CO$_2$ Capture & Compression Technologies
Agenda

• CO$_2$ value chain
• GE CO$_2$ compression experience
• Compression & pumping
• Summary
CO$_2$ value chain
3 Main Carbon Sequestration Solutions

Post Combustion

- Coal, NG, Oil
- Air

Pre Combustion/IGCC

- Coal
- Coal Waste
- NG, Oil
- Air/O₂ & Steam

Reformation

- NGCC or Boiler/ST
- CO₂ Separation
- CO₂ Compression

Gasification

- CO₂ Separation
- GT Combined Cycle
- N₂, O₂ & H₂O

Boiler

- CO₂
- H₂O

Oxyfuel

- Air
- O₂
- H₂O

Air Separation

- N₂
- H₂O

EOR Sequestration

- H₂O

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## Existing Sequestration Projects

<table>
<thead>
<tr>
<th>Project</th>
<th>Outlook</th>
<th>CO₂ injected (Mton/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gorgon Australia</td>
<td>• CO₂ captured from LNG plant to start by ’14 … Largest CO₂ compression station</td>
<td>3.3</td>
</tr>
<tr>
<td>Weyburn Canada</td>
<td>• Capture CO₂ from IGCC plant &amp; injected for EOR since ’00</td>
<td>1.7</td>
</tr>
<tr>
<td>In Salah Algeria</td>
<td>• CO₂ stripped from NG field … since ’04</td>
<td>1</td>
</tr>
<tr>
<td>Sleipner Norway</td>
<td>• CO₂ injected in a saline aquifer since ’96</td>
<td>1</td>
</tr>
<tr>
<td>Snøhvit Norway</td>
<td>• CO₂ captured from LNG plant &amp; re-injected in subsea aquifer since ‘08</td>
<td>0.7</td>
</tr>
</tbody>
</table>
CO$_2$ Compression Experience
• When CO2 is compressed becomes dense ... behaving like a fluid
• Extremely high density (up to 800 kg/m³) ... difficult to compress
• Supercritical (dense phase) fluid thermodynamic behavior
• Highly corrosive in presence of water
• Critical point: 74 bar / 31°C,... Very low compressibility factor
• Temp <50°C lead to low values of compressibility (Z) and high sensitivity vs. Pressure

• Sensitivity to Pr requires EOS gas properties validation to predict density and size compressors

• GE technology covering Z values up to 0.4 ... optimized compression stages sequence
>40ys Experience in CO₂ Handling

Equation Of State:

**GE Model**

- Applicable up to 300b (~4350 psi) on regular basis and up to 540b (~7830 psi) with CO₂ + HC mix
- Literature data not suitable for liquid-vapour equilibrium calculations above 540 bar (~7830 psi)
- Many existing CO₂ EOS optimized only for pure CO₂... not for mixtures
- ... Introducing a new thermodynamic model to improve predictability
Product solutions for CO₂ compression

Discharge Pressure (bar)

Centrifugal Pumps

Reciprocating

Inlet Volume (m³/h)

Screw

Integrally Geared

Best fitting solution to all working conditions
CO₂ Reciprocating Compressor Experience

• Started with fertilizers plants

• >180 machines in operation processing CO₂ or gases containing CO₂, H₂ and H₂S

• Up to 750 bara (>10,000 psi) disch. pressure ... 19,000 Nm³/h max requested capacity

• Most recent major experience CO₂+H₂S re-injection ... 55,000 Nm³/h @ 486 bara (~7000 psi) max. discharge pressure
CO₂ Centrifugal Compressor Experience

- **Since 1968** … +200 units operating in 90+ Urea Processes… 13 Million Operating hours

- Discharge pressure up to 280 bara … up to 18 MW & Inlet flow 300,000 Nm³/h

- World’s Largest Single Train capacity (3450 t/d QAFCO Qatar)

- Aerodynamics … Very high pressure ratio and compressibility
Integrally Gear Solution optimized for CO2

- New modular package designed to reduce footprint & installation time
- All compressors stages well referenced
- Adopting best in class gear box design,... Flender Graffenstaden, BHS
CO₂ Pumps Experience

- Leveraging experience from GE O&G HP centrifugal compressors
- Design pressure 670 bar (API 6A 10000) … discharge pressure 540 bar (~ 7800 psi)
- Flowrate 10 kg/s
- “Three points” base-plate for FPSO applications

1st pump ever used for this service!!
Compression & Pumping
Where GE O&G Fits in the Value Chain

- Depleted O&G fields <200 bar
- Saline aquifer <250 bar
- Supercritical transportation
- EOR > 250 bar
CO₂ Injection ... Possible Configurations

1) + • In line compressors
<200 bar T>30°

2) • Integrally geared compressors

3) + • Integrally geared + Pumps

1) + • In line compressors
<250 bar T>40°

2) • Integrally geared + In line

1) + • In line + Pump
>250 bar

2) • Integrally geared + Pumps
4 Different Ways to Reach 220 bar

Gas Compression – Traditional API 617

Subcritical Compression (IG) + Pumping

Supercritical Compression (IG) + Pumping

Refrigerated Compression (IG + Pump)

4-Stage Refrigerated Cycle
Summary
CO₂ Injection Summary

Technology
• Both compressor and pump technology in-house
• Compression + pumping thermodynamic optimization

Experience
• >40 years of experience in CO₂ compression,... >40 years in HP pump design
• Apply experience in HP re-injection compression,...rotordynamics, seals & low flow stage aerodynamics

Footprint
• Leveraging technology from “sister” industries through WW GE organization

Commitment
• GE O&G supports GHG emission reduction & green energy
Thank You!