Monitoring for offshore storage
What we have learned from 19 years of operations

Philip Ringrose
Statoil ASA, Trondheim, Norway

US DoE Carbon Storage R&D Project Review Meeting
Pittsburgh, PA, 18-20 August 2015
The big questions for CO$_2$ monitoring

• What type of monitoring is really necessary?

• Several stakeholder viewpoints:
  1. What is important from an operational point of view?
  2. What is required from a regulatory perspective?
  3. What is in the public interest?

• In response to these questions CO$_2$ storage projects have developed fit-for-purpose approaches to monitoring.

• The biggest technical challenge is that projects need to monitor:
  the reservoir (saline formations)
  … and the overburden
  … and the regional surface area
  … and the facilities
  … and plans for post site closure

With a limited budget!
Ideal CO$_2$ storage monitoring portfolio

So what should the CO$_2$ monitoring portfolio look like?

• Geological characterisation
• Standard wellhead and downhole measurements
• Distributed fibre-optic P, T and acoustic sensing
• Low footprint surface seismic nodes – passive & active
• Gravity field monitoring
• Surface gas detectors
• Remote sensing: e.g. InSAR or seabottom sonar
• With significantly lower costs than today

Ringrose 2013
Statoil CO₂ storage projects

- 22 Mt CO₂ stored safely underground

Unique blend of site experience:
- Shallow/deep
- Offshore/onshore
- Vertical/horizontal wells
- Different reservoir geology

Eiken et al., 2011
The pioneering CCS project at Sleipner

- Confirming the feasibility of geological storage of CO₂
- Demonstrating the value of seismic imaging for monitoring
- Making a strong case for remote geophysical monitoring as the key tool

Furre et al., 2015; Kiær et al., 2015
Sleipner injection and monitoring history

- Cost-effective monitoring and geophysical portfolio design

![Graph showing injected CO₂ (Mt) over years from 1994 to 2014. The graph includes Seismic surveying, Gravity surveying, Seafloor mapping, and CSEM survey. CO₂ Injection rate ~0.9Mtpa.]
Sleipner gravimetric monitoring

- Developed accurate offshore gravity monitoring technology
  - Precision of ~2-3 μGal in time-lapse signal achieved
  - Valuable complement to 4D seismic
- Alnes et al. (2011; pers comm) use gravity data to estimate:
  - Average in-situ CO$_2$ density of 720 ± 80 kg/m$^3$
  - Upper bound on the dissolution rate of 2.7% per year
Sleipner seabed/marine monitoring summary

- Initial site survey and yearly scanning near pipelines
- 2006: Sleipner dedicated echo beam and sidescan sonar surveys
  - Sidescan sonar
  - Bathymetry
  - Water column surveillance
  - Water and sediment sampling

Current technology status is about developing best practice and understanding potential impacts (e.g. Jones et al., 2015)
Regional mapping of shallow seismic features

Public interest in seabed feature (Hugin fracture) 25km north of Sleipner (2013):

- Storage integrity assurance will need regional mapping and analysis to better understand glacial processes and their impact on the shallow rock system

Analysis of shallow seismic data (Furre et al., 2014)

Regional observations on glacial valleys and channels (van der Vegt et al., 2012)
Snøhvit CO₂ capture and storage

First onshore capture - offshore storage project (combined with LNG)

- 150km seabed CO₂ transport pipeline
- Saline aquifers c. 2.5km deep adjacent to gas field
- CO₂ stored initially in the Tubåen Fm. (2008-11) and then in the Stø Fm. (2011-)

First onshore capture - offshore storage project (combined with LNG)

- 150km seabed CO₂ transport pipeline
- Saline aquifers c. 2.5km deep adjacent to gas field
- CO₂ stored initially in the Tubåen Fm. (2008-11) and then in the Stø Fm. (2011-)

LNG plant (Melkøya)
**Snøhvit well intervention in 2011**

- Gradual rise in reservoir pressure indicated limited injection rate/capacity
- Repeat seismic survey (2009) showed CO\textsubscript{2} injection mainly confined to lower unit – reservoir permeability lower than expected
- Well Intervention operation successfully completed in May 2011

Seismic sections

- 2009 Seismic Survey
- 4D (Amplitude difference)

Amplitude change map

- Increasing amplitude
Estimate flow from seismic:
80% in Lower Perforation
20% in two upper

Logged flow:
81% in Lower Perforation
19% in two upper
Monitoring techniques applied at Snøhvit

- **Seismic**
  - 3D/4D repeats (so far 3 repeats)
  - 2D repeats (so far 1 repeat)
- **Temperature / pressure monitoring**
  - Continuous guage measurement
  - Weekly shut-in measurements
  - Long fall-off when feasible
- **Downhole flow measurement**
  - In-flow logging
- **Gravimetry**
  - 86 bases positioned (1 repeat)
Main lessons learned – monitoring

1. Geophysical monitoring has proven essential for site management
   - Safe CO₂ storage containment confirmed

2. Monitoring of pressure is as important as saturation:
   - Down-hole gauges are highly desirable

3. Practical learnings about capacity and injectivity from well operation
   - Reservoir geology always has unpredictable elements

4. Monitoring the overburden is as important as the reservoir:
   - May require analysis of regional and near-surface datasets

5. Time-lapse seismic imaging of CO₂ plume development gives much improved understanding of flow processes:
   - Builds confidence in model forecasts

6. Sharing experience is important for building confidence in CCS
   - Different stakeholders have different interests in monitoring data
There’s never been a better time for good ideas

Presented by Philip Ringrose

With thanks to many colleagues for discussions and insights

Acknowledgements to Statoil and project partners for permissions and use of data

www.statoil.com
References


