Workshop on Future Large CO2 Compression Systems
Large CO2 Source & Capture Systems
Agenda

• CO2 Pipelines in USA for EOR

• 3 Large CO2 Source/Capture/Compression Plants
  – ExxonMobil LaBarge-Shute Creek, WY *Natural Gas* Plant
  – CDT Inc / Lubbock, TX CO2-from-*CFPP-Flue Gas*
  – Coffeyville Resources (KS) *Gasification*-based Fertilizer Plant
CO2 Pipelines in USA for EOR (Enhanced Oil Recovery)
Major CO2 Pipelines in USA for EOR
Source: Melzer Consulting / 6th Annual Conference CC&S Conf-Pittsburgh / 10May2007

![Image of table and graph showing major CO2 pipelines in the USA for EOR.](image-url)

600 MW- IGCC @ 90% CO2 Capture = 4.3 MM T/Y CO2
**CO2 Pipelines in USA for EOR**
Source: Polytec (Norway) / 08January2008
State-of-Art Overview / CO2 Pipeline Transport

<table>
<thead>
<tr>
<th></th>
<th>Canyon Reef Carriers (4)</th>
<th>Central Basin Pipeline (5)</th>
<th>Sheep Mountain (6) (7; 8)</th>
<th>Bravo Dome Source (9)</th>
<th>Cortez Pipeline (10)</th>
<th>Weyburn (11)</th>
<th>Jackson Dome, NEJD</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>85-98</td>
<td>98.5</td>
<td>96.8-97.4</td>
<td>99.7</td>
<td>95</td>
<td>96</td>
<td>98.7-99.4</td>
</tr>
<tr>
<td>CH₄</td>
<td>2-15</td>
<td>0.2</td>
<td>1.7</td>
<td>-</td>
<td>1-5</td>
<td>0.7</td>
<td>Trace</td>
</tr>
<tr>
<td></td>
<td>C6H14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N₂</td>
<td>&lt;0.5</td>
<td>1.3</td>
<td>0.6-0.9</td>
<td>0.3</td>
<td>4</td>
<td>&lt;300 ppm</td>
<td>Trace</td>
</tr>
<tr>
<td>H₂S</td>
<td>&lt;200 ppm (spec)</td>
<td>&lt; 20 ppm</td>
<td>--</td>
<td>-</td>
<td>0.002</td>
<td>0.9</td>
<td>Trace</td>
</tr>
<tr>
<td>C₂⁺</td>
<td>-</td>
<td>0.3-0.6</td>
<td>-</td>
<td>Trace</td>
<td></td>
<td>2.3</td>
<td>-</td>
</tr>
<tr>
<td>CO</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td>0.1</td>
<td>-</td>
</tr>
<tr>
<td>O₂</td>
<td>-</td>
<td>&lt;10 ppm wt (spec)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>&lt;50 ppm wt</td>
<td>-</td>
</tr>
<tr>
<td>NOₓ</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SOₓ</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>H₂</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Trace?</td>
<td>-</td>
</tr>
<tr>
<td>Ar</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>H₂O</td>
<td>50 ppm wt</td>
<td>257 ppm wt</td>
<td>129 ppm wt</td>
<td>-</td>
<td>257 ppm wt</td>
<td>20 ppm vol</td>
<td>-</td>
</tr>
</tbody>
</table>
Workshop on Future Large CO2 Compression Systems
Large CO2 Source & Capture Systems
Agenda

• CO2 Pipelines in USA for EOR

• 3 Large CO2 Source/Capture/Compression Plants
  – ExxonMobil LaBarge-Shute Creek, WY Natural Gas Plant
  – CDT Inc / Lubbock, TX CO2-from-CFPP-Flue Gas
  – Coffeyville Resources (KS) Gasification-based Fertilizer Plant
ExxonMobil Shute Creek NG Plant
CO2 Capture & Compression for EOR
Shute Creek, WY NG Treating Facility

ExxonMobil -- Shute Creek, WY Gas Treating Facility
Source: EXOM – Midland CO2 Conference / 2005
ExxonMobil Shute Creek Natural Gas (NG) Plant
CO2 Capture & Compression for EOR
Gas Processing Overview

• LaBarge NG Field & Shute Creek Gas Treating Facility
  • Commissioned in 1986 in SW-Wyoming
    – Initial Capacity of 480 MMSCFD of NG
    – Expanded in 2005 to 700 MMSCFD
  • NG Feed: 5%V H2S – 66%V CO2 – 21%V CH4 – 0.6%V He – 7%V N2
  • Marketable Products: CH4, CO2, He, & Sulfur
  • Selexol Process (2-trains) used for Acid Gas Removal:
    – H2S-Rich Acid Gas (65 MMSCFD H2S & 25 MMSCFD CO2)
      • Originally sent to Claus-SRU for Elemental Sulfur
      • Now Compressed, Liquified, and Pumped into Formation
      • Largest-known Facility for AG-Injection in Operation
    – CO2 for Compression to Pipeline for EOR Fields
ExxonMobil LaBarge / Shute Creek Facilities
Overall Block Flow Diagram

Source: EXOM / RM-GPA Mtg / Sept 1985
ExxonMobil LaBarge/Shute Creek Facilities
CO2 Capture & Compression for EOR
CO2 Source and CO2 Flood Locations

Source: Melzer Consulting / 6th Annual Conference on CC&S Conf-Pittsburgh / 10May2007
ExxonMobil Shute Creek NG Plant
Selexol Unit Process Flow Diagram
H2S Removal Section

Source: Stearns Rogers / AIChE Mtg / August 1983
ExxonMobil Shute Creek NG Plant
Selexol Unit Process Flow Diagram
H2S Removal Section

Source: Stearns Rogers / AIChE Mtg / August 1983
ExxonMobil Shute Creek NG Plant
Selexol Unit Process Flow Diagram
CO2 Removal Section

Source: Stearns Rogers / AIChE Mtg / August 1983
ExxonMobil Shute Creek NG Plant
Selexol Unit Process Flow Diagram
CO2 Regeneration Section

Source: Stearns Rogers / AIChE Mtg / August 1983
ExxonMobil Shute Creek NG Plant

CO2 Capture & Compression for EOR

*Existing* CO2 Compression & Pipeline Steps

- Selexol Unit Supplies CO2 at 200 & 60 (& LP?) psia
- 270 MMSCFD (15673 STD) CO2 Compressed to 1750 psig
  - 49,000 HP in 4 Compressor Trains
  - Supplied by Dresser-Rand
- CO2 is transported via 2 pipelines
  - 24-inch diameter / 48-mile long line
  - 20-inch diameter / 112-mile line
ExxonMobil Shute Creek NG Plant
CO2 Capture & Compression for EOR

*Expansion* of CO2 Compression & Pipeline

• Expansion of Facilities for Additional 110 MMSCFD (6385 STD) CO2 for Pipeline EOR

• Fully-funded $72MM Project:
  – Detailed Design in November 2007
  – Long-lead Equipment Purchases Initiated in May 2008
  – Construction Initiated in late-2008
  – Commissioning Targeted by June 2010

• Project Engineering Execution:
  • 25 EXOM Engineering Staff
  • 15 Washington Group Engineering Staff
ExxonMobil Shute Creek NG Plant
CO2 Capture & Compression for EOR
*Expansion* of CO2 Compression & Pipeline

- Single 20,000-HP MP/HP compressor and a 3,000-HP LP compressor, both supplied by Dresser-Rand
  - LP Compressor is a Dresser-Rand DATUM Model D6R4S -- radial (barrel-type) design with 4 impellers with a straight-thru casing configuration
  - MP/HP Compressor is a Dresser-Rand DATUM Model D10R8B -- radial (barrel-type) design with 8 impellers with a back-to-back casing configuration

- Will be the largest compressor unit in ExxonMobil USA Production Operations
ExxonMobil Shute Creek NG Plant
CO2 Capture & Compression for EOR
CO2 Compression – Existing & Expansion
Workshop on Future Large CO2 Compression Systems
Large CO2 Source & Capture Systems
Agenda

