
# Characterisation of European $CO_2$ storage

## Dry-run storage permit applications

## Lessons learned from the perspective of operators and regulators

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## Motivation

- To date, one application has been made for a storage permit under the Storage Directive
- Demonstration projects are working towards submitting permits
  - But are not yet ready
  - Regulators are not able to receive applications in some MS
- The process of permit development needs to be tested at credible sites
  - 'Low' risk dry-run environment without the constraints of commercial projects
  - Allow testing of permitting in future storage situations (onshore and in saline aquifers)
  - Allow testing and refinement of the SiteChar workflow

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## Objectives

- To develop credible storage permit applications
- To ensure site characterisation is fit for purpose and complies with the regulatory requirements
- To evaluate ‘Dry-run’ storage licence application documents from selected sites evaluated by a separate team

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## Scope of licence applications

- Two teams have produced credible, if limited, licence applications with ‘research-level’ resources
  - Detailed permit applications are not produced
  - Includes most of key elements required by the Storage Directive
  - Key issues that should be addressed are identified.
- Based on existing data
  - No additional exploration, injections tests, core analysis or new site characterisation has been undertaken
- Out of scope:
  - Full EIA
  - Provision relating to the acceptance and injection of $CO_2$
  - Details of financial security
  - A provisional post-closure plan
  - Provisions for reporting

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## Comparisons between Vedsted and Moray Firth – permitting perspective

### Moray Firth

- Offshore
- Identified from previous regional reviews of UK northern North Sea storage targets
- 'Theoretical' study
  - Low risk – can try different permitting scenarios
  - No acquisition of new data
  - Range of injection scenarios
- Risks addressed in SiteChar:
  - Definition of storage complex
  - Caprock integrity
  - Potential for seismic monitoring

### Vedsted

- Onshore
- Previously applied for licence prior to Directive to promote dialogue with Regulators
- Real project, now stopped
  - Application fits predefined concept & original licence application
  - Baseline monitoring data acquired
- Risks addressed in SiteChar :
  - Oil well integrity and abandonment status
  - Regional pressure responses and management

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## The UK northern North Sea site

- Multi-store site
  - A depleted hydrocarbon field, early storage capability;
  - The host saline aquifer sandstone: greater storage potential, later in the storage cycle.
- Captain Sandstone
  - Identified as feasible for storage
  - Host to hydrocarbon fields
- Project concept
  - $CO_2$ injection into a depleted hydrocarbon field
  - Up-dip migration beyond the field into the surrounding sandstone


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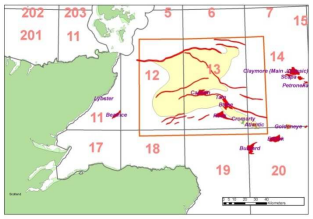
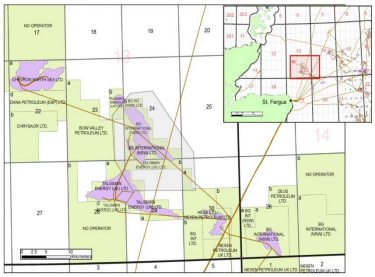
## The UK northern North Sea site

- Selection of the hydrocarbon field component
  - Four fields within area of study hosted in Captain Sandstone: Blake Oil Field
  - Meet geological criteria, >800 m depth
  - Sufficiently large estimated storage capacity, >20 Mt $CO_2$
  - Data available for project
    - High quality, 3D seismic survey
    - Abundance, 36 well penetrations
    - Accessible, publicly available
    - Within the resources of a research project



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## Objective of the UK multi-store site characterisation

- Evaluate a storage site that combines a hydrocarbon field and a saline aquifer sandstone
- Test an injection strategy to *maximise* the capacity at the site appropriate for commercial-scale storage
- Investigate the relationship between the predicted performance of the storage site and adjacent hydrocarbon fields
- Undertake site characterisation sufficient to inform a 'dry-run' storage permit application

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## Characterisation for a ‘dry-run’ storage permit application

- Demonstrate understanding of the site for a $CO_2$ storage permit
- Competent Authority must be satisfied that:
- Permit applicant has sufficient understanding of the site
- Proposed site operation will securely contain $CO_2$
- Application must comply with requirements of EC Directive
- Develop ‘dry-run’ storage permit application, as far as possible, in SiteChar

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## Scope of the ‘dry-run’ storage permit

- SiteChar is a research project, some components are not developed
  - Environmental Impact Assessment, Reporting Plan, Details of Financial Security, Reporting Plan
- The storage project, