



Goldeneye monitoring

Balancing the requirements for an EU permit and the need to contain costs

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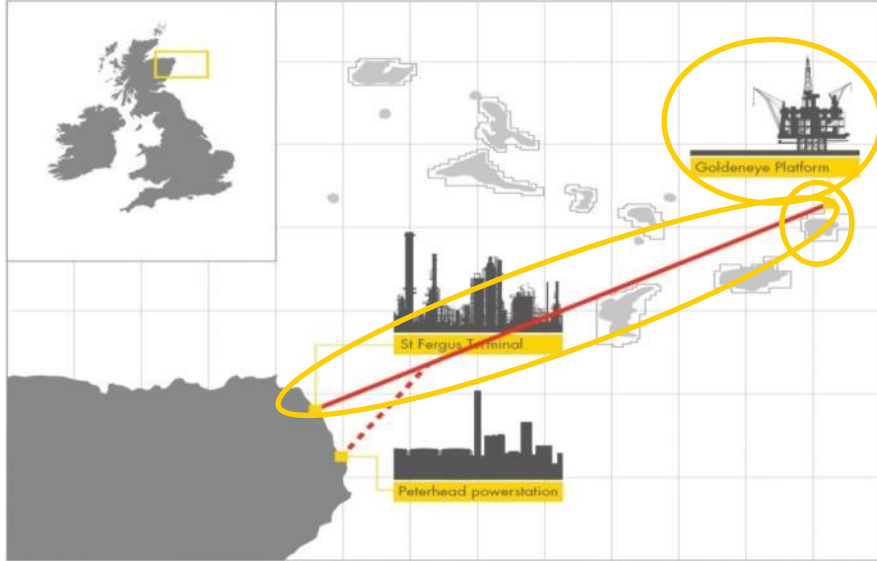
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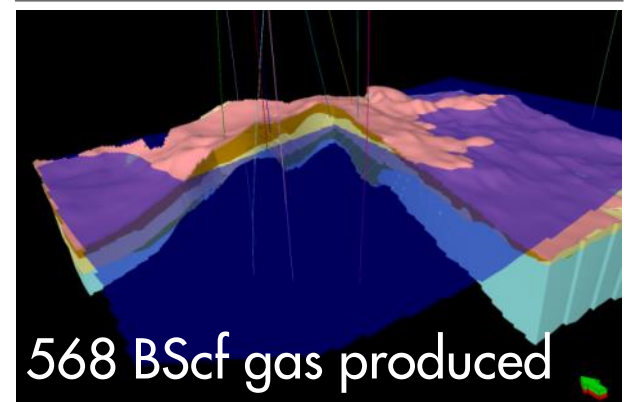
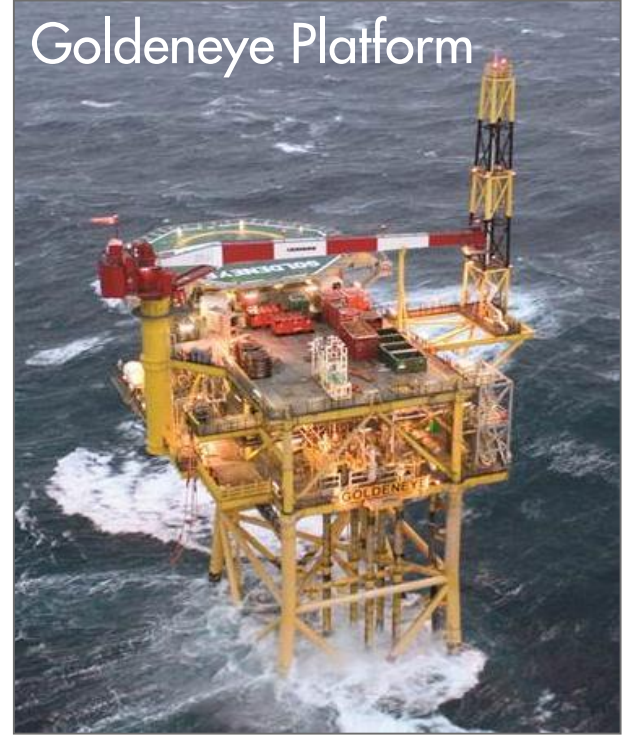
Former Peterhead CCS project



- Assets that would have been reused:
 - 102km of 20 inch pipeline + methanol line
 - Platform which started life in 2004
 - Depleted gas field with pressure history starting in 1996, production history from 2004
 - Five production wells
 - Core, seismic, sea bed surveys

- Planned to be the first full-scale CCS project on a gas-fired power station
- Capture at Peterhead Power Station; storage in depleted Goldeneye gas reservoir
- Halted when funding withdrawn by UK Government, 25th November 2015

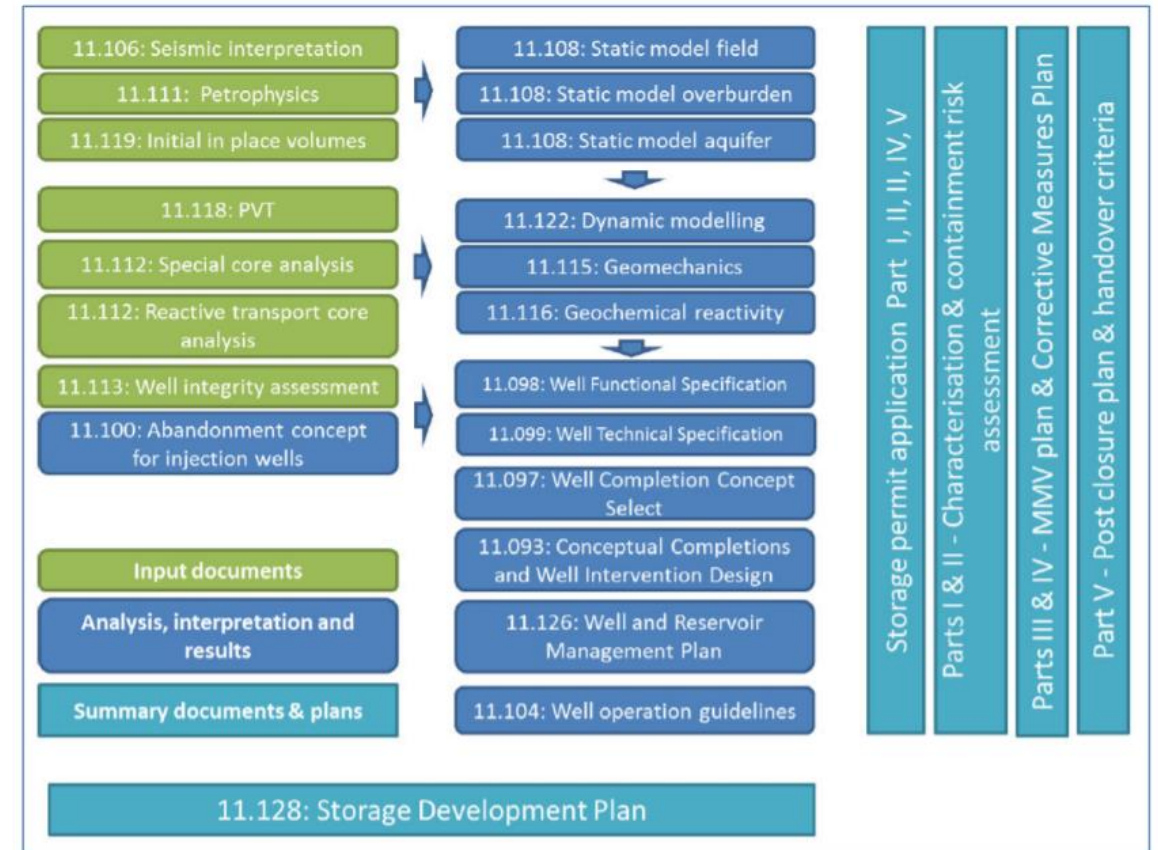
Goldeneye Platform



Peterhead CCS project reached a point just prior to the final investment decision

- FEED was complete
- Costs were all but firmed up
- Subsurface work was complete and had been externally reviewed by the British Geological Survey
- The Environmental Impact Assessments had been written and submitted
- The storage permit application had been agreed with the UK regulator, submitted, and they had submitted it to the EU commission for their opinion

Most results and more details are available online at <https://www.gov.uk/government/collections/carbon-capture-and-storage-knowledge-sharing>



Legislation & Regulation set the framework

Europe

- Directive on the geological storage of carbon dioxide
 - Storage permit
- Guidance documents



United Kingdom

- The Energy Act of 2008 (Chapter 3: Storage of Carbon Dioxide)
 - Storage License
- The Crown Estate, the “land owner”
 - Agreement for lease
- Carbon Dioxide (Licensing etc.) Regulations 2010 & Carbon Dioxide (Termination of Licences) Regulations 2011
 - Storage permit
- Specific application guidance issued by the UK Oil and Gas Authority

- UK regulations combine with the EU directive (often referring back to the directive) to create the requirement for a permit application and award
- EU commission has rights to review the storage permit application and the draft storage permit

The EU directive has the following requirements:

Member States shall ensure that the operator carries out monitoring of the injection facilities, the storage complex (including where possible the CO₂ plume), and where appropriate the surrounding environment for the purpose of:

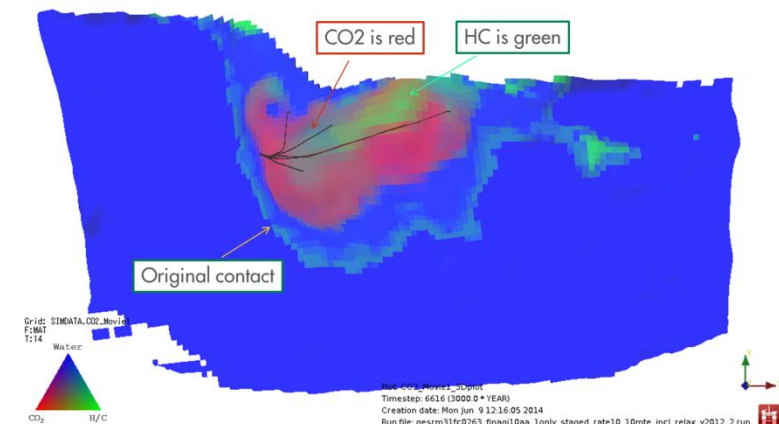
- (a) comparison between the actual and modelled behaviour of CO₂ and formation water, in the storage site;*
- (b) detecting significant irregularities;*
- (c) detecting migration of CO₂;*
- (d) detecting leakage of CO₂;*
- (e) detecting significant adverse effects for the surrounding environment, including in particular on drinking water, for human populations, or for users of the surrounding biosphere;*
- (f) assessing the effectiveness of any corrective measures taken pursuant to Article 16;*
- (g) updating the assessment of the safety and integrity of the storage complex in the short and long term, including the assessment of whether the stored CO₂ will be completely and permanently contained.*

■ *They are performance based not prescriptive and can be divided into Conformance and Containment*

Handover criteria are also supported by the monitoring plan

Goldeneye proposed performance criteria for handover

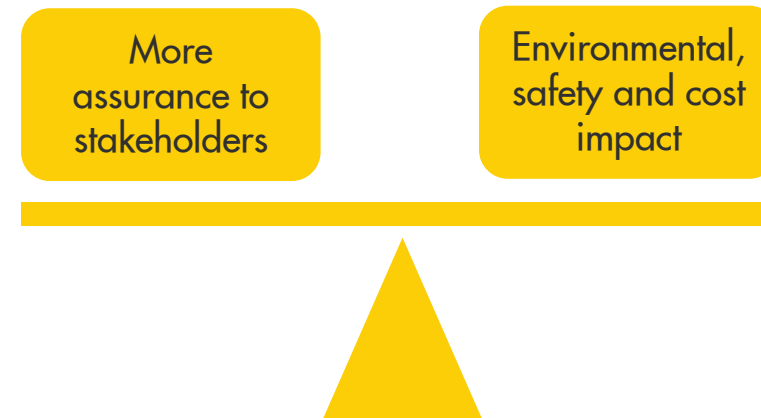
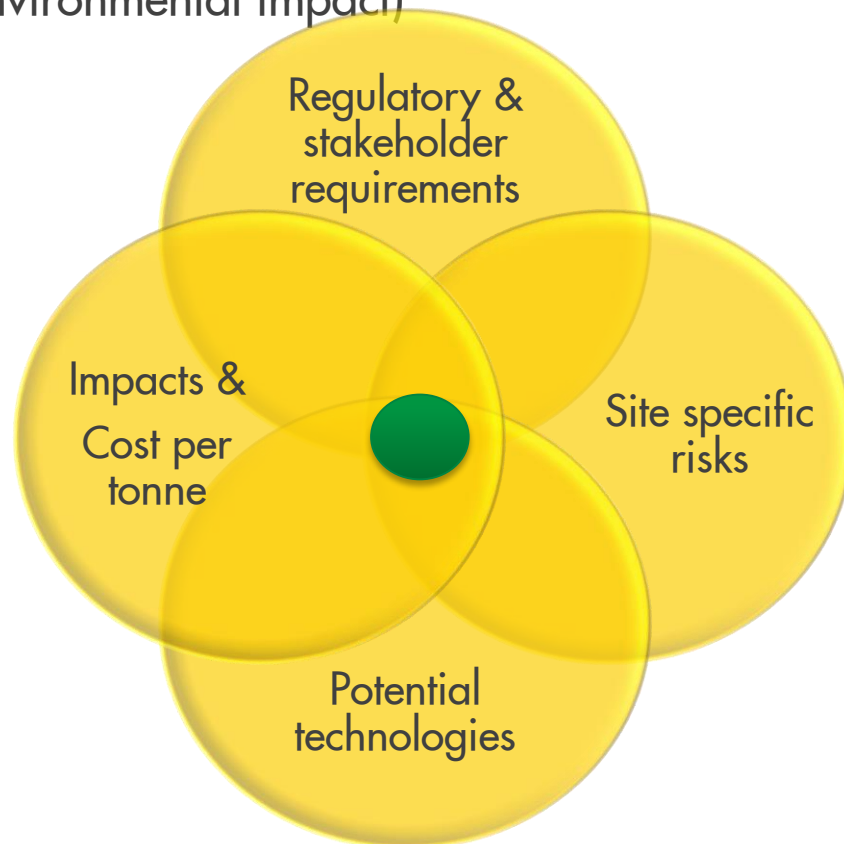
- *CO₂ is behaving as predicted and is unlikely to deviate from prediction*
 - 3D dynamic simulation forecasts of the movement of continuous phase CO₂ indicate that the continuous phase CO₂ is approaching a gravity stable equilibrium within the site.
- *No leaks or unexpected migration paths are observed:* Two separate seismic surveys – with an expected separation of five years, show that continuous phase CO₂ is not migrating laterally or vertically from the licensed storage site.



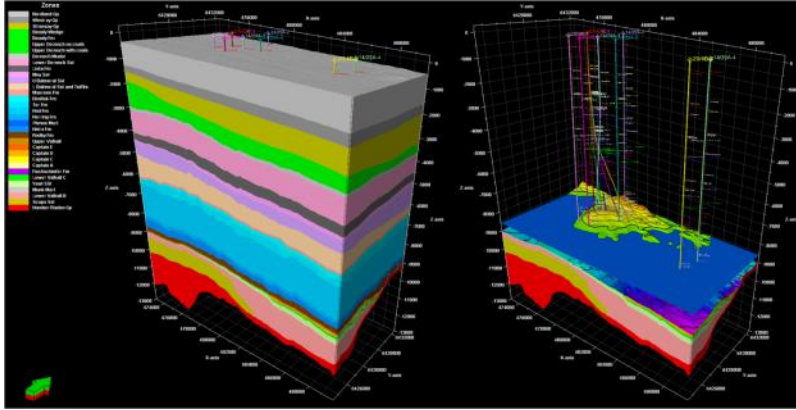
How do we build a plan that satisfies the site specific, project, technological and stakeholder constraints.

Conformance and containment can be confirmed in a number of ways

The key is to adopt a programme that satisfies both technical and non-technical stakeholders, whilst avoiding over-monitoring (environmental impact)

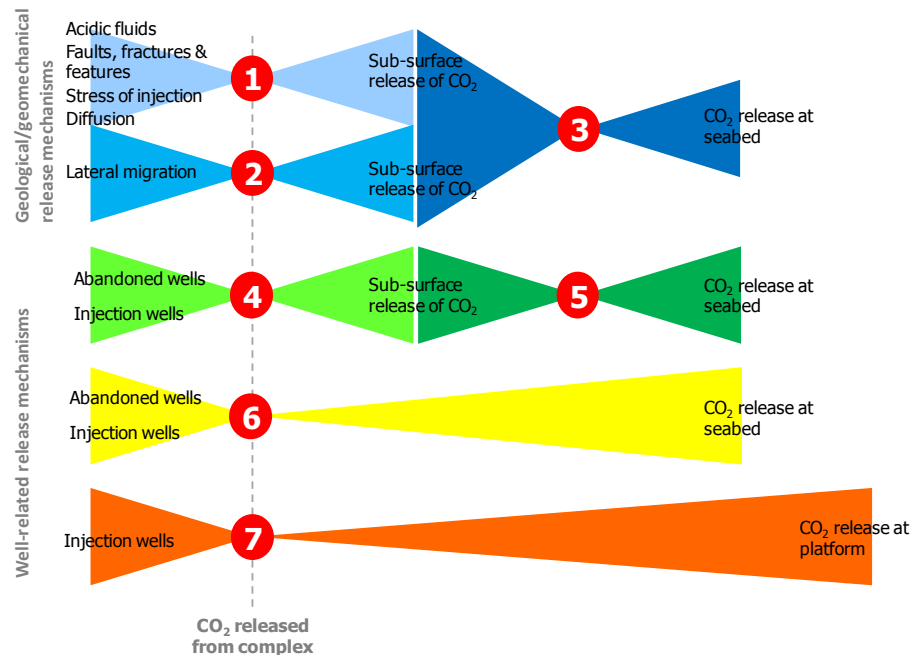


Build the MMV plan upon the containment risk assessment

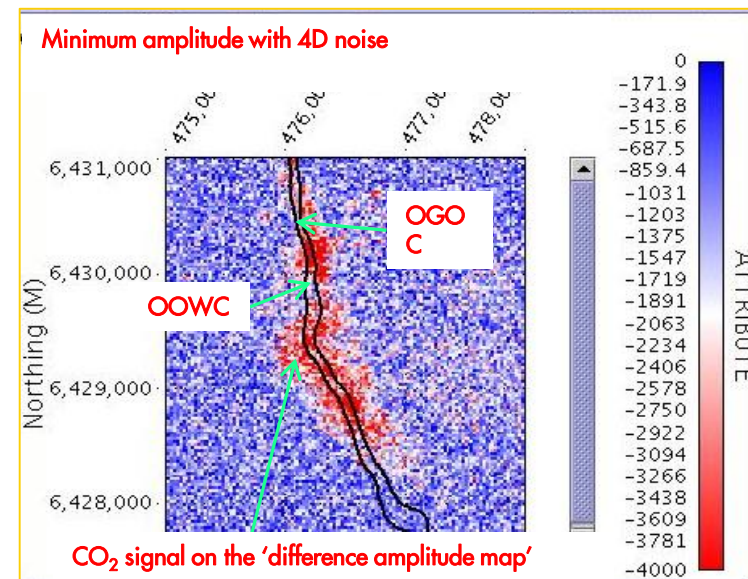
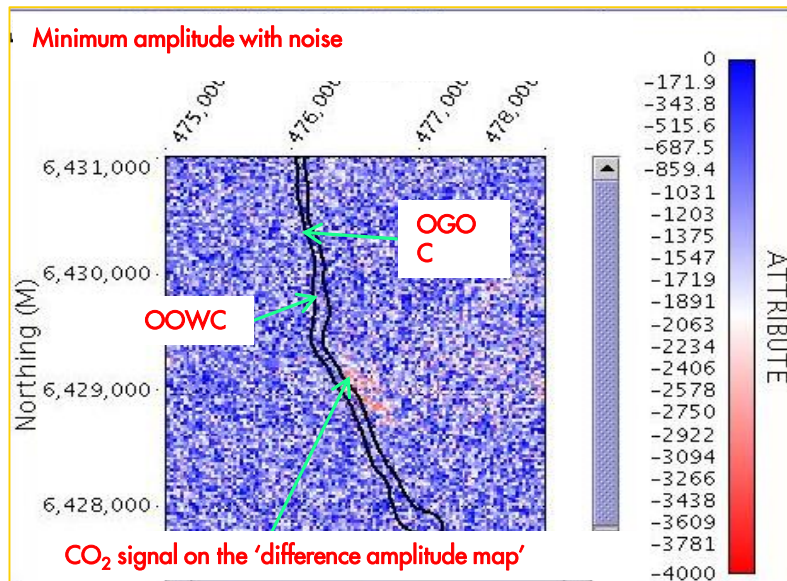
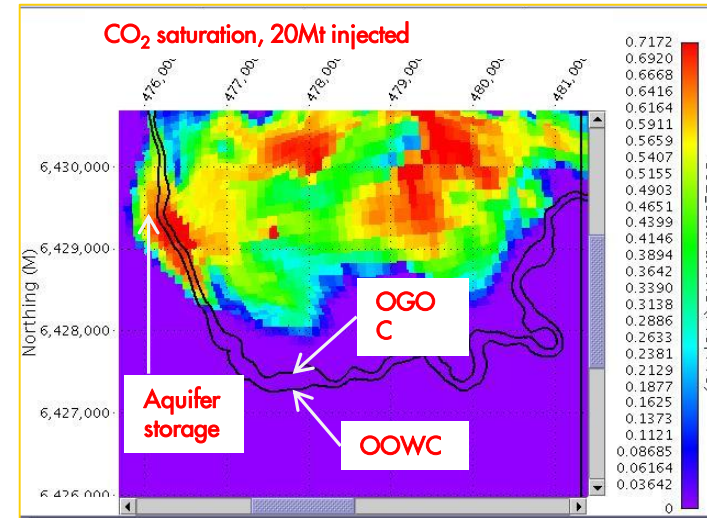
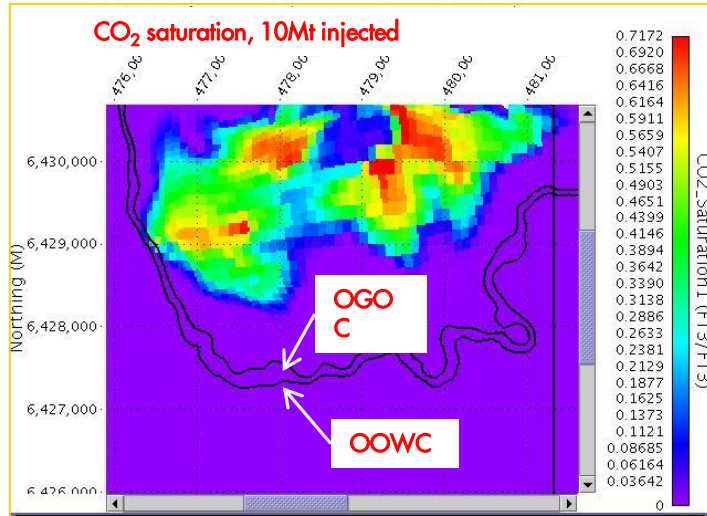
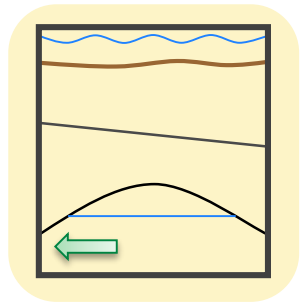


