CO$_2$ Sources

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Laramie WY, USA
Sources of CO$_2$

- Electricity Power Plants powered by fossil fuels, especially coal fired power plants
- Coal Gasification and Coal to Liquids plants
- Indigenous fields with a high CO$_2$ content
- Oil refineries
- Petrochemical plants
- Fertilizer plants
Indigenous Fields and CO$_2$ Pipelines in USA
CO₂ Pipeline To Canada

[Map showing pipeline from Weyburn in Canada to Beulah in North Dakota]
Major Power Plants with ~MMSCF/D CO₂ Potential in Wyoming, Colorado, and Utah

- Colstrip (1050)
- Wyodak (170)
- Neil Simpson (65)
- Dave Johnson (380)
- Laramie (850)
- Rawhide (150)
- Arapahoe (115)
- Cherokee (355)
- Jim Bridger (1055)
- Naughton (350)
- Intermountain (820)
- Bonanza (200)
- Craig (670)
- Hayden (230)
- Huntington (450)
- Hunter (660)
- Carbon (90)
# Wyoming CO2 Capture Potential Balances - New Oil & Gas

## TABLE 1

<table>
<thead>
<tr>
<th>Target Potential Power Plant Station</th>
<th>MW Capacity</th>
<th>Coal Feeds ~Short T/D</th>
<th>Estimated CO2 Capture for EOR Tonnes/D</th>
<th>CO2 Capture MMSCF/D</th>
<th>Sequestered Potential (*) New Oil Bbl/D</th>
<th>Credit (**) N2 for ECBM Natural Gas MMSCF/D</th>
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<tr>
<td><strong>Basin Electric - Laramie</strong></td>
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<tr>
<td>Unit #1</td>
<td>570</td>
<td>8,668</td>
<td>14,728</td>
<td>284</td>
<td>66,988</td>
<td>187.4</td>
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<tr>
<td>Unit #2</td>
<td>570</td>
<td>8,668</td>
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<td>8,668</td>
<td>14,728</td>
<td>284</td>
<td>66,988</td>
<td>187.4</td>
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<td><strong>Black Hills - Neil Simpson</strong></td>
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<td>517</td>
<td>879</td>
<td>17</td>
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<td>1,217</td>
<td>2,067</td>
<td>40</td>
<td>9,402</td>
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<tr>
<td>Unit #1</td>
<td>106</td>
<td>1,612</td>
<td>2,739</td>
<td>53</td>
<td>12,457</td>
<td>34.9</td>
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<tr>
<td>Unit #2</td>
<td>106</td>
<td>1,612</td>
<td>2,739</td>
<td>53</td>
<td>12,457</td>
<td>34.9</td>
</tr>
<tr>
<td>Unit #3</td>
<td>330</td>
<td>5,018</td>
<td>8,527</td>
<td>164</td>
<td>38,783</td>
<td>108.5</td>
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<td>Unit #4</td>
<td>220</td>
<td>3,346</td>
<td>5,685</td>
<td>110</td>
<td>25,855</td>
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<tr>
<td>Unit #1</td>
<td>530</td>
<td>8,060</td>
<td>13,695</td>
<td>264</td>
<td>62,287</td>
<td>174.3</td>
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<tr>
<td>Unit #2</td>
<td>530</td>
<td>8,060</td>
<td>13,695</td>
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<td>174.3</td>
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<td>530</td>
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<td>13,695</td>
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<td>8,656</td>
<td>167</td>
<td>39,370</td>
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<td><strong>Totals</strong></td>
<td>5,756</td>
<td>77,422</td>
<td>148,731</td>
<td>2,867</td>
<td>598,309</td>
<td>1,673.9</td>
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</table>

(*) Anadarko in WY using 6,530 MT/D of CO2 for EOR project yielding 29,700 B/D (~ 4,000 scf/Bbl) new oil production, then making an adjustment for total Wyoming potential.

