italy</td>
<td>Tar</td>
<td>Texaco</td>
<td>270</td>
<td>1999</td>
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<tr>
<td>ISAB</td>
<td>Italy</td>
<td>Asphalt</td>
<td>Texaco</td>
<td>535</td>
<td>1999</td>
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<td>Sarlux</td>
<td>Italy</td>
<td>Residual Oil</td>
<td>Texaco</td>
<td>665</td>
<td>2000</td>
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<tr>
<td>EPZ</td>
<td>Netherlands</td>
<td>Wood Wastes</td>
<td>Lurgi</td>
<td>50</td>
<td>2000</td>
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<tr>
<td>Exxon Singapore</td>
<td>Singapore</td>
<td>Petroleum</td>
<td>Texaco</td>
<td>200</td>
<td>2000</td>
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<td>Celanese Singapore</td>
<td>Singapore</td>
<td>Residual Oil</td>
<td>Texaco</td>
<td>120</td>
<td>2000</td>
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<td>Fife Power</td>
<td>Scotland</td>
<td>Coal/Wastes</td>
<td>BGL</td>
<td>125</td>
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<tr>
<td>Bioelettrica</td>
<td>Italy</td>
<td>Biomass</td>
<td>Lurgi</td>
<td>12</td>
<td>2000</td>
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<tr>
<td>NPRC</td>
<td>Japan</td>
<td>Vacuum Resid</td>
<td>Texaco</td>
<td>345</td>
<td>2003</td>
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## Gasification Plants in Operation, Under Construction, or Under Development since 1995

*(continued)*

<table>
<thead>
<tr>
<th>Plant Name</th>
<th>State</th>
<th>Feedstock</th>
<th>Gasifier</th>
<th>Capacity, MW</th>
<th>Start-Up</th>
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<tr>
<td>Wabash River IGCC</td>
<td>IN</td>
<td>Coal</td>
<td>E-Gas</td>
<td>320</td>
<td>1995</td>
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<td>Polk Power IGCC</td>
<td>FL</td>
<td>Coal</td>
<td>Texaco</td>
<td>250</td>
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<tr>
<td>Texaco El Dorado</td>
<td>KS</td>
<td>Petcoke</td>
<td>Texaco</td>
<td>6</td>
<td>1996</td>
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<tr>
<td>Pinon Pine IGCC</td>
<td>NV</td>
<td>Coal</td>
<td>KRW</td>
<td>105</td>
<td>1997</td>
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<tr>
<td>Motiva (Star) DE City</td>
<td>DE</td>
<td>Petcoke</td>
<td>Texaco</td>
<td>285</td>
<td>2001</td>
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<tr>
<td>Farmland Industries</td>
<td>KS</td>
<td>Petcoke</td>
<td>Texaco</td>
<td>160</td>
<td>2000</td>
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<tr>
<td>Exxon Baytown</td>
<td>TX</td>
<td>Resid Oil</td>
<td>Texaco</td>
<td>190</td>
<td>2000</td>
</tr>
</tbody>
</table>
## IGCC Gas Turbines

