Pre-Combustion Carbon Capture Selexol Process for IGCC Plants
Overview

• IGCC Power with Capture

• Water-Gas Shift Reactors

• Physical Solvents

• Selexol Process

• Impact of pre-combustion capture on IGCC systems
IGCC Power Plant With CO$_2$ Capture
SOA Technology

**IGCC without CCS**

**Emission Controls:**
- **PM:** Water scrubbing and/or candle filters
- **NOx:** LNB, N₂ dilution
- **Sulfur:** Sulfinol or MDEA and Claus plant with tail gas recycle
- **Hg:** Activated carbon beds

**Advanced F-Class Turbine:** 232 MWe – ISO conditions

**Steam Conditions:** 1800 psig/1050°F/1050°F

**Steam Conditions:**

- **Combined Cycle**
- **HRSG**
- **Reheat/ Humid.**
- **Sulfur**
- **Claus Plant**
- **Fuel Gas**
- **Syngas Cooler/ Quench**
- **Particulate Removal**
- **Syngas Cooler**
- **H₂S Removal**
- **Hg Removal**
- **Gasifier**
- **Cryogenic ASU**
- **Oxygen Coal**
- **Steam**
SOA Technology

**IGCC with CCS**

Green Blocks Indicate Unit Operations Added for CO₂ Capture Case

**Emission Controls:**
- **PM:** Water scrubbing and/or candle filters
- **NOx:** LNB, N₂ dilution
- **AGR:** Selexol and Claus plant with tail gas recycle
- **Hg:** Activated carbon beds

**Advanced F-Class Turbine:** 232 MWe – ISO Conditions

**Steam Conditions:** 1800 psig/1000°F/1000°F
**Water-Gas Shift Reactor System**

**Design:**
- Sulfur Tolerant Catalyst
- Up to 98.5% CO Conversion
- 2 stages for GE and Shell, 3 stages for E-Gas
- $H_2O/CO = 1.8 – 2.25$ (to achieve 90% $CO_2$ capture)

$$H_2O + CO \leftrightarrow CO_2 + H_2$$

**Diagram Details:**
- **H$_2$O/CO Ratio**: 1.8 – 2.25
- **Steam as % of Main Steam Enthalpy**
  - 22 – 40
- **800 psia, 550°F**
- **Heat Integration**

1. Recovered from Heat Integration
Physical Solvents for Acid Gas Removal

Characteristics:

- Dilution occurs as a result of acid gas solubility
- No kinetics, dissolution is an equilibrium process
- Regenerated by pressure reduction
- Most useful when stream to be treated is at high pressure
- Low corrosion

AGR physical solvents:

- DEPG
  - Selexol™, Coastal AGR®
- NMP
  - Purisol®
- Methanol
  - Rectisol®
- Propylene Carbonate
  - Flour Solvent™
Physical vs. Chemical Solvents

- Physical
- Chemical

High acid gas partial pressures in syngas are ideal for physical solvent application.
## Commercial Solvent Property

<table>
<thead>
<tr>
<th>Process Name</th>
<th>Selexol</th>
<th>Rectisol</th>
<th>Fluor Solvent</th>
<th>Purisol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solvent</td>
<td>PEGDME</td>
<td>MeOH</td>
<td>PC</td>
<td>NMP</td>
</tr>
<tr>
<td>Viscosity at 25°C (cP)</td>
<td>5.8</td>
<td>0.6</td>
<td>3.0</td>
<td>1.65</td>
</tr>
<tr>
<td>Specific Gravity at 25°C (kg/m³)</td>
<td>1030</td>
<td>785</td>
<td>1195</td>
<td>1027</td>
</tr>
<tr>
<td>Molecular Weight</td>
<td>280</td>
<td>32</td>
<td>102</td>
<td>99</td>
</tr>
<tr>
<td>Vapor Pressure at 25°C (mmHg)</td>
<td>0.00073</td>
<td>125</td>
<td>0.085</td>
<td>0.40</td>
</tr>
<tr>
<td>Freezing Point (°C)</td>
<td>-28</td>
<td>-92</td>
<td>-48</td>
<td>-24</td>
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<tr>
<td>Boiling Point at 760 mm Hg (°C)</td>
<td>275</td>
<td>65</td>
<td>240</td>
<td>202</td>
</tr>
<tr>
<td>Thermal Conductivity (Btu/hr/ft/°F)</td>
<td>0.11</td>
<td>0.122</td>
<td>0.12</td>
<td>0.095</td>
</tr>
<tr>
<td>Maximum Operating Temperature (°C)</td>
<td>175</td>
<td>-</td>
<td>65</td>
<td>-</td>
</tr>
<tr>
<td>Specific Heat 25°C</td>
<td>0.49</td>
<td>0.566</td>
<td>0.339</td>
<td>0.40</td>
</tr>
<tr>
<td>CO₂ Solubility (ft³/U.S. gal) at 25°C</td>
<td>0.485</td>
<td>0.425</td>
<td>0.455</td>
<td>0.477</td>
</tr>
</tbody>
</table>
**Selexol™ Process**

