Marine Monitoring for CCS using Cost Effective Autonomy

Kim Swords, Senior Application Engineer
8280 Willow Place Drive North, Houston, Texas, 77070
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Agenda
(1) Marine CCS MMV progress in the UK
(2) ‘PMT the InSAR of the Seas’
The ETI is a public-private partnership between global energy and engineering companies and the UK Government.

Their role is to act as a conduit between academia, industry and the government to accelerate the development of low carbon technologies.
“The purpose of the Project is to develop and demonstrate a cost-effective MMV system for ongoing environmental assessment of emissions in the marine and shallow subsurface environment in order that operators involved in the injection of carbon dioxide into the subsurface can meet the legislative requirements for such activities.”
**Key Functional Requirements**

- Detect and locate the source of leaks from a CO$_2$ storage site in the form they are expected to emanate from the sea bed;

- Provide a capability to detect CO$_2$ leaks which have the potential to damage the marine environment, jeopardise the financial success of the store, or represent no more than 0.01% loss store-wide per annum of the planned inventory at the end of the injection phase.

- Operate in marine environments of water depth of between 5 - 200m, CO$_2$ store depth between 800 - 4600m, over stores having an areal extent of 10 - 3000 km$^2$, at distances of 25 - 150 miles from land, and within sea temperatures between 5 - 17 °C

- Provide data analysis and interpretation capability to enable leaks from CO2 storage sites to be discriminated from other seabed emissions;
A challenging environment
North Sea

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A reminder of the offshore CCS Environment in the North Sea
We have worked together to understand the problem:

- pH and seawater chemistry variations on a sea scale across the seasons (& ocean interaction)
- How much might leak out of a reservoir
- How the leak may appear at the seabed
- Tidal mixing processes and how a leak signature would disperse
- How gas and chemical plumes would form and disperse
- What risks there are from different storage sites
- Mechanical vs geological risks (discuss later!)
'A system of systems configurable to meet the needs of different stores'
Underwater Sensing Solutions
Processing
Decision Making
Static Landers & AUVs / ASVs
Chemical Sensing – ‘Smelling or tasting the leak’ – Data flows

Technologies

- Chemical Sensor 1
- Chemical Sensor 2
- Chemical Sensor 3
- Chemical Sensor 4
- Chemical Sensor 5

Sensor Processing Hub

- Communication to Shore
- Validation & Display

Sonar

- AUV Navigation
  - Physical Sensor 1
  - Physical Sensor 2
  - Physical Sensor 3
“10 l/min CO₂ gas leak, 2.65m tall plume from seabed”
Seabed Lander Solutions
Autonomous Point Sensing
Active Lander Technologies

- ALDS-B head
- Processor Hub
- Compatt 6
- Battery (up to 6 packs)
- Subsea Basket 1.4m x 1.8m
- Attachment points for spreader frame
- Battery (only 1 pack for HAT)
- Subsea Basket 1.4m x 1.8m
Passive & Chemical Lander Technologies

- Chemical Sensors
- Processor Hub
- Subsea Basket 1.4m x 1.8m (grills removed for clarity)
- 6 Battery Packs
- Passive Transducer Array
- Compatt 6
- Lifting Point
- Subsea Basket 1.4m x 1.8m
- Single Battery Pack for
Passive Lander
Geodesy : Settlement : Heave

‘PMT the underwater InSAR’
The Process...

Seafloor Subsidence Monitoring

Reservoir before production

Reservoir during production

Vertical Displacement

Horizontal Displacement

Production
Pressure/Depth measurement

Seafloor Subsidence Monitoring

Absolute Pressure
(measured by sensors which drift)

Gravity
(≈ 9.8m/s² .....but not constant on earth surface)

Density
(affected by temp/salinity etc., Major source of variability!!)

Atmospheric Pressure
(weather variation)

\[ p_{\text{abs}} = h \rho g + p_{\text{atm}} \]
• Instruments continually measure:
  – Horizontal Displacement using two way acoustic ranging – accuracy (1cm/km)
  – Vertical Displacement using highly accurate pressure sensors
  – Extremely high precision and long term monitoring is required to detect/monitor minute settlement velocities.
Seafloor Settlement Monitoring

Equipment...

Sensor Options

- Pressure
- Inclination
- Temperature
- Acoustic Range
- Conductivity
- Sound Velocity

Instrument Types
Example Project: Ormen Lange

Located in Norwegian Sea at site of Storegga landslides, circa 6000BC

Seabed depth 850-1100m

Reservoir depth 3000m below seabed

Production induced uncertainties:
  - Aquifer influx (water replacing gas)
  - Compartmentalisation (regions of reservoir cut off from production)

Reservoir uncertainties have large impact on recovery estimates and drilling decisions

Long term geodesy monitoring campaign was focused on reducing these uncertainties
• 10 Settlement Monitoring Transponders deployed at Ormen Lange in 2007.

• 220 Autonomous Monitoring Transponders deployed 2010 onwards.

• Each AMT woke up every hour and measured the distances to all its neighbours and stored range and sensor data.
• Network spread over an area of 50km x 20km
• System detected any seabed settlement of a few centimetres per year or better
• >600 million range observations made
• 0.6 Gigabyte of data uploaded acoustically
• System recovered in June 2016
Network spread over an area of 50km x 20km

System detected any seabed settlement of a few centimetres per year or better

> 600 million range observations made

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System recovered in June 2016

A long-term seafloor deformation monitoring campaign at Ormen Lange gas field

Shaun Dunn\textsuperscript{1}, Paul Hatchell\textsuperscript{2}, Annemieke van den Beukel\textsuperscript{2}, Robin de Vries\textsuperscript{2} and Tomas Frafjord\textsuperscript{3} discuss the use of a seafloor geodesy system to monitor production induced changes to the reservoir and overburden at offshore fields.
Stakeholder Engagement
Sea Trials 17th July 2017

Please contact graham.brown@sonardyne.com

Marine Robotics Innovation Centre
NOC, Southampton, UK