(**) Nitrogen (N2) for enhanced coal bed methane (ECBM) displacement, assumed 4 volumes of N2 yielding one (1) volume methane.
Capturing CO$_2$ from a Power Plant

- Amine Units
- Oxy-fired units and retrofits
- Activated Carbon
- New Adsorbents
<table>
<thead>
<tr>
<th>Operator</th>
<th>Location</th>
<th>Capacity (tons/day CO₂)</th>
<th>Fuel Source</th>
<th>CO₂ Use</th>
<th>Technology</th>
<th>Status</th>
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<tbody>
<tr>
<td>Carbon Dioxide Technology</td>
<td>Lubbock, TX</td>
<td>1200</td>
<td>gas boiler</td>
<td>EOR</td>
<td>Dow MEA</td>
<td>Shut</td>
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<tr>
<td>North American Chemical Co.</td>
<td>Trona, CA</td>
<td>800</td>
<td>coal boiler</td>
<td>Carbonation of brine (soda ash)</td>
<td>Kerr-McGee MEA</td>
<td>Operational since 1978</td>
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<tr>
<td>Mitchell Energy</td>
<td>Bridgeport, TX</td>
<td>493</td>
<td>gas heaters, engines, turbine</td>
<td>EOR</td>
<td>Inhibited MEA</td>
<td>Shut</td>
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<tr>
<td>Soda Ash Botswana</td>
<td>Sua Pan,</td>
<td>300</td>
<td>coal boiler</td>
<td>Carbonation of brine (soda ash)</td>
<td>Kerr-McGee MEA</td>
<td>Operational since 1991</td>
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<tr>
<td>Applied Energy Systems</td>
<td>Poteau, OK</td>
<td>200</td>
<td>coil boiler (fluidized bed)</td>
<td>PURPA (food-grade)</td>
<td>Kerr-McGee MEA</td>
<td>Operational since 1991</td>
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<tr>
<td>Sumitomo Chemicals</td>
<td>Chiba, Japan</td>
<td>165</td>
<td>gas boilers plus oil/coal boiler</td>
<td>food-grade</td>
<td>Fluor Daniel</td>
<td>Operational since 1994</td>
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<tr>
<td>Luzhou Natural Gas</td>
<td>China</td>
<td>160</td>
<td>NH₃ plant reformer exhaust</td>
<td>Urea</td>
<td>Dow MEA</td>
<td>No Information</td>
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<td>Indo Gulf Fertilizer Co.</td>
<td>India</td>
<td>150</td>
<td>NH₃ plant reformer exhaust</td>
<td>Urea</td>
<td>Dow MEA</td>
<td>Operational since ~1988</td>
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<tr>
<td>N-ReN Southwest</td>
<td>Carlsbad, NM</td>
<td>104</td>
<td>gas boiler plus NH₃ reformer exhaust</td>
<td>EOR</td>
<td>Retrofit to Dow MEA</td>
<td>Shut</td>
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<tr>
<td>Prosint</td>
<td>Rio de Janeiro, Brazil</td>
<td>90</td>
<td>gas boiler</td>
<td>food-grade</td>
<td>Fluor Daniel</td>
<td>Operational since 1997</td>
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<td>Liquid Air Australia</td>
<td>Australia</td>
<td>2 x 60</td>
<td>gas boiler</td>
<td>food-grade</td>
<td>Dow MEA</td>
<td>Operational since ~1985</td>
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</table>