Set of linked bow ties

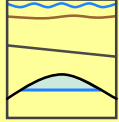
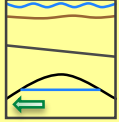
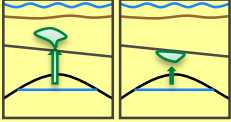
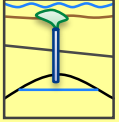
- Logical evidence based approach
- Identify potential migration paths and mechanisms
- Selection based on characterisation
- Engineered system designed with multiple barriers
- Monitoring and corrective measures to complement engineered system – **reactive barriers**



Model potential responses from different techniques



Example of Technology Screening: Geophysics

	Plume reservoir 	Plume aquifer 	Plume overburden 	Well related 	Caprock (fracturing)	Fault (movement)		PoS
					Events			
Streamer, OBC or OBN 3D survey covering field	✗	✓	✓	✓	-	-		✓
3D swath or 2D line*	✗	✓	✓	✓	-	-		✓
Hi-Res 2D seismic (<1000m)	✗	✗	✓	✓	-	-		✓
3D VSP **	✗	✓	✓	✓	-	-		✓
Crosswell seismic	✗	✗	✗	✗	-	-		✗
Microseismic **	-	-	-	✗	✓	✓		✓
Seabed deformation	✗	✗	✗	✗	-	✗		✗
CSEM (vessel towed)	✗	✗	✗	✗	-	-		✗
Gravity (seabed)	✗	✗	✗	✗	-	-		✗

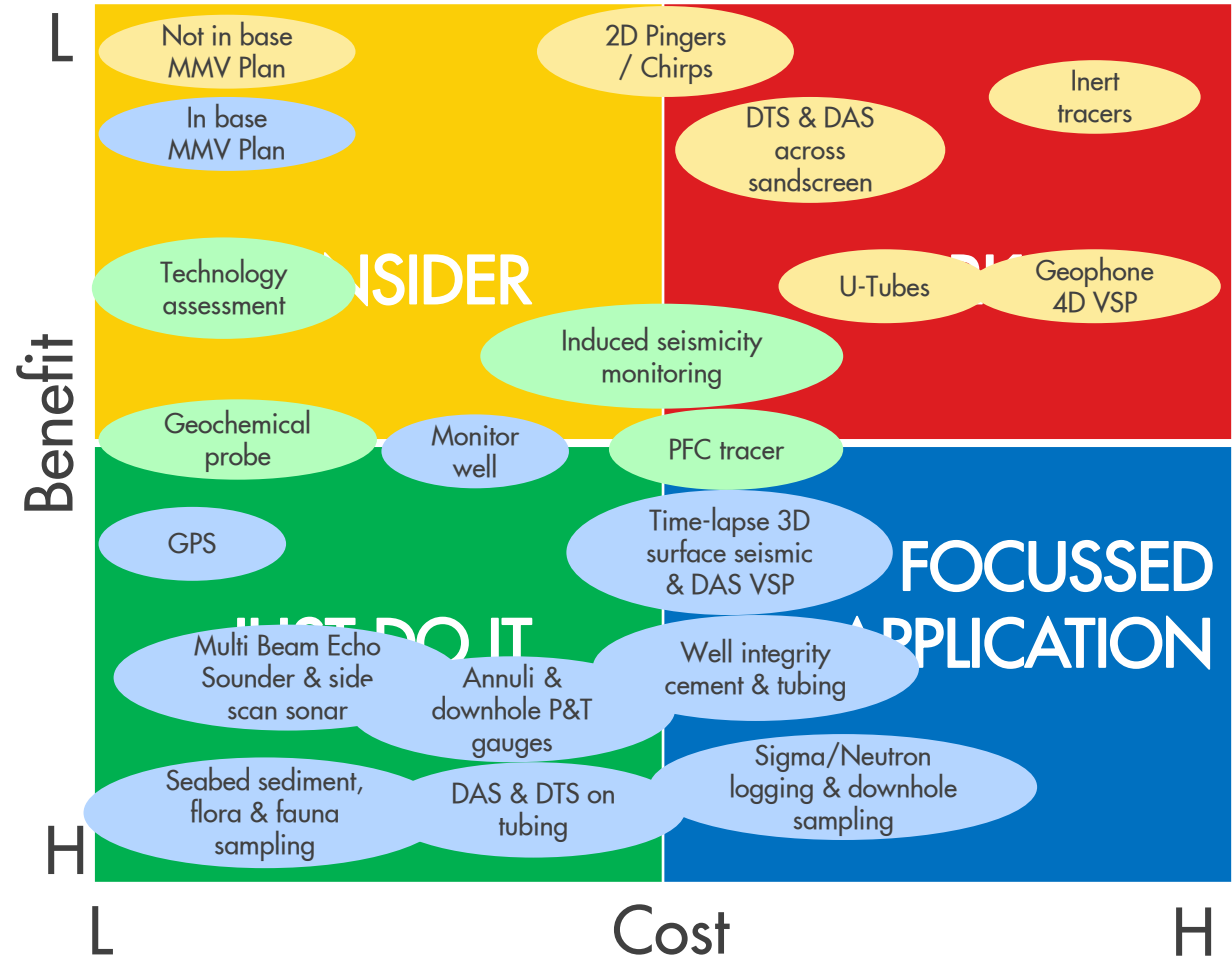
✓ Feasible
 ✗ Regretted
 - Not Applicable