<table>
<thead>
<tr>
<th>Project</th>
<th>Date</th>
<th>Supplier</th>
<th>$MWe$</th>
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<tbody>
<tr>
<td>Cool Water, USA</td>
<td>1984</td>
<td>GE Frame 7E</td>
<td>80</td>
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<tr>
<td>Dow Plaquemine, USA</td>
<td>1987</td>
<td>Westinghouse 501D</td>
<td>92</td>
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<tr>
<td>Shell Buggernum, The Netherlands</td>
<td>1995</td>
<td>Siemens V94.2</td>
<td>156</td>
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<tr>
<td>PSI Wabash River, USA</td>
<td>1996</td>
<td>GE Frame 7FA</td>
<td>192</td>
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<tr>
<td>Texaco El Dorado, USA</td>
<td>1996</td>
<td>GE Frame 6B</td>
<td>35</td>
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<td>Tampa Electric, USA</td>
<td>1996</td>
<td>GE Frame 7FA</td>
<td>192</td>
</tr>
<tr>
<td>ILVA ISE, Italy</td>
<td>1996</td>
<td>3 x GE Frame 9E</td>
<td>130 (each)</td>
</tr>
<tr>
<td>Schwarze Pumpe, Germany</td>
<td>1996</td>
<td>GE Frame 6B</td>
<td>40</td>
</tr>
<tr>
<td>Puertollano, Spain</td>
<td>1996</td>
<td>Siemens V94.3</td>
<td>190</td>
</tr>
<tr>
<td>Shell Pernis, The Netherlands</td>
<td>1997</td>
<td>2 x GE Frame 6B</td>
<td>40 (each)</td>
</tr>
<tr>
<td>Sokolovska Uhelna, Czech Rep.</td>
<td>1997</td>
<td>2 x GE Frame 9E</td>
<td>140 (each)</td>
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<tr>
<td>API Energia, Italy</td>
<td>1998</td>
<td>ABB Type 13E2</td>
<td>175</td>
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<tr>
<td>ISAB, Italy</td>
<td>1998</td>
<td>2 x Siemens/Ansaldo V94.2</td>
<td>162 (each)</td>
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<td>Fife Energy, Scotland</td>
<td>1999</td>
<td>GE Frame 6FA</td>
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<td>Motiva Refinery, USA</td>
<td>1999</td>
<td>2 x GE Frame 6FA</td>
<td>87 (each)</td>
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<tr>
<td>Pinon Pine Sierra Pacific, USA</td>
<td>1999</td>
<td>GE Frame 6FA</td>
<td>61</td>
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<tr>
<td>Sarlux, Italy</td>
<td>2000</td>
<td>3 x GE Frame 9E</td>
<td>123 (each)</td>
</tr>
<tr>
<td>Fife Electric, Scotland</td>
<td>2000</td>
<td>GE Frame 9FA</td>
<td>286</td>
</tr>
<tr>
<td>Exxon Singapore, Singapore</td>
<td>2000</td>
<td>2 x GE Frame 6FA</td>
<td>87 (each)</td>
</tr>
<tr>
<td>IBIL Sanghi, India</td>
<td>2001</td>
<td>GE Frame 6B</td>
<td>36</td>
</tr>
<tr>
<td>General Sakiyu K.K. (GSK), Japan</td>
<td>2001</td>
<td>GE Frame 9EC</td>
<td>215</td>
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<tr>
<td>Bioelecttrica, Italy</td>
<td>2001</td>
<td>Nuovo Pigone PGT10B</td>
<td>20</td>
</tr>
</tbody>
</table>

GE is the market leader
IGCC Technology

Cost / Economics

FLUOR®
## Typical IGCC Plant Costs

<table>
<thead>
<tr>
<th></th>
<th>$ / kW (1) (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid Feed</td>
<td>900 - 1,200</td>
</tr>
<tr>
<td>Solid Feed</td>
<td>1,000 - 1,300</td>
</tr>
</tbody>
</table>

### Notes:
(1) Includes oxygen plant
(2) Depends upon:
- Site conditions
- Size
- Plant configuration
- Heat recovery option
- Sparing
- Local labor cost and efficiency
IGCC Economy of Scale

Capital Cost Relative to a 200 MW Plant, %

IGCC Plant Capacity, MW
## Typical IGCC Plant Capital Cost Distribution

<table>
<thead>
<tr>
<th>Category</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasification and feed preparation</td>
<td>10 - 20</td>
</tr>
<tr>
<td>Air separation unit</td>
<td>10 - 15</td>
</tr>
<tr>
<td>Gas treating and sulfur recovery</td>
<td>10 - 15</td>
</tr>
<tr>
<td>Power block</td>
<td>25 - 30</td>
</tr>
<tr>
<td>Utilities and support facilities</td>
<td>20 - 30</td>
</tr>
</tbody>
</table>

### Key Variables:
- Feedstock type (solid, liquid)
- Gasification train sparing (none, 100%, 50%)
- Sharing of existing utilities and infrastructure
Recent Cost Trends in Last 5 Years