Notes:
1. ABB Lummus Crest licensed the Kerr-McGee MEA technology in 1990.
2. Fluor Daniel licensed the Dow MEA technology (ECONAMINE FG) in 1989.
3. A number of small plants (~6 tons/day CO₂) producing food-grade CO₂ exist in the Philippines and other places using Fluor Daniel/Dow MEA technology.
Some data from Herzog (MIT, 1999) on cost of CO$_2$ capture from electric generating plants using MEA technology.
<table>
<thead>
<tr>
<th>Data Description</th>
<th>Units</th>
<th>IGCC Today</th>
<th>IGCC 2012</th>
<th>PC Today</th>
<th>PC 2012</th>
<th>NGCC Today</th>
<th>NGCC 2012</th>
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<td><strong>Reference Plant</strong></td>
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<td>coe: CAPITAL</td>
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<td>17</td>
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<td>1145</td>
<td>1150</td>
<td>1095</td>
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<td>Net Power Output</td>
<td>MW</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
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<td>CO₂ emitted</td>
<td>kg/kWh</td>
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<td>0.65</td>
<td>0.77</td>
<td>0.73</td>
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<td>Thermal Efficiency (LHV)</td>
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<td></td>
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<tr>
<td>Heat Rate (LHV)</td>
<td>Btu/kWh</td>
<td>8124</td>
<td>7137</td>
<td>8462</td>
<td>8042</td>
<td>6308</td>
<td>5677</td>
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<tr>
<td>Cost of Electricity</td>
<td>$/kWh</td>
<td>4.6</td>
<td>4.1</td>
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<td>4.1</td>
<td>3.3</td>
<td>3.1</td>
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<td>39</td>
<td>33</td>
<td>45</td>
<td>40</td>
<td>26</td>
<td>22</td>
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</tr>
<tr>
<td></td>
<td>CCE: FUEL (mill/kWh)</td>
<td>12</td>
<td>10</td>
<td>13</td>
<td>12</td>
<td>21</td>
<td>18</td>
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<tr>
<td></td>
<td>CCE: O&amp;M (mill/kWh)</td>
<td>8</td>
<td>8</td>
<td>11</td>
<td>11</td>
<td>6</td>
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<tr>
<td>Capital Cost</td>
<td>$/kW</td>
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<td>1433</td>
<td>1967</td>
<td>1748</td>
<td>1120</td>
<td>956</td>
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<td>Net Power Output</td>
<td>MW</td>
<td>421</td>
<td>443</td>
<td>400</td>
<td>417</td>
<td>432</td>
<td>463</td>
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<td>CO₂ emitted</td>
<td>kg/kWh</td>
<td>0.09</td>
<td>0.07</td>
<td>0.10</td>
<td>0.09</td>
<td>0.04</td>
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<td>Thermal Efficiency (LHV)</td>
<td>%</td>
<td>35.4%</td>
<td>42.4%</td>
<td>32.2%</td>
<td>35.4%</td>
<td>46.8%</td>
<td>55.6%</td>
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<td>Btu/kWh</td>
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<td>8056</td>
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<td>¢/kWh</td>
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<td>6.9</td>
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<th>¢/kWh</th>
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<th>2.7</th>
<th>2.2</th>
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<td>Incremental CCE</td>
<td>¢/kWh</td>
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<td>11%</td>
<td>20%</td>
<td>17%</td>
<td>14%</td>
<td>7%</td>
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<td>Energy Penalty</td>
<td>$/tonne CO₂</td>
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<td>40</td>
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<td>47</td>
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<td>Mitigation Cost vs. ref</td>
<td>$/tonne CO₂</td>
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<td>76</td>
<td>135</td>
<td>132</td>
<td>61</td>
<td>47</td>
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<td>Mitigation Cost vs. gas</td>
<td>$/tonne CO₂</td>
<td>96</td>
<td>76</td>
<td>135</td>
<td>132</td>
<td>61</td>
<td>47</td>
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<th>Basis</th>
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<th>15.0%</th>
<th>15.0%</th>
<th>15.0%</th>
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<td>Capital Charge Rate</td>
<td>hrs/yr</td>
<td>6570</td>
<td>6570</td>
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<td>Yearly Operating Hours</td>
<td>$/MMBtu</td>
<td>1.24</td>
<td>1.24</td>
<td>1.24</td>
<td>1.24</td>
<td>2.93</td>
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</table>
The Amine process

- The liquid moves countercurrent to sour gas, and is either Monoethanolamine (MEA), Diethanolamine (DEA),
- Equipment includes a contactor, filter, regenerator, heat exchangers, and a pump
- Process principles
- The $\text{H}_2\text{S}$ and $\text{CO}_2$ react with a base to give a water soluble acidic salt. The reaction is reversible with heat. The acid gases are absorbed from 60 to 120°F and desorbed from 240 to 300°F, and both are influenced by acid gas partial pressure.
Typical Gas Sweetening by Chemical Reaction