- Physical liquid solvents
- Highly selective for H₂S and CO₂
- CO₂ is produced at pressure
- 30+ years of commercial operation (55 plants worldwide).

- Absorption/regeneration process for selective removal of H₂S, COS, RSH & CO₂
  - Uses a physical solvent
  - Loading directly proportional to partial pressure
  - Uses a typical solvent-extraction flow-scheme
Selexol Solvent Characteristics

Polyethylene glycol dimethyl ether (PEGDME):
$CH_3O(C_2H_4O)_nCH_3$ (n is between 2 and 9)

Relative Selectivity:

<table>
<thead>
<tr>
<th></th>
<th>Methane</th>
<th>Hydrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>$CO_2$</td>
<td>~9</td>
<td>~45</td>
</tr>
<tr>
<td>$H_2S$</td>
<td>~135</td>
<td>~680</td>
</tr>
<tr>
<td>$CH_3SH$</td>
<td>~340</td>
<td>~1700</td>
</tr>
<tr>
<td>$CO$</td>
<td>~0.43</td>
<td>~2.2</td>
</tr>
<tr>
<td>COS</td>
<td>~35</td>
<td>~175</td>
</tr>
</tbody>
</table>
Selexol Characteristics

Good Selectivity for CO$_2$ over H$_2$:
- Supports separate CO$_2$ production
- Minimizes downstream H$_2$ purification

High Selectivity of H$_2$S over CO$_2$ allows:
- Selective absorption of H$_2$S in the Absorber
- Enhanced recovery of CO$_2$ in flash drum
- Minimizes CO$_2$ in acid gas
- Lowers SRU costs
- Higher power production
Advantages

• Low corrosion rates
  - No formation of heat-stable salts

• Minimal process effluents
  - Reclaiming and/or purging of solvent not required

• Protection of downstream equipment
  - Metal carbonyls are captured by Selexol
Selexol Process for H₂S Removal

Sulfur removal 10 to 20 ppmv
UOP Selexol™ for Ammonia Fertilizer Complex, Coffeyville, Kansas

Process Licensors

- **Gasification:**
  - ChevronTexaco

- **Gas Purification Block:**
  - Acid Gas Removal: Selexol
  - H₂ Purification: Polybed PSA

- **Sulfur:**
  - Black & Veatch Pritchard

- **Air Separation:**
  - BOC

- **Ammonia / UAN:**
  - Ammonia Casale / Weatherly

- **EPC Contractor:**
  - Black & Veatch Pritchard

- **Feedstock:**
  - 45 MT/H petroleum coke

- **Gas Purification Block**
  - Removal of acid gases in a 2-stage Selexol unit with refrigerated solvent
  - H₂S and CO₂ are captured separately with hydrogen product sent to the ammonia synthesis plant and CO₂ sent to the UAN plant
  - Final H₂ purification in Polybed PSA unit

- **Commercial Operation:**
  - July 2000
Feed Stream Specifications

- Feed Flowrate 169,000 Nm³/hr (151 MM SCFD)
- Pressure 36.9 bar-a (535 psia)
- Temperature 38 ºC (100 ºF)
- Component Mole %

H₂ > 56
CO ~ 1.2
CO₂ ~ 41
H₂S and COS ~ 0.6
CH₄, Ar, & N₂ ~ 1
H₂O Saturated
**UOP Selexol™ Coffeyville Design Basis**

**Product Stream Specifications**

- **Raw H₂ Product**
  - Flowrate: 101,900 Nm³/hr (90 MM SCFD)
  - Product Purity: 93 mole % H₂ (minimum)

- **Raw CO₂ Product**
  - Flowrate: 11,900 Nm³/hr (10.6 MM SCFD)
  - Product Purity: 95 mole % CO₂ (minimum)

