Gasification of coal
G-L01-2

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Prof. nadzw.
Thermal conversion processes

Thermal Conversion

Excess air: Combustion → Heat
Partial air: Gasification → Fuel Gases (CO + H₂)
No Air: Pyrolysis & Hydrothermal → Liquids
Marketplace for coal gasification

- Emergence of CO2 emissions as an issue in the selection of technology for the power industry. Carbon Capture and Storage/Sequestration (CCS) getting more serious consideration.
- Many environmental groups supportive of IGCC over PC (with CCS) for its environmental attributes but without much understanding of the effects of design variations and coal types on the cost of CCS and a competitive Cost of Electricity (COE)
- In the power industry IGCC is generally perceived as not yet fully commercially proven, whereas capture of CO2 from coal gasification derived syngas, via the shift reaction (CO + H2O = CO2+ H2) and subsequent CO2 removal is commercially mature. In contrast PC plants are fully commercially proven but post combustion CO2 capture from PC plants is not proven at the scale needed for deployment.
- Without consideration of capture the COE from currently offered IGCC with bituminous coals has mostly been evaluated as being 10-20% greater than the COE from PC plants. That margin is greater with low rank coals such as PRB and lignite. Both margins may be reduced with increased IGCC commercial deployment.
Marketplace for chemicals

- The high price of natural gas has made syngas from coal or petroleum residuals more attractive for chemical synthesis (Ammonia, Methanol, DME, olefins)
- The even higher price of crude oil has prompted serious consideration of gasification of low value fossil resources (remote gas GTL, Coal CTL) to provide syngas for the synthesis of liquid transportation fuels via the Fischer-Tropsch (F-T) technology. For CTL economies of scale are important and larger gasifiers to match the syngas requirements of large F-T reactors are highly desirable. F-T reactors of 10,000-20,000 bbl/d size require gasification of 6,000-12,000 tons/day of typical bituminous coal.
- The emergence of a 50 Hz IGCC market in Europe and Asia based on low value feedstocks and fuels. Larger gasifiers (factor 1.4) will also be needed to match the larger size 50 Hz gas turbines. Even larger gas turbines (GE 9H, Siemens 6000G and 8000H) may require gasification capacity of 4000 tpd of bituminous coal.
History of development 1940-1980

- Modern gasification began in the 1930s with the development of large scale cryogenic air separation units for low cost oxygen Lurgi dry ash - moving bed gasifier for high-pressure methane (CH4) rich “town gas”
- Winkler - fluid bed gasifier for low-pressure syngas (H2 & CO)
- Koppers-Totzek (K-T) entrained flow gasifier for low-pressure syngas
- Choice of Lurgi dry ash gasification for Sasol CTL & Great Plains SNG (now Dakota Gasification) in 1970s reflected:
  - Timing - required commercially well-proven pressurized gasification
  - Feedstock - high moisture, ash & ash fusion temperature low rank coal
  - Application - high direct CH4 make for SNG & F-T makes CH4 anyway
  - Integration - Lurgi cannot use fine - needed large PC boilers anyway
Modern gasifiers development

- Commercial gasifiers all high-pressure, O2-blown, entrained flow
- Texaco, now GE, first oil/NG in 60s & then coal water slurry gasifier - Eastman Chemical next Cool Water & Polk County IGCC demos
- Shell (like Texaco first oil/NG) with Krupp-Koppers on pressurized dry coal feed gasifier - Buggenum & Puertollano European IGCC demos
- E-Gas, Dow then Destec, now ConocoPhillips- coal water slurry & twostage gasifier - Plaquemine subbit & Wabash coke/bit coal IGCC demos
- Oil shocks of 1970s led to funding of many other gasifiers some finally moving toward large-scale commercial status now
  - Moving bed - British Gas Lurgi (BGL) Slagger
  - Fluid beds - RWE/Rheinbraun HTW + Southern/KBR transport reactor
  - Entrained flow - GSP: coal via Siemens/Future Energy & oil/NG via Lurgi
  - MPG + Japanese enriched air (MHI) & O2 (J-Power) blown gasifiers
  - ECUST multi burner technology developed by China
Worldwide existing gasification technologies