- Sweet gas
- Outlet separator
- Contactor
- Lean cooler
- Flash tank
- Flash gas
- Sour gas
- Inlet separator
- Acid gas
- Condenser
- Reflux separator
- Reclaimer
- Rich/Lean exchanger
- Stripper
- Reboiler
- Optional equipment
Properties of The Common Amines

- MEA is a stronger base with a lower molecular weight which allows use of a smaller pump, less heat, etc.
- The molecular weight comparison of MEA:DEA:TEA as 1.00:1.72:2.44.
- MEA has a lower boiling point (distillation). However, MEA losses are greater as the vapor pressure is higher.
- The sour gas flows upward (at 80 to 100°F) through the amine-water solution 15% (10 to 20%)
### TABLE 2

Physical Properties of Amines

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>MEA</th>
<th>DEA</th>
<th>TEA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formula</td>
<td>HOC₂H₄NH₂</td>
<td>(HOC₂H₄)₂NH</td>
<td>(HOC₂H₄)₃N</td>
</tr>
<tr>
<td>Molecular Weight</td>
<td>61.08</td>
<td>105.14</td>
<td>149.19</td>
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<tr>
<td>Specific Gravity @ 68°F</td>
<td>1.0179</td>
<td>1.0919</td>
<td>1.1258</td>
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<tr>
<td>Density, lbs/gal</td>
<td>8.47</td>
<td>9.09</td>
<td>9.37</td>
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<tr>
<td>Melting Point, °F</td>
<td>50.9</td>
<td>82.4</td>
<td>70.2</td>
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<tr>
<td>Boiling Point, °F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>@ 760 mm Hg</td>
<td>339</td>
<td>516*</td>
<td>680</td>
</tr>
<tr>
<td>@ 50 mm Hg 212369471</td>
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<tr>
<td>@ 10 mm Hg 156302406</td>
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<tr>
<td>Vapor Pressure @ 68°F, mm Hg</td>
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<td>0.01</td>
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<td>Freezing Point, °F</td>
<td>50.9</td>
<td>82.4</td>
<td>70.2</td>
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<td>Absolute Viscosity @ 68°F,</td>
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<td>centipoises</td>
<td>24.13801</td>
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<tr>
<td>Heat of Vaporization, btu/lb</td>
<td>355</td>
<td>284</td>
<td>230</td>
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<tr>
<td>Solubility in Water @ 68°F</td>
<td>Complete</td>
<td>95.4 wt. %</td>
<td>Complete</td>
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<td>Physical Properties of Gas Treating Chemicals</td>
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</tr>
<tr>
<td><strong>Formula</strong></td>
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<td>Diethanolamine</td>
<td>Triethanolamine</td>
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<td>-----------------</td>
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<tr>
<td><strong>Molecular Wt</strong></td>
<td>61.08</td>
<td>105.14</td>
<td>148.19</td>
</tr>
<tr>
<td><strong>Boiling point @ 760 mm Hg, °F</strong></td>
<td>338.9</td>
<td>516.2</td>
<td>680 (decomposes)</td>
</tr>
<tr>
<td><strong>Freezing point, °F</strong></td>
<td>50.9</td>
<td>82.4</td>
<td>72.3</td>
</tr>
<tr>
<td><strong>Critical constants</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pressure, psia</td>
<td>868</td>
<td>474.7</td>
<td>355</td>
</tr>
<tr>
<td>Temperature, °F</td>
<td>662</td>
<td>827.8</td>
<td>957.7</td>
</tr>
<tr>
<td>Density @ 20°C, gm/ce.</td>
<td>1.018</td>
<td>1.095</td>
<td>1.124</td>
</tr>
<tr>
<td>Weight, lb/gal</td>
<td>8.48 @ 60°F</td>
<td>9.09 @ 60°F</td>
<td>9.37 @ 68°F</td>
</tr>
<tr>
<td>Specific gravity 20°C/20°C</td>
<td>1.0179</td>
<td>1.0919 (30/20°C)</td>
<td>1.1258</td>
</tr>
<tr>
<td>Specific heat @ 60°F, Btu/lb/°F</td>