• CO2 Pipelines in USA for EOR

• 3 Large CO2 Source/Capture/Compression Plants
  – ExxonMobil LaBarge-Shute Creek, WY Natural Gas Plant
  – CDT Inc / Lubbock, TX CO2-from-CFPP-Flue Gas
  – Coffeyville Resources (KS) Gasification-based Fertilizer Plant
Carbon Dioxide Technology Corp
1150 STD CO2 from Coal-Fired PP in Lubbock, TX
Operational 1983-1984 for EOR Floods

- Built by Procon (UOP)
- Dow Amine Technology
- Gas Spec FS-1L Solvent
- Lubbock Power & Light 2x50MW CFPP
- 4-Stages CO2 Compression to 2000 psig

Parallel Amine Absorbers
190 feet elevation

Common Stripper
CO2 Purity > 99.5%V
CO2 Delivery ~ 5 psig

Source: NTNU - 2003
CO2 Capture from Flue Gas
EPRI-Nexant Report # 1014924
CO2 Compression Process Flow Diagram

21.3 psia Inlet

2200 psia outlet
Workshop on Future Large CO2 Compression Systems
Large CO2 Source & Capture Systems
Agenda

• CO2 Pipelines in USA for EOR

• 3 Large CO2 Source/Capture/Compression Plants
  – ExxonMobil LaBarge-Shute Creek, WY Natural Gas Plant
  – CDT Inc / Lubbock, TX CO2-from-CFPP-Flue Gas
  – Coffeyville Resources (KS) Gasification-based Fertilizer Plant
Coffeyville Resources / USA
Gasification-based NH3 Plant w Full CO2 Capture
Key Processing Design Features

- NH3 / UAN Fertilizer Complex (Commissioned July 2000):
  - 1140 MTD Ammonia Production
  - 1800 MTD Urea Ammonium Nitrate Solution Production
- Coffeyville Resources Refinery Pet Coke as Feedstock (1270 MTD)
- GE Quench Gasifiers (2 x 100%) @ ~42 barg pressure
- Linde (BOC) ASU Outside Battery Limits (1450 MTD O2)
  - High Purity N2 to NH3 Synthesis Loop
  - O2 to Gasifier
- 2-Stage Sour CO-Shift
- 2-Stage Selexol Unit AGRU (UOP) for separate H2S & CO2 Capture
- 10-bed PSA (UOP) for High-Purity H2 to NH3 Synthesis Loop
  - 101,900 NM3/Hr of 99.3%V H2 with <5 ppmv COX & <5 ppbv Sulfur
Gasification-based NH3 Plant w Full CO2 Capture

Key Processing Design Features (cont)

• Recycle of PSA Tail Gas to CO-Shift Unit (partial blow-down to fuel) for:
  – Maximum H2 Production
  – Maximum CO Conversion to CO2

• EPC – Black & Veatch Pritchard
• Sulfur Recovery – Tessenderlo Kerley
• NH3 / UAN – Ammonia Casale / Weatherly
• Well-Operated / Knowledgeable Staff / Many Lessons-Learned
• Profitable and Expanding Capacity
  – USA NH3 Industry Based on NG Virtually Eliminated in Past 5 Years
Coffeyville Resources
2-Stage SELEXOL Process Flow Diagram

Source: UOP – GTC Conf 2007
Coffeyville Resources
Syngas Composition
Post-CO-Shift & Cooling – Feed to Selexol

<table>
<thead>
<tr>
<th>Feed Flowrate</th>
<th>169,000 Nm$^3$/hr (151 MM SCFD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>36.9 bar-a (535 psia)</td>
</tr>
<tr>
<td>Temperature</td>
<td>38 ºC (100 ºF)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Component</th>
<th>Mole %</th>
</tr>
</thead>
<tbody>
<tr>
<td>H$_2$</td>
<td>&gt; 56</td>
</tr>
<tr>
<td>CO</td>
<td>~ 1.2</td>
</tr>
<tr>
<td>CO$_2$</td>
<td>~ 41</td>
</tr>
<tr>
<td>H$_2$S and COS</td>
<td>~ 0.6</td>
</tr>
<tr>
<td>CH$_4$, Ar, &amp; N$_2$</td>
<td>~ 1</td>
</tr>
<tr>
<td>H$_2$O</td>
<td>Saturated</td>
</tr>
</tbody>
</table>