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>Operating 2010 (operating, construction, start-up)</th>
<th>Operating 2007 (operating, construction, start-up)</th>
<th>Difference</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>MWth 36,315</td>
<td>30,825</td>
<td>5,490</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Gasifiers 201</td>
<td>212</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Plants 53</td>
<td>45</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Petroleum</td>
<td>MWth 17,938</td>
<td>18,454</td>
<td>-516</td>
<td>-3</td>
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<tr>
<td></td>
<td>Gasifiers 138</td>
<td>145</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Plants 56</td>
<td>59</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Petcoke</td>
<td>MWth 911</td>
<td>1,441</td>
<td>-530</td>
<td>-37</td>
</tr>
<tr>
<td></td>
<td>Gasifiers 5</td>
<td>8</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Plants 3</td>
<td>5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Biomass/waste</td>
<td>MWth 373</td>
<td>1,174</td>
<td>-801</td>
<td>-68</td>
</tr>
<tr>
<td></td>
<td>Gasifiers 9</td>
<td>21</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Plants 9</td>
<td>13</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>MWth 55,537</td>
<td>51,894</td>
<td>3,643</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Gasifiers 353</td>
<td>386</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Plants 121</td>
<td>122</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Total capacity of gasifiers versus fuel used (current and forecast by 2016)
Total capacity of gasifiers versus product manufactured (current and forecast by 2016)
Total capacity of reactors using coal as the main fuel, breakdown by technological groups (current and forecast by 2016)
• Of the technologies used for coal gasification in entrained flow reactors (operating plants), the Shell (dry feeding) and GE/Texaco (slurry feeding) have the dominant share in gas production (77 %), followed by the ECUST – OMB Opposed multi-burner (15.3 %) technology.

• The third place position of the use of ECUST (East China University of Science and Technology) technology in developing plants is noteworthy because of the rapid pace of the ECUST – OMB technology development. Beginning with a pilot plant (22 t/d of fuel) in 1996, the technology led to operational demonstration plants in the years 2001 – 2005 (750 and 1,150 t/d of coal) and 17 commercial gasifiers that were implemented by 2010 (capacity of up to 2,000 t/d of coal).
Gasification a viable energy alternative

- High and volatile oil and gas prices driving search for alternatives
- Relatively low and stable coal prices, even as demand is growing

Energy Security
- Over reliance on Major energy resource holders
- Coal abundance and availability in major industrial countries

Clean Coal Technology

Environment
- Environmental pressures on emission standards
- Favorable environmental performance
  - Allows CO2 capture
  - Excellent ash treatment
Fuel flexibility

**Fuel Flexibility**

- **Coals**
  - PRB
  - Lignite
  - Bit.
  - Sub. Bit.
  - Anth.
  - Petcoke
  - Biomass

- **Partial Oxidation**
- **Syngas CO, H₂**
- **Shift Reaction**
- **CO₂**
  - Organizations CO₂ expertise leveraged for CO₂ flooding and CCS opportunities

- **Hydrogen**
  - FC Vehicles
  - Heavy Oil Upgrading

- **Electricity**
  - Syngas for Power Generation

- **Chemicals**
  - Methanol & Ammonia Applications

- **Fischer-Tropsch**
- **Liquid Fuels**
  - Coal to Liquids Opportunities

**Vehicles**

**IGCCs**

**Diesel**

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Basic Block Flow Diagram

Intent is to be able to add sweet shift, CO₂ capture, and SNG production to the IGCC facility.
Gasification reactions

- **Gasification with Oxygen**
  \[ C + \frac{1}{2}O_2 \rightarrow CO \]

- **Combustion with Oxygen**
  \[ C + O_2 \rightarrow CO_2 \]

- **Gasification with Carbon Dioxide**
  \[ C + CO_2 \rightarrow 2CO \]

- **Gasification with Steam**
  \[ C + H_2O \rightarrow CO + H_2 \]

- **Gasification with Hydrogen**
  \[ C + 2H_2 \rightarrow CH_4 \]

- **Water-Gas Shift**
  \[ CO + H_2O \rightarrow H_2 + CO_2 \]

- **Methanation**
  \[ CO + 3H_2 \rightarrow CH_4 + H_2O \]

**Gasifier Gas Composition (Vol %)**

- \(H_2\) 25 - 30
- \(CO\) 30 - 60
- \(CO_2\) 5 - 15
- \(H_2O\) 2 - 30
- \(CH_4\) 0 - 5
- \(H_2S\) 0.2 - 1
- COS 0 - 0.1
- \(N_2\) 0.5 - 4
- \(Ar\) 0.2 - 1

