LARGE SCALE CO₂ STORAGE IN THE NORTH SEA CAN HANDLE ALL EU COAL POWER CO₂ EMISSIONS

Erik Lindeberg, SINTEF Norway

Utsira and Norwegian gas and oil fields

- Utsira is a 24,000 km² sand formation with a typical porosity of 35% and high permeability (1000 to 2000 mD)
- The thickness is 90 m in average varying between 0 and 350 m. The sand is divided by many thin shales reducing the effective vertical permeability to 0.1 of the horizontal permeability
- Typical top depth is 800 m, however, the impression that is also is flat is somewhat delusive...
Top of Utsira seen from east

- The top depth varies from the peaks in central western parts of 500 m to the deep northern slope ending at 1500 m depth (125 km apart)
- The dip angle of the steepest parts is still only $0.4^\circ$
Reservoir model

- A numerical model of the formation is constructed from by approximately 1 million active grid blocks of 500 m x 500 m lateral size and average of 9 m height.
- The horizontal permeability is set to 1500 mDarcy and the average effective vertical permeability 150 mDarcy
- Porosity is 35%
- The topography of the top and floor is based on an seismic interpretation by Kirby et al. (2001)
- The formation is assumed to be a closure, shaling out or thinning out at its borders
• **Conservative presumptions**
  
  • Capillary pressure not included
  
  • Molecular diffusion not included and accordingly convection due to destabilisation of the water column under-estimated
  
  • The intra-sand shales are not represented as discrete items, but included in the up-scaled vertical permeability ($k_v = 0.1 \, k_h$)
  
  • Only four well campaigns during 300 years

• **Non-conservative presumption**
  
  • Large gird blocks
  
  • Solubility included
  
  • Hysteresis included
Well and injection data

- Injection and water production wells are distributed in a regular 5 spot pattern

- Two different cases tested
  - 7 km well distance (210 injectors and 210 producers)
  - 13 km well distance (70 injectors and 70 producers)

- Injection rate 133 million tonne per year (15% of the yearly power production emissions in EU)

- Injection period 300 years
Pressure field, 70 injector scenario
Year
2023
Year
2027
Year
2031
Year 2080
Year
2170
Year 2190
East-west profile illustrating the major challenge: gas coning into water production wells
Water producer, 1 block perforated

Water producer, 5 blocks perforated
Comparing a profile of free and dissolved after 5000 years: density driven convection

Free CO$_2$

Dissolved CO$_2$
Number of water production wells and their performance

- 210 wells, 500 m perforations, horizontal wells
- 70 wells, 10 m perforations
- 210 wells, 45 m perforations, vertical wells
- 210 wells, 10 m perforations, vertical wells
- 70 wells, 80 m perforations
No real optimisation, e.g. only utilising the thickest era could reduce the number of wells
Formations without wells?
Monitoring and remediation

• 40 Gtonne CO$_2$ stored during 300 years corresponds to approximately 15% of all CO$_2$ from power production in EU for the same period of time

• 40 Gtonne CO$_2$ stored represents a value of 823 billon USD with the present EU CO$_2$ quota price (20.6 USD/tonne CO$_2$) in the emission trading system.

• The CO$_2$ emission penalty has to be at least 50 USD/tonne and in this case the stored CO$_2$ would represent a value of 2000 billion USD

• The project could therefore afford monitoring and well remediating program at least during the injection period.
Consequences

• Is this exercise not only a worst case scenario because the Utsira formation is probably in pressure communication with other pressure units, and therefore not so many water production wells would be needed?

• No, each project must manage the pressure so that neighbouring storage resources (other pressure units, ref. to EC directive on storage) are not impaired

• In closed systems this means that for each project approximately the same volume of water in the formation must be produced as CO₂ volume being injected

• Offshore storage may have an advantage compared to onshore in getting emission permits for saline water. An emission permit for approximately 50 km³ 3% brine into the North Sea will be needed
Compressibility storage

• Assuming the formation is a closure

\[
\beta = -\frac{1}{V} \left( \frac{\partial V}{\partial p} \right)_T
\]

\[
\beta_{\text{total}} = \beta_{\text{brine}} + \beta_{\text{pore volume}}
\]
# Compressibility Storage

<table>
<thead>
<tr>
<th></th>
<th>Utsira</th>
<th>Johansen</th>
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<tbody>
<tr>
<td>Initial pressure under cap rock, bar</td>
<td>80</td>
<td>225</td>
</tr>
<tr>
<td>Rock compressibility, bar⁻¹</td>
<td>4.50 · 10⁻⁴</td>
<td>1.00 · 10⁻⁵</td>
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<tr>
<td>Brine compressibility, bar⁻¹</td>
<td>4.36 · 10⁻⁵</td>
<td>4.74 · 10⁻⁵</td>
</tr>
<tr>
<td>Total compressibility, bar⁻¹</td>
<td>4.94 · 10⁻⁴</td>
<td>5.74 · 10⁻⁵</td>
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<td>Lithostatic pressure, bar</td>
<td>140</td>
<td>450</td>
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<tr>
<td>Storage - pressurize to Lithostatic pressure, %</td>
<td>2.96</td>
<td>1.29</td>
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<tr>
<td>Storage - pressurize to 0.8 · (Lithostatic pressure)</td>
<td>1.58</td>
<td>0.78</td>
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Selection of mature of sites

- Skade formation below Utsira
- Sele formation below Frigg
Gassum formation in the Skagerrak
What do we NOT need to study?

• Chemical reaction – will occur but due to the buffering in the residual water they will quickly stop

• Well cement – they are fine

• Core flooding of cores with brine with dissolved CO$_2$ – it is not an analogue to what will happen during storage

• Pipeline transportation – long record of successful transport

• Equation of state for CO$_2$ or CO$_2$-rich mixtures – GREG 2008 etc are sufficiently accurate

• Improved reservoir simulators. We have both commercial and academic simulators that can take care of the most of the physics involved
Technology for a better society