Innovation Now
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
- NGCC or Boiler/ST
- CO₂ Separation
- N₂, O₂ & H₂O

**Pre Combustion/IGCC**
- Coal Waste
- Air/O₂ & Steam
- Gasification
- CO₂ Separation
- CO₂
- GT Combined Cycle
- N₂, O₂ & H₂O
- H₂
- NOₓ
- CO₂
- Boiler
- O₂
- H₂O
- CO₂
- Air Separation
- O₂
- H₂O
- N₂
- H₂O
- EOR
- Sequestration

**Oxyfuel**
- Coal NG Oil
- Air
- Reformation
- CO₂
- Boiler
- CO₂
- H₂O
- EOR
- Sequestration
# Existing Sequestration Projects

<table>
<thead>
<tr>
<th>Project</th>
<th>Outlook</th>
<th>CO₂ injected (Mton/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gorgon</strong></td>
<td>• CO₂ captured from LNG plant to start by ’14 … Largest CO₂ compression station</td>
<td>3.3</td>
</tr>
<tr>
<td>Australia</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Weyburn</strong></td>
<td>• Capture CO₂ from IGCC plant &amp; injected for EOR since ’00</td>
<td>1.7</td>
</tr>
<tr>
<td>Canada</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>In Salah</strong></td>
<td>• CO₂ stripped from NG field … since ’04</td>
<td>1</td>
</tr>
<tr>
<td>Algeria</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sleipner</strong></td>
<td>• CO₂ injected in a saline aquifer since ’96</td>
<td>1</td>
</tr>
<tr>
<td>Norway</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Snøhvit</strong></td>
<td>• CO₂ captured from LNG plant &amp; re-injected in subsea aquifer since ‘08</td>
<td>0.7</td>
</tr>
<tr>
<td>Norway</td>
<td></td>
<td></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
**Deep Knowledge on CO2 Compressibility**

- 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

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 reduced footprint & installation time
- All compressors stages well referenced
- Adopting best in class gear box design,... Flender Graffenstaden, BHS
CO$_2$ 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

Gas to domestic supply
Natural gas + CO₂ capture
CO₂ geological storage
Industrial uses
Biomass
Coal
Cement / steel / refineries etc.
Electricity generation
Petrochemical plants
Future H₂ use
Ocean storage (Ship or pipeline)
CO₂ Injection ... Possible Configurations

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

2) < 250 bar T>40°
   - Integrally geared compressors

3) < 250 bar T>30°
   - Integrally geared + Pumps

1) > 250 bar
   - In line compressors

2) > 250 bar
   - Integrally geared + Pump

1) > 250 bar
   - Integrally geared + Pumps
4 Different Ways to Reach 220 bar

Gas Compression – Traditional API 617
- 13.5 MW

Supercritical Compression (IG) + Pumping
- 11.4 MW

Subcritical Compression (IG) + Pumping
- 11.1 MW

Refrigerated Compression (IG + Pump)
- 9.5 MW
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!