\(\text{NH}_3 + \text{HCN}\) 0 - 0.3

Ash/Slag/PM

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Process configuration

[Diagram showing the process configuration with stages for Feed Prep, Gasification, Gas Cleanup, and End Products. The diagram includes details on feedstock and byproducts.]
Basic Block Flow Diagram for Chemical Plant

AIR
AIR SEPARATION UNIT (ASU)
NITROGEN (N₂)
HYDROGEN (H₂)
CARBON DIOXIDE (CO₂)
OXYGEN (O₂) TO GASIFIER
PUBLIC POWER TO ASU
COAL SUPPLY
FLYASH SULFUR (S)
CO₂ to EOR
SLAG
TAIL GAS
MEDIUM PRESSURE SATURATED STEAM
1500# STEAM TO KNO
550# STEAM TO POWER BLOCK
POWER TO GASIFIER
POWER TO KNO
BOILER FEED WATER TO POWER BLOCK
COAL FIRED POWER PLANT
ENHANCED OIL RECOVER (EOR)
POWER TO GRID

N₂ + H₂ = NH₃
AMMONIA
TO FERTILIZER MARKETS
NH₃ + CO₂ = CO(NH₂)₂
UREA

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Gasification for hydrogen and power
Selexol two step process
Gasification for methanol
Fischer – Tropsch synthesis

[Diagram showing the process flow for Fischer-Tropsch synthesis involving gasification, clean-up, Fischer Tropsch (FT) reactor, air separation unit, power block, and hydrocracker. The diagram includes the flow of inputs like H₂O, coal, oxygen, and steam, as well as outputs like fuel products.

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Process diagrams of hydrogen production
Process diagram of methanol production
Process diagrams of liquid fuel production
Gasification reactors

Moving Bed

Entrained Flow

Fluidized Bed

Transport

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Raw gas composition

<table>
<thead>
<tr>
<th>Składniki gazu</th>
<th>Typ reaktora</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>złoże stałe</td>
</tr>
<tr>
<td>CO2</td>
<td>29.7</td>
</tr>
<tr>
<td>CO</td>
<td>18.9</td>
</tr>
<tr>
<td>H2</td>
<td>39.1</td>
</tr>
<tr>
<td>N2 + Ar</td>
<td>4.3</td>
</tr>
<tr>
<td>CH4</td>
<td>7</td>
</tr>
<tr>
<td>CnHm</td>
<td>1</td>
</tr>
<tr>
<td>H2S + COS</td>
<td></td>
</tr>
</tbody>
</table>

zależy od zawartości siarki w weglu
## Desirable Syngas Characteristics for Different Applications

<table>
<thead>
<tr>
<th>Product</th>
<th>Synthetic Fuels</th>
<th>Methanol</th>
<th>Hydrogen</th>
<th>Fuel Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FT Gasoline &amp; Diesel</td>
<td>~2.0</td>
<td>High</td>
<td>Unimportant</td>
</tr>
<tr>
<td>H₂/CO</td>
<td>0.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>Low</td>
<td>Low</td>
<td>Not Important</td>
<td>Not Critical</td>
</tr>
<tr>
<td>Hydrocarbons</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>N₂</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Note</td>
</tr>
<tr>
<td>H₂O</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>Note</td>
</tr>
<tr>
<td>Contaminants</td>
<td>&lt;1 ppm Sulfur</td>
<td>&lt;1 ppm Sulfur</td>
<td>&lt;1 ppm Sulfur</td>
<td>Low Part.</td>
</tr>
<tr>
<td></td>
<td>Low Particulates</td>
<td>Low Particulates</td>
<td>Low Particulates</td>
<td>Low Metals</td>
</tr>
<tr>
<td>Heating Value</td>
<td>Unimportant</td>
<td>Unimportant</td>
<td>Unimportant</td>
<td>High</td>
</tr>
<tr>
<td>Pressure, bar</td>
<td>~20-30</td>
<td>~50 (liquid phase)</td>
<td>~28</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>200-300</td>
<td>500-600</td>
<td></td>
<td>~400</td>
</tr>
<tr>
<td>Temperature, °C</td>
<td>300-400</td>
<td>100-200</td>
<td>100-200</td>
<td>500-600</td>
</tr>
</tbody>
</table>
Classification of gas cleaning processes