2 Stages of CO-Shift

CO$_2$/H$_2$S Ratio ~ 70/1

Source: UOP – GTC Conf 2002
Coffeyville Resources / USA
Gasification-based NH3 Plant w Full CO2 Capture
CO2 Purification & Compression for UAN

• ~1/3 of the CO2 (~ 780 STSD) for the CO2 Compressors at ~150 psia for Urea Production

• ~2/3 of the CO2 is Presently Vented at ~5 psig

• HP CO2 for Urea goes through Pre-Purification Steps before Compression for Removal of Sulfur (H2S/COS) and H2/CO to Trace Levels

• CVR uses a Single Dresser-Rand Reciprocating Compressor to Compress the CO2 from about ~150 to 3800 psig in three stages using 2500 HP
Coffeyville Resources
CO₂ (for UAN) Trim Purification PFD

Raw CO₂ from Selexol

O₂ from ASU

Activated Zinc Oxide

Oxidation Catalyst

H₂S + ZnO \rightarrow ZnS + H₂O
H₂ + O₂ \rightarrow 2H₂O
CO + 1/2O₂ \rightarrow CO₂

Water KO

Purified CO₂ - Compression to UAN

Source: BVP – LRGCC Conf 2000
Coffeyville Resources Ammonia-UAN Fertilizer Complex – Kansas, USA CO2 Purity – Pre & Post CO2 Purification

![Table 4: CO2 Purification Feed Composition](image)

<table>
<thead>
<tr>
<th>Component</th>
<th>Mole %</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2</td>
<td>99.32</td>
</tr>
<tr>
<td>H2</td>
<td>Nil</td>
</tr>
<tr>
<td>CH4 &amp; CO</td>
<td>Nil</td>
</tr>
<tr>
<td>H2S &amp; COS</td>
<td>Nil</td>
</tr>
<tr>
<td>H2O</td>
<td>0.68 (Saturated @ 140 psia and 100°F)</td>
</tr>
</tbody>
</table>

Pressure: ~140 psia
Temperature: ~100°F

Raw CO2 from Selexol Unit to Pre-Purification Unit
Source: UOP LLC (a Honeywell Company) & BV Pritchard Presentation
Laurence Reid Gas Conditioning Conference / March 2000
Coffeyville Resources Ammonia-UAN Fertilizer Complex – Kansas, USA
Aerial View of Plant

Source: UOP – GTC Conf 2002
Coffeyville Resources (UOP) SELEXOL and PSA Units

Source: UOP – GTC Conf 2002
CVR Fertilizer Complex
Blueprint for IGCC w CO2 Capture
Coffeyville Resources
Plant Block Flow Diagram

Source: UOP – GTC Conf 2002
Coffeyville Resources Fertilizer Plant
Path Forward to IGCC w CO2 Capture

- Solid (Pet Coke) Feedstock
- Quench Gasifier for CO-Shift-Ready Syngas
- 2-Stage Sour CO-Shift for High CO Conversion
- 2-Stage Selexol for Separate H2S and CO2 Capture
  - CO2 Capture > 90%
  - Portion of CO2 Delivered at Elevated Pressure for Compression
  - Portion of CO2 “Sequestered” via N2-Fixation (Fertilizer)
- Combination of H2 and N2 for NH3 Synthesis
  - (For IGCC – combination to Gas Turbine)
- CO2 Trim Purification (dependent upon specifications)
- Production of High-Purity H2 by PSA
  - (Potential for Fuel Cell Usage)
Coffeyville Resources Fertilizer Plant – foreground
Coffeyville Resources Refinery – background
Thank You & Questions!

Source: UOP – GTC Conf 2007