<td>0.608 @ 68°F</td>
<td>0.600</td>
<td>0.70</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Btu/[(hr • sq ft • °F)/ft] @ 68°F</td>
<td>0.148</td>
<td>0.127</td>
<td>-</td>
</tr>
<tr>
<td>Latent heat of vaporization, Btu/lb</td>
<td>355 @ 760 mmHg</td>
<td>288 @ 73 mmHg</td>
<td>230 @ 760 mmHg</td>
</tr>
<tr>
<td>Heat of reaction, Btu/lb of Acid Gas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H₂S</td>
<td>-400</td>
<td>-674</td>
<td>-</td>
</tr>
<tr>
<td>CO₂</td>
<td>-630</td>
<td>-850</td>
<td>-</td>
</tr>
<tr>
<td>Viscosity, cp</td>
<td>24.1 @ 68°F</td>
<td>350 @ 68°F</td>
<td>1013 @ 68°F</td>
</tr>
<tr>
<td>(at 90% wt. solution)</td>
<td>(at 95% wt. solution)</td>
<td>198 @ 113°F</td>
<td>86 @ 129°F</td>
</tr>
<tr>
<td>Refractive index, N₅ 68°F</td>
<td>1.4539</td>
<td>1.4776</td>
<td>1.4852</td>
</tr>
<tr>
<td>Flash point, COC, °F</td>
<td>200</td>
<td>280</td>
<td>365</td>
</tr>
<tr>
<td></td>
<td>Propylene Carbonate</td>
<td>Methyldeethanol-amine</td>
<td>Sulfolane®</td>
</tr>
<tr>
<td>---------------------------</td>
<td>---------------------</td>
<td>-----------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Formula</td>
<td>C₈H₆CO₃</td>
<td>(HOCH₂)₂NCH₃</td>
<td>C₄H₈SO₂</td>
</tr>
<tr>
<td>Molecular Wt</td>
<td>102.09</td>
<td>119.16</td>
<td>120.17</td>
</tr>
<tr>
<td>Boiling point @ 760 mm Hg, °F</td>
<td>467</td>
<td>477.0°C</td>
<td>545</td>
</tr>
<tr>
<td>Freezing point, °F</td>
<td>-56.6</td>
<td>-9.3°F</td>
<td>81.7</td>
</tr>
<tr>
<td>Critical constants</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pressure, psia</td>
<td>–</td>
<td>767.3</td>
<td>1153.9</td>
</tr>
<tr>
<td>Temperature, °F</td>
<td>–</td>
<td>1013.8</td>
<td>464</td>
</tr>
<tr>
<td>Density @ 20°C, gm/cc.</td>
<td>1.2057</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight, lb/gal</td>
<td>8.68</td>
<td>10.623 @ 30°C/30°C</td>
<td>9.254</td>
</tr>
<tr>
<td>Specific gravity 20°C/20°C</td>
<td>1.203</td>
<td>1.0418</td>
<td>0.7917</td>
</tr>
<tr>
<td>Specific heat @ 60°F, Btu/lb°F</td>
<td>0.335</td>
<td>0.535</td>
<td>0.35 @ 30°C</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Btu/[hr • sq ft • °F]/ft] @ 68°F</td>
<td>0.12 @ 50°F</td>
<td>0.159</td>
<td>0.114 @ 100°F</td>
</tr>
<tr>
<td>Latent heat of vaporization, Btu/lb</td>
<td>208 @ 760 mmHg</td>
<td>204</td>
<td>225.7 @ 212°F</td>
</tr>
<tr>
<td>Heat of reaction, Btu/lb of Acid Gas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H₂S</td>
<td>–</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Viscosity, cp</td>
<td>1.67 @ 100°F</td>
<td>1.3 cs @ 50°F</td>
<td>10.3 @ 86°F</td>
</tr>
<tr>
<td></td>
<td>19.4 cs @ -40°F</td>
<td>0.68 cs @ 100°F</td>
<td>6.1 @ 122°F</td>
</tr>
<tr>
<td></td>
<td>1.79 cs @ 100°F</td>
<td>0.28 cs @ 212°F</td>
<td>2.5 @ 212°F</td>
</tr>
<tr>
<td></td>
<td>0.827 cs @ 210°F</td>
<td></td>
<td>1.4 @ 302°F</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.97 @ 392°F</td>
</tr>
<tr>
<td>Refractive index, Na 68°F</td>
<td>1.4209</td>
<td>1.469</td>
<td>1.481 @ 86°F</td>
</tr>
<tr>
<td>Flash point, COC, °F</td>
<td>270</td>
<td>265</td>
<td>350</td>
</tr>
</tbody>
</table>
The popular Selexol process is an example of a physical solvent process. These processes are based on physical absorption and operate with a flow scheme as shown next.
Typical Gas Sweetening by Physical Absorption
In general, a physical solvent process are considered when:
- The partial pressure of the acid gas in the feed is greater than 50 psi.
- The heavy hydrocarbon concentration in the feed gas is low.
- Bulk removal of the acid gas is desired.
- Selective removal of $\text{H}_2\text{S}$ is desired.
These processes are economically attractive because little or no energy is required for regeneration. The solvents are regenerated by:

- Multi-stage flashing to low pressures.
- Regeneration at low temperatures with an inert stripping gas.
- Heating and stripping of solution with steam/solvent vapors.
- In general, physical solvents are capable of also removing COS, CS$_2$, and mercaptans.
- In certain instances, physical absorption processes are capable of simultaneously dehydrating and treating the gas although additional equipment and higher energy requirements may be needed to dry the solvent.
The processes operate at ambient or sub-ambient temperature to enhance the solubility of the acid gases. The solvents are relatively noncorrosive so carbon steel can be used. Chemical losses are low due to low solvent vapor pressure. Physical solvents will absorb heavy hydrocarbons from the gas stream resulting in high hydrocarbon content in the acid gas stream as well as possibly significant hydrocarbon losses.
Selexol

- This process uses a **polyethylene glycol derivative** as a solvent.
- The solvent is selective for RSH, CS$_2$, H$_2$S, and other sulfur compounds. The process can be used to selectively or simultaneously remove sulfur compounds, carbon dioxide, water, as well as paraffinic, olefinic, aromatic and chlorinated hydrocarbons from a gas or air stream.
Because water and heavy hydrocarbons are highly soluble in Selexol, the treated gas from a Selexol unit normally meets both water and hydrocarbon dew point specifications. The solvent is very stable, no degradation products are formed or disposed of, and no solvent reclaiming is required.

Depending on the applications, the operating pressure could be as low as ambient though higher pressure is preferred. Operating temperature varies from 0°F to ambient.

Selexol is a Union Carbide Corporation technology.
**COMBINATION PROCESSES**

There are several gas treating processes which use the effects of both physical solvents and chemical solvents. Many are in the development stage but one which has proven successful is:

**Sulfinol Process**

The Sulfinol Process, licensed by Shell E&P Technology Company, is used to remove \( \text{H}_2\text{S}, \text{CO}_2, \text{COS}, \text{CS}_2, \text{mercaptans} \) and polysulfides from natural and synthetic gases. Sulfinol is a mixture of Sulfolane (a physical solvent), water and either DIPA or MDEA (both chemical solvents).
It is this dual capacity as both a physical and a chemical solvent that gives Sulfinol its advantages. Sulfinol with DIPA (Sulfinol-D) is used when complete removal of H₂S, CO₂, and COS is desired.

Sulfinol with MDEA (Sulfinol-M) is used for the selective removal of H₂S in the presence of CO₂, with partial removal of COS.

Both Sulfinols can reduce the total sulfur content of treated gas down to low ppm levels.