<table>
<thead>
<tr>
<th>Temperature range</th>
<th>Basic type</th>
<th>Effectiveness</th>
<th>Gas cleaning system</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 - 60 °C</td>
<td>Wet</td>
<td>Tar, particles, metal compounds, permanent pollutant gas fractions</td>
<td>Packed column scrubber, quench column, venturi scrubber, (wet) electrostatic precipitator (ESP), etc.</td>
</tr>
<tr>
<td>140 - 300 °C</td>
<td>Dry</td>
<td>Particles, metal compounds, pollutant gas fractions</td>
<td>Dust ESP, filtration de-duster, etc.</td>
</tr>
<tr>
<td>300 - 800 °C</td>
<td>Dry</td>
<td>Particles, pollutant gas fractions (tar)</td>
<td>Filtration de-duster, dust ESP, etc.</td>
</tr>
</tbody>
</table>
Typical separation efficiencies of gas cleaning systems
Overview of wet scrubber types and their characteristics

<table>
<thead>
<tr>
<th>Type</th>
<th>Packed column scrubber</th>
<th>Jet scrubber</th>
<th>Dip scrubber</th>
<th>Venturi-scrubber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical grain size</td>
<td>0.7 – 1.5</td>
<td>0.8 – 0.9</td>
<td>0.6 – 0.9</td>
<td>0.05 – 0.2</td>
</tr>
<tr>
<td>size at ρ = 2.42 g/cm³</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>in [μm]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean relative speed</td>
<td>1</td>
<td>10 – 25</td>
<td>8 – 20</td>
<td>40 – 150</td>
</tr>
<tr>
<td>[m/s]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[mbar]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Washing medium/gas</td>
<td>0.05 – 5</td>
<td>5 – 20</td>
<td>-</td>
<td>0.5 – 5</td>
</tr>
<tr>
<td>$\frac{f(h)}{h}\cdot \frac{m^3}{m^2}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy requirement</td>
<td>0.2 – 1.5</td>
<td>1.2 – 3</td>
<td>1 – 2</td>
<td>1.5 – 6</td>
</tr>
<tr>
<td>[kWh/1000m³]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Multi-layer filter candle
Hydrogen

Hydrogen is currently produced in large quantities via steam reforming of hydrocarbons over a Ni catalyst at ~800oC. This process produces a syngas that must be further processed to produce high-purity hydrogen. The syngas conditioning required for steam reforming is similar to that which would be required for a biomass gasification derived syngas; however, tars and particulates are not as much of a concern. To raise the hydrogen content, the product syngas is fed to one or more water gas shift (WGS) reactors, which convert CO to H2 via the reaction:

\[ \text{CO} + \text{H}_2\text{O} \rightarrow \text{H}_2 + \text{CO}_2 \]

The gas stream leaving the first WGS stage has a CO content of about 2%; in a second stage this is reduced further to about 5000 ppm.
Methanol

• Commercial methanol synthesis involves reacting CO, H2, and steam over a copper-zinc oxide catalyst in the presence of a small amount of CO2 at a temperature of about 260oC and a pressure of about 70 bar. The methanol synthesis reaction is equilibrium controlled, and excess reactants (CO and H2) must be recycled to obtain economic yields.
• The formation of methanol from synthesis gas proceeds via the watergas-shift reaction and the hydrogenation of carbon dioxide:

\[
\begin{align*}
\text{CO} + \text{H}_2\text{O} & \Rightarrow \text{H}_2 + \text{CO}_2 \\
3\text{H}_2 + \text{CO}_2 & \Rightarrow \text{CH}_3\text{OH} + \text{H}_2\text{O} \\
2\text{H}_2 + \text{CO} & \Rightarrow \text{CH}_3\text{OH}
\end{align*}
\]

\[\text{Water-gas-shift} \]
\[\text{Hydrogenation of carbon dioxide}\]

• Methanol production also occurs via direct hydrogenation of CO, but at a much slower rate

\[
2\text{H}_2 + \text{CO} \Rightarrow \text{CH}_3\text{OH}
\]

\[\text{Hydrogenation of carbon monoxide}\]
• To best use the raw product syngas in methanol synthesis and limit the extent of further syngas treatment and steam reforming, it is essential to maintain:
  – A H2/CO of at least 2
  – A CO2/CO ratio of about 0.6 to prevent catalyst deactivation and keep the catalyst in an active reduced state
  – Low concentrations of N2, CH4, C2+, etc. to prevent the build up of inerts within the methanol synthesis loop
  – Low concentrations of CH4 and C2+ to limit the need for further steam reforming.
Synthetic FT Fuels