- **CO₂ Removed:**
  - ~ 94 %

- **Acid Gas Product Purity:**
  - 44 mole % H₂S (minimum)
# UOP Selexol™ Coffeyville Operation Results

## Raw \( \text{H}_2 \) to PSA

<table>
<thead>
<tr>
<th></th>
<th>Design</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{H}_2 ), %</td>
<td>93</td>
<td>&gt; 93</td>
</tr>
<tr>
<td>( \text{CO}_2 ), %</td>
<td>NA</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>( \text{H}_2\text{S} ), ppm</td>
<td>NA</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>( \text{COS} ), ppm</td>
<td>NA</td>
<td>&lt; 1</td>
</tr>
</tbody>
</table>

## Raw \( \text{CO}_2 \) to UAN

<table>
<thead>
<tr>
<th></th>
<th>Design</th>
<th>Actual</th>
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</thead>
<tbody>
<tr>
<td>( \text{CO}_2 ), %</td>
<td>95</td>
<td>&gt; 95</td>
</tr>
<tr>
<td>( \text{H}_2\text{S} ), ppm</td>
<td>NA</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>( \text{COS} ), ppm</td>
<td>NA</td>
<td>&lt; 10</td>
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</table>
GE Gasifier IGCC without Capture
GE IGCC with Capture
# IGCC Performance Results

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>NO</td>
<td>748</td>
<td>25</td>
<td>98</td>
<td>126</td>
<td>622</td>
<td>8,756</td>
<td>39.0</td>
<td>-</td>
</tr>
<tr>
<td>YES</td>
<td>734</td>
<td>26</td>
<td>115</td>
<td>191</td>
<td>543</td>
<td>10,458</td>
<td>32.6</td>
<td>6.4</td>
</tr>
</tbody>
</table>

¹ CO₂ Capture Energy Penalty = Percent points decrease in net power plant efficiency due to CO₂ Capture

- **Steam for Selexol**
- ³ in ASU air comp. load w/o CT integration
- Includes H₂S/CO₂ Removal in Selexol Solvent
## IGCC Performance Results

<table>
<thead>
<tr>
<th></th>
<th>GE Energy</th>
<th>E-Gas</th>
<th>Shell</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CO₂ Capture</strong></td>
<td>NO</td>
<td>YES</td>
<td>NO</td>
</tr>
<tr>
<td><strong>Gross Power (MW)</strong></td>
<td>748</td>
<td>734</td>
<td>738</td>
</tr>
<tr>
<td><strong>Auxiliary Power (MW)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base Plant Load</td>
<td>25</td>
<td>26</td>
<td>24</td>
</tr>
<tr>
<td>Air Separation Unit</td>
<td>98</td>
<td>115</td>
<td>86</td>
</tr>
<tr>
<td>Gas Cleanup/CO₂ Capture</td>
<td>3</td>
<td>19</td>
<td>3</td>
</tr>
<tr>
<td>CO₂ Compression</td>
<td>-</td>
<td>31</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total Aux. Power (MW)</strong></td>
<td>126</td>
<td>191</td>
<td>113</td>
</tr>
<tr>
<td><strong>Net Power (MW)</strong></td>
<td>622</td>
<td>543</td>
<td>625</td>
</tr>
<tr>
<td><strong>Heat Rate (Btu/kWh)</strong></td>
<td>8,756</td>
<td>10,458</td>
<td>8,585</td>
</tr>
<tr>
<td><strong>Efficiency (HHV)</strong></td>
<td>39.0</td>
<td>32.6</td>
<td>39.7</td>
</tr>
<tr>
<td><strong>Energy Penalty¹</strong></td>
<td>-</td>
<td>6.4</td>
<td>-</td>
</tr>
</tbody>
</table>

¹CO₂ Capture Energy Penalty = Percent points decrease in net power plant efficiency due to CO₂ Capture
# IGCC Economic Results

<table>
<thead>
<tr>
<th>CO₂ Capture</th>
<th>GE Energy</th>
<th>E-Gas</th>
<th>Shell</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO</td>
<td>1,426</td>
<td>1,708</td>
<td></td>
</tr>
<tr>
<td>YES</td>
<td>1,719</td>
<td>2,164</td>
<td></td>
</tr>
</tbody>
</table>