* Dependent on 3D swath / 2D line coverage ** Observation well location dependent

Screen and rank: 45 technologies were assessed and 27 were found to be suitable for the site.

- Carefully assessed which would actually support containment, conformance or stakeholder requirements
 - Seabed geophones – out
 - Downhole geophones – replaced with optical fibres
 - PFC tracer – out, but noble gas tracer in

Cost/benefit matrix



Delivering the base case monitoring plan

More stakeholder focussed

Dictated by conformance & containment

	Pre-Injection	Injection	Post-Injection
Seabed and Shallow Layers	<ul style="list-style-type: none"> CO₂ flux baseline monitoring Flux detection under the platform Seabed surveys (MBES/SSS) Seabed samples 	<ul style="list-style-type: none"> MBES/SSS Seabed samples 	<ul style="list-style-type: none"> MBES/SSS Seabed samples
Geosphere	<ul style="list-style-type: none"> Time-lapse 3D seismic/VSP 	<ul style="list-style-type: none"> Time-lapse VSP 	<ul style="list-style-type: none"> Time-lapse 3D seismic/VSP
Monitoring Wells	<ul style="list-style-type: none"> Cement bond/casing integrity Sigma/Neutron PDG/Long term gauge 	<ul style="list-style-type: none"> Annular pressure and DTS+DAS Sigma/Neutron Downhole sampling 	
Injection Wells	<ul style="list-style-type: none"> Cement bond/casing integrity Sigma/Neutron PDG/Long term gauge 	<ul style="list-style-type: none"> Annular pressure and DTS+DAS Tubing integrity 	

High cost

High cost

Deploy ground breaking technology to drive down costs

■ Goldeneye DAS VSP Feasibility Study

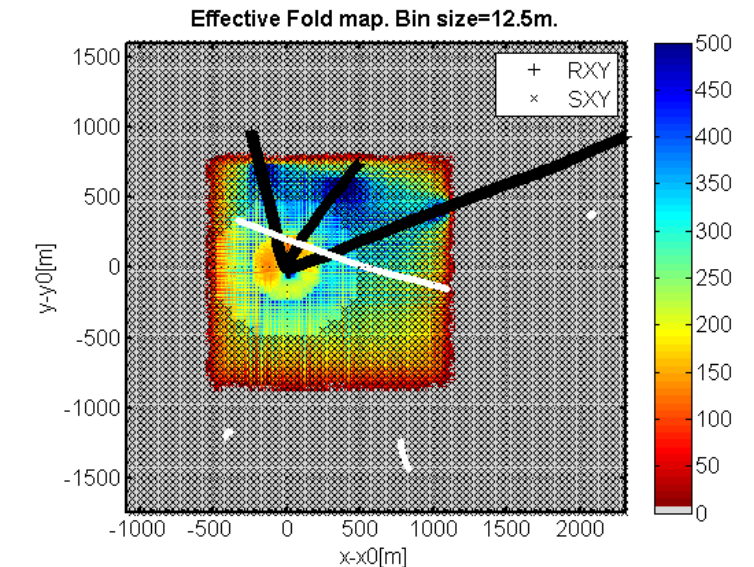
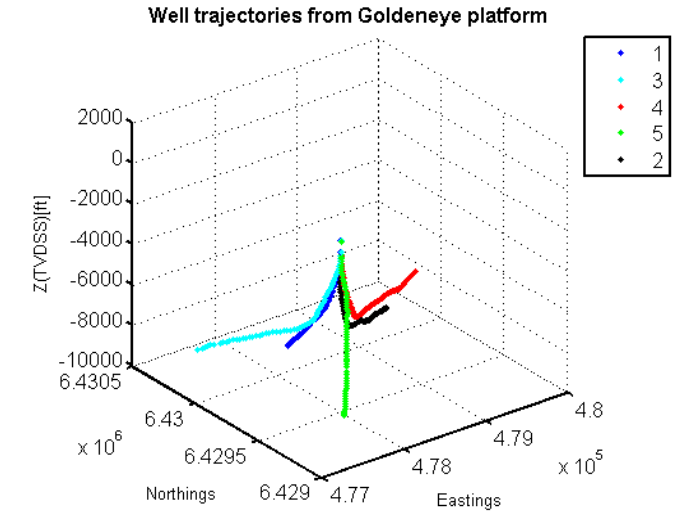
- Multi-well DAS VSP can provide high fold image of $\sim 2\text{km}^2$ around wells at reservoir level and $\sim 0.5\text{km}^2$ at the level of secondary storage¹