• Synthetic fuels such as gasoline and diesel can be produced from synthesis gas via the Fischer-Tropsch (FT) process. There are several commercial FT plants in South Africa producing gasoline and diesel, both from coal and natural gas, and a single plant in Malaysia feeding natural gas. The FT synthesis involves the catalytic reaction of H2 and CO to form hydrocarbon chains of various lengths (CH4, C2H6, C3H8, etc.). The FT synthesis reaction can be written in the general form:

\[(n/2 + m)H_2 \ + \ mCO \rightarrow C_mH_n \ + \ mH_2O\]
where \( m \) is the average chain length of the hydrocarbons formed, and \( n \) equals \( 2m+2 \) when only paraffins are formed, and \( 2m \) when only olefins are formed. Iron catalyst has water-gas-shift (WGS) activity, which permits use of low H2/CO ratio syngas.

Gasifier product gases with a H2/CO ratio around 0.5 to 0.7 is recommended as a feed to the FT process when using iron catalyst. The WGS reaction adjusts the ratio to match requirements for the hydrocarbon synthesis and produce CO2 as the major by-product.

On the other hand, cobalt catalysts do not have WGS activity, and the H2 to CO ratio required is then \((2m + 2)/m\). Water is the primary by-product of FT synthesis over a cobalt catalyst.
Trends of coal gasification technology development
Entrained bed gasifiers

GEE Texaco Gasifier

ConocoPhillips E-Gas

Shell SCGP

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ECUST – Chinese technology
Technology comparison

<table>
<thead>
<tr>
<th>Gasifier</th>
<th>Feed system</th>
<th>(CO+H₂) %</th>
<th>Carbon conversion %</th>
<th>Oxygen consumption Nm³O₂ / 1000Nm³(CO+H₂)</th>
<th>Coal consumption kg coal / 1000Nm³(CO+H₂)</th>
<th>Coal type</th>
</tr>
</thead>
<tbody>
<tr>
<td>New type gasifier (Pilot trial)</td>
<td>pulverized coal</td>
<td>89~93</td>
<td>98~99</td>
<td>300~320</td>
<td>530~540</td>
<td>Present coal type for Lunan gasifier (Ash: 9.14%)</td>
</tr>
<tr>
<td></td>
<td>coal water slurry</td>
<td>83</td>
<td>&gt;98</td>
<td>380</td>
<td>550</td>
<td>Former coal type for Lunan gasifier (Ash: 7.67%)</td>
</tr>
<tr>
<td>Shell (Shell China Limited)</td>
<td>pulverized coal</td>
<td>90</td>
<td>&gt;99</td>
<td>340</td>
<td>590</td>
<td>Ash: 18%</td>
</tr>
</tbody>
</table>
Gasifier features

- High carbon conversion and low oxygen/coal consumption because of proper flow pattern in the gasifier
- Easy to scale up (like 2000-3000 ton coal/day) because of multi-burner
- High efficient of syngas primary purification section, low process pressure lost and low fly ash i syngas(1mg/Nm³ syngas) because of “Step-by-Step” concept
Siemens gasifier development

- Multi-fuel gasifier accepts a wide variety of feedstocks (e.g., bituminous coal, sub-bituminous coal, lignite, biomass and liquid wastes)
- Technology development started in mid-1970s
- Major features include dry feed, a reliable cooling screen design, high carbon conversion, and operating pressure up to 40 bar
Construction of gasification section
Burner and feeding system
Scaling of gasifiers

- 200 MW
  - \( \sim 46,000 \text{Nm}^3/\text{h} \)
  - \( (\text{H}_2+\text{CO}) \)

- 500 MW
  - \( \sim 120,000 \text{Nm}^3/\text{h} \)
  - \( (\text{H}_2+\text{CO}) \)

- 1000 MW
  - \( \sim 246,000 \text{Nm}^3/\text{h} \)
  - \( (\text{H}_2+\text{CO}) \)

- 1500 MW
  - \( \sim 370,000 \text{Nm}^3/\text{h} \)
  - \( (\text{H}_2+\text{CO}) \)
Shell gasification technology

Differences:
- non-slagging condition
- refractory lined gasifier
- liquid/gas feed system
- fired tube boiler
- soot water handling
- slagging condition
- membrane wall gasifier
- dry feed system
- water tube boiler
- solid slag handling
Plant block diagram
Technical features