- Decreasing combined cycle costs
  - From $700 / kW to < $600 / kW

- Decreasing air separation plant costs
  - From $21,000 to $16,000 / TPD of O₂

- Some syngas plant improvements
  - Smaller size due to combustion turbine efficiency improvements
Example Projects
Pernis IGCC Plant

Three-Train Gasification Unit
Fluor provided engineering, procurement, and construction management for this three-train gasification unit, which was part of Shell’s Per+ project at its Pernis refinery. The Shell gasification process is used to gasify 1,656 metric tons/day of vacuum-flashed cracked residual oil to a syngas. Part of this syngas is used to produce 285 metric tons/day (118 million standard cubic feet per day) of hydrogen for the hydrocracker. The balance of the syngas is used, after sulfur removal, as fuel for combined-cycle power production via General Electric 6B combustion turbines. The start-up of this gasifier plant is highly automatic and is believed to be the most advanced control system ever applied to a heavy oil gasifier.

Soot Ash Recovery Unit
Shell was committed to the development of a technology that would reduce the cost of recycling and reprocessing unconverted carbon from the gasifiers as part of the Per+ project. Fluor assisted Shell with the pioneer development and detailed design of the soot ash recovery unit (SARU) technology. This included filtration of the soot slurry from the gasifiers, followed by multiple-hearth furnace processing to produce a metals concentrate high in vanadium and nickel, which is of interest to metals reclaimers.

Minimum Disruption to Operations
The project is closely integrated with Shell’s existing operations, and due to constraints regarding site space availability, required relocation of various storage and service facilities. Fluor worked closely with Shell and several other engineering contractors to complete the project with minimum disruption to ongoing refinery operations.

Project:
IGCC Plant
Location:
Pernis, The Netherlands
Client:
Shell Nederland Raffinaderij B.V. (SNR)
Scope:
Engineering, Procurement, & Construction Management
Texaco Petroleum Coke IGCC

Process Description
This refinery-based gasification plant (using Texaco technology) uses 180 tons per day of low/negative-value petroleum coke produced in the refinery and 10 tons per day of refinery secondary material streams, such as API separator bottoms, acid soluble oil, primary sludge, and phenolic residue, to produce 35 megawatts electricity and 180,000 pounds per hour of steam for export to the refinery. The power block consists of one General Electric 6B gas turbine that has air extraction and nitrogen injection capabilities. The extracted air is fed to the air separation plant to produce the oxygen required for the gasification process, with the nitrogen returned to the gas turbine for NOx reduction. The syngas to the gas turbine is supplemented with natural gas and the gas turbine also has the capability of operating on natural gas only. This gasification cogeneration unit, by converting low-value petroleum coke and refinery wastes into syngas which is used to produce electricity and steam, makes the refinery self-sufficient for its energy needs.

Environmental and Economic Benefits
The Texaco gasification process allows coke and oily secondary material to be used as a feedstock, providing an economic benefit through allowing the use of this low-cost material as feedstock for the process and avoiding incineration or landfilling for materials that would otherwise be a hazardous waste if disposed. The U.S. Environmental Protection Agency formally allowed the Kansas Department of Health and Environment to consider the gasification unit a refinery process rather than a waste treatment unit. This allowed for refinery oily secondary materials to be used as a feedstock for the gasifier without being designated as hazardous waste. Also, sulfur dioxide and nitrogen oxide emissions are much lower than competing technologies that use coke as the feedstock. The process produces non-leachable solids that comprises only 1 percent of the original coke. Texaco expects to save from $12 million to $14 million per year in utility costs and $1 million per year in waste shipment and disposal costs.

Fluor’s Role
As part of the engineering, procurement, and construction management activities, Fluor was responsible for overall plant design and integration of various units, such as the gasification plant (licensed by Texaco), air separation unit (supplied by Praxair), combustion turbine (supplied by General Electric), and the slurry preparation unit (supplied by Svedela).
QUESTIONS?
THANK YOU!