■ Containment monitoring near injectors

- CO_2 leaks *vertically* out of Captain, a 4D DAS VSP may be able to resolve 4D anomalies as the CO_2 enters secondary storage²
- CO_2 leaks out of abandoned wells in image area

■ Expected 4D signals

- 4D signal caused by saturation changes are expected to be small within depleted gas reservoir but significant outside when gas replaces brine³
- 4D signals associated with pressure differences are uncertain and depend on compartmentalization



4D DAS VSP offers a localized low-cost monitoring solution

Partner to create deployable reliable marine monitoring

Learning from external studies and technology developments:

■ ECO2, QICS, RISCs, CO2CRC

- Environmental impact assessments
- Testing state-of-the-art marine monitoring systems
- Collaboration of academic institutions with industry input

■ Energy Technologies Institute (ETI) MMV Project

- Development of marine monitoring system for the North Sea utilizing state-of-the-art marine monitoring technologies – now passed harbor trials
 - North Sea applicable, regulatory framed
 - Technologically feasible, operationally efficient
 - AUV based areal monitoring (acoustic, chemical sensing)
 - Continuous monitoring for CO₂ leaks at seabed
 - Automated acquisition and storage of data using autonomous monitoring transponders
 - Communication to shore via wave gliders and satellite links



Conclusion



- Permit development was successful and received positive comments from the EU Commission - leading to the assumption that the MMV plan was sufficient for regulatory requirements.
- Only some of the potential technological solutions were selected
- R&D deployed to create lower cost solutions during the lead time from final investment decision to deployment



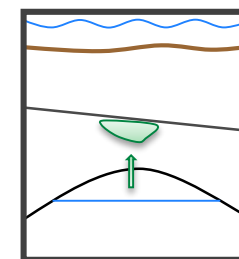
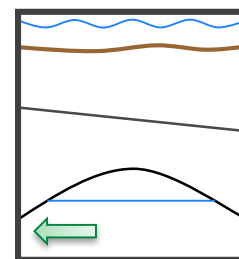
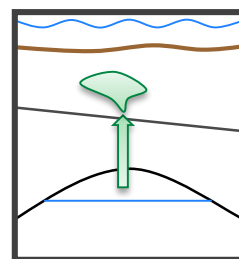
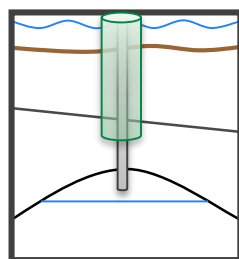
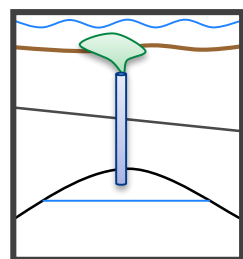
Questions and Answers

Q&A



It is not possible to be prescriptive but contingency monitoring can be tested against migration scenarios

Trigger: Suspected migration



Detection:
Regular
Seismic,
Seabed
sampling
Delineation:
Additional
Seismic,
MBES, Seabed
Sampling

Detection:
DTS/pressure,
Geochemical
probe/seabed
sampling,
Regular
seismic
Delineation:
Wireline,
Additional
Seismic,
MBES, Seabed
Sampling

Detection:
Regular
seismic
Delineation:
Additional
Seismic,
MBES, Seabed
Sampling

Detection:
FFM
prediction,
Regular
Seismic
Delineation:
Additional
Seismic,
Seabed
Sampling

Detection:
Regular
Seismic
Delineation:
Additional
Seismic,
Seabed
Sampling

Consequence
risk assessment

Corrective measures
plan

Update containment
risk assessment and
monitoring plan