- Entrained flow, dry coal feed, compact equipment, good scale-up possibility
- Membrane-wall gasifier
  - Long life time of membrane wall (>25 yrs)
  - and coal burners (>20,000 hrs)
  - High carbon conversion (>99%)
  - Applicable to most coals
  - Low coal consumption, and
  - low oxygen consumption
- High cold gas efficiency (>80 % LHV)
KBR transport gasifier
Flow diagram - TRIG

KBR’s TRIG™ Island Process: unlock the potential of low rank coal

Developed specifically with low-rank, high-ash coals in mind.
Reactor’s sections
## Comparison

<table>
<thead>
<tr>
<th>Gasifier Type</th>
<th>Energy Use</th>
<th>Availability</th>
<th>OPEX</th>
<th>Gasifier Throughput</th>
<th>Tars and Oils</th>
</tr>
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<tbody>
<tr>
<td>Slagging-Entrained Flow</td>
<td>●</td>
<td>○</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>Moderate</td>
<td>High</td>
<td>Moderate</td>
<td></td>
</tr>
<tr>
<td>Non-Slagging Fixed/Moving Bed</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
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</tr>
<tr>
<td>KBR TRIG™ (Non-Slagging)</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
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<tr>
<td></td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td></td>
</tr>
</tbody>
</table>

**Legend:**  
- ● Large Advantage  
- ○ Small Advantage  
- ○ No Advantage  

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ConocoPhilips gasifier

1975 Pilot
36 TPD

1979
Proto 1 - 400 TPD

1983
Proto 2 - 1600 TPD

LGTI 1987–1995
2,400 TPD

Wabash
1995 - 2006
2,600 TPD

Sub-Bituminous
Rochelle Mine

For 2010 Start-up
E-Gas™
Technology
Commercial
Offerings

Bituminous
Sub-Bituminous
Pet coke

Bituminous IL #6 coal
Pet coke – Multiple refineries.
E-Gas (ConocoPhillips)
GE Gasification technology

- Oxygen
- Petroleum Coke Slurry
- Slurry Feed System
  - Co-Feed Wastes
  - Entrained Flow
  - Refractory Lined Gasifier
- Pressures Up To 1250 psig
  - Water Recycle
  - Fines Recycle
- Syngas
- Slag & Water
- Lockhopper
- Glassy Slag
- Lockhopper System for Solids Removal
  - Marketable Solids

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SKŁAD GAZU SUROWEGO

Diagram przedstawia skład gazu surowego w procentach objętościowych. Na osi pionowej podano koncentracje gazów w procentach, a na osi poziomej - różne gazy: CO, H2, CO2, H2O, Ar+N2, H2S+COS. Diagram pokazuje koncentracje dla firmy Shell (niebieski kolor) i Texaco (czerwony kolor).
Polk Power Station
Reaktor zgazowania - Texaco

Paliwo: 30-40% węgiel, 60-70% koks naftowy

Wys. konstrukcji – 100 m
Polk Station
zgazowanie + tlenownia
Zero emission power plant
Engineering Scope of Work

• Design Engineering
  – Detailed Process Modeling
  – Heat and Material Balances
  – Process Flow Diagrams
  – Facility General Arrangement
  – Equipment Sizing
  – Utility Summary

• Economic Analysis
  – Investment cost
  – Operating cost
Capital cost comparison

TCR, $/kW (2006 dollars)

- Avg IGCC
- Avg IGCC with CO2
- PC Sub
- PC Sub with CO2
- PC Super
- PC Super with CO2
- NGCC
- NGCC with CO2

TCR = Total Capital Requirement. (Includes equipment, materials, labor, indirect construction costs, engineering, contingencies, cost of money, real estate, royalty allowance, preproduction costs, and initial inventories.)
Efficiency comparison

<table>
<thead>
<tr>
<th>HHV Efficiency (%)</th>
<th>Avg IGCC</th>
<th>Avg IGCC w/ CO2 Capture</th>
<th>PC-Sub</th>
<th>PC-Sub w/ CO2 Capture</th>
<th>PC-Super</th>
<th>PC-Super w/ CO2 Capture</th>
<th>NGCC</th>
<th>NGCC w/ CO2 Capture</th>
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<tr>
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<td>39.0</td>
<td>31.5</td>
<td>36.3</td>
<td>23.9</td>
<td>38.5</td>
<td>26.9</td>
<td>50.6</td>
<td>43.4</td>
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Cost of electricity comparison