The advantages of Sulfinol are:

- Low energy requirements
- Low foaming and noncorrosive nature
- High acid gas loadings allowed
- Some removal of trace sulfur compounds

The disadvantages of Sulfinol are:

- Higher heavy hydrocarbon co-absorption
- Reclaimer sometimes required when removing CO₂
Separation with Solid Absorbents

- There are currently no such commercial processes
- But zeolites with an amine attachment and molecular sieves are a possibility
- Or Li$_3$ZrO$_3$ which reacts with CO$_2$ to form Li$_2$CO$_3$
- Or Polyionic liquids
- Or activated carbon.
- This process may look something like the natural gas drying processes that use solid dessicants
Example of CO₂ PSA Process

Step 1
Silica Gel is a generic name for a gel manufactured from sulfuric acid and sodium silicate. It is essentially pure silicon dioxide, SiO$_2$.

A hydrated form of **alumina oxide** (Al$_2$O$_3$).

**Molecular sieves** are a class of aluminosilicates and possess the highest water capacity, will produce the lowest water dewpoints, and can be used to simultaneously sweeten and dry gases and liquids.
Inlet and Outlet Temperatures During Typical Solid Desiccant Bed Regeneration Cycle.
CO$_2$ Sorbents

- We are developing and testing novel adsorbents and adsorption cycles or processes for capture of CO$_2$ using pressure or temperature-swing process
- To determine the impact of process parameters (cycle time, cycle configuration, temperature) on CO$_2$ capture efficiency.
- To determine capital and power requirements by using simulation tools to scale up to appropriate size.
- To acquire sufficient process performance data for the adsorption processes developed so as to permit technical and economic assessment of the viability of adsorption technologies.
Membrane Technology

• Carbon Dioxide can be separated from nitrogen or natural gas by selectively permeation through a hollow fiber membrane. The driving force is the partial pressure difference across the membrane for CO₂, CH₄ and other gas components. CO₂ is the “fast” gas whereas CH₄ is the “slow” gas. Membrane technology is based on polymeric hollow fibers. The pressurized feed gas enters the bundle from the shell side, the methane stays under pressure, and the CO₂ is collected at a lower pressure.
Open fibers

Permeate gas
3 bar a
$CO_2, H_2S, H_2O...$

Closed fibers

Residue gas
59.8 bar a
$CH_4, C_2H_6, C_3H_8, CO_2, H_2S, H_2O...$

Feed gas
60 bar a
$CH_4, C_2H_6, C_3H_8, C_4H_10...$

Hollow fiber membrane flow general pattern
New Polymer membranes
Ionic Liquid Polymer Membrane

CO$_2$/N$_2$ Permselectivity vs. CO$_2$ permeability (Barrer)

- Representative polymers
- P[MATMA][BF4]-g-PEG 2000
- P[VBTMA][BF4]-g-PEG 2000
- [emim][dca]
$\text{BPPO}_{dp}/10$ nm-silica nanocomposite membranes
Oxy-Fired Plants

If coal is burned in pure $O_2$ with CO2 recycle the only produced product is pure CO2 plus H2O. This CO2 is then ready for EOR or sequestration.

So instead of separating CO2 from the flue gas you are separating O2 from the inlet air.

There are certain advantages to doing this.

The carrier gas becomes CO2 instead of N2
Pulverized Coal Plant (oxy-fired)

Non-Emissive CO₂ Capture Technology Reactions

Coke, S, N + O₂/CO₂ + K₂CO₃ → CO₂ + H₂O + K₂SO₄ + KNO₃

CO₂ Recycle

Coke Fuel + K₂

> 97% O₂

PC Boiler

H₂O

CO₂ Captured
No Stack gas
Steam to EOR
Steam to Power

Solids (K₂SO₄ & KNO₃)
IGCC DESIGN FEATURES

- No separation of compounds is done between the gasifier and the turbine. No cooling or treatment needed.
- Exhaust is primarily CO2 and H2O.
- A working aero-derived turbine is used to produce compressed air for process flow streams such as: (a) the air cycle machines (ACM) used to boost O2/H2O pressure to the gasifier, and (b) the pressure swing O2 generators.
- Working aero-derived turbines not only drive the electric generation units but the hot exhaust is used to produce heat for water vaporization to be used in the steam turbine.
- CO2 from the exhaust is recycled as carrier gas in the gas turbines.