## Total Plant Cost, $/kWe (2007$)¹

| Base Plant | 1,426 | 1,708 | 1,804 | 1,719 | 2,164 |
| Air Separation Unit | 312 | 429 | 281 | 437 | 285 | 421 |
| Gas Cleanup/CO₂ Capture | 249 | 503 | 209 | 500 | 213 | 521 |
| CO₂ Compression | - | 71 | - | 76 | - | 75 |

### Total
| Total | 1,987 | 2,711 | 1,913 | 2,817 | 2,217 | 3,181 |

## COE, $/MWh (2007$)

| Capital | 43.4 | 59.1 | 41.7 | 61.5 | 48.2 | 69.2 |
| Fixed   | 11.3 | 14.8 | 11.1 | 15.5 | 12.1 | 16.7 |
| Variable | 7.3 | 9.3 | 7.2 | 9.8 | 7.8 | 9.9 |
| Fuel    | 14.3 | 17.1 | 14.0 | 18.0 | 13.3 | 17.9 |
| CO₂ TS&M | 0.0 | 5.3 | 0.0 | 5.6 | 0.0 | 5.7 |

### Total²
| Total² | 76.3 | 105.7 | 74.0 | 110.4 | 81.3 | 119.5 |

## CO₂ Avoided, $/tonne (2007$)

| Same technology | - | 43 | - | 54 | - | 61 |
| Compared to SCPC | - | 66 | - | 73 | - | 86 |

¹Total Plant Capital Cost (Includes contingencies and engineering fees but not owner's costs)
²80% Capacity Factor
Selexol PEGDME Summary

• Selexol PEGDME has a higher viscosity which reduces mass transfer rates, tray efficiencies and increases packing or tray requirements, especially at reduced temperatures.

• Selexol PEGDME is of very low vapor pressure, and therefore, requires no water wash to recover solvent.

• Selexol PEGDME is suitable for operation at temperatures between 0°F (-18°C) and up to 347°F (175°C).
Rectisol™ Process

- Rectisol process, operated by Linde and Lurgi, uses refrigerated methanol as the solvent for physical absorption. CO₂ and other acid gases are physically absorbed by the solvent, and then desorbed by reducing the pressure of solvent, stripping and if required reboiling the solvent.

\[\text{CH}_3\text{-OH}\]
Rectisol™ Process Principle

Adsorption coefficient of various gases in methanol (Partial pressure: 1 bar)
Rectisol™ has Higher CO₂ Capacity

CO₂ bulk removal capacity of different types of solvents.
Rectisol™ in Lurgi Multi Purpose Gasification Process (MPG®): Desulfurization and CO₂ removal
Rectisol® Process Summary

- Rectisol process typically operates between -40°F and -80°F (-40°C and -62°C).
- Solubilities of H2S and CO2 in methanol are higher than in DMPEG.
- Deep refrigeration or special recovery methods are required to prevent high solvent losses due to relatively high vapor pressure of methanol at normal process conditions.
- The supply of refrigeration at low temperatures requires much power. Low temperature also reduces solvent losses by lowering the vapor pressure of the methanol.
- Water washing of effluent streams is often used to recover the methanol.
Fluor Solvent Process

- **Fluor Solvent**
  - Propylene Carbonate (PC)

- **Operating temperature for PC** is limited between 0°F (-18°C) and 149°F (65°C).

- **PC requires no water wash** to recover the solvent due to its low vapor pressure.

- **Furthermore, PC reacts slowly but irreversibly** with water and CO$_2$ around 194°F (90°C) making it unsuitable for water control by atmospheric distillation.

- **PC has lower solubilities** of light hydrocarbons in natural gas and hydrogen in synthesis gas. This lower solubility results in lower recycle gas compression requirements for the gas flashed from the rich solvent at intermediate pressures, and lower hydrocarbon losses in the CO$_2$ vent gas stream.
Purisol® process

- Purisol Solvent
  - N-Methyl-2-Pyrrolidone (NMP)
- Purisol flow schemes are similar to Selexol. The process can be operated either at ambient temperature or down to about 5°F (-15°C)
- NMP has a relatively high vapor pressure compared to Selexol or Fluor solvents. Water washing is necessary for solvent recovery.
- NMP has high selectivity for H₂S over CO₂.
- Purisol process is particularly well suited to the purification of high-pressure, high CO₂ synthesis gas for gas turbine integrated gasification combined cycle (IGCC) systems because of the high selectivity for H₂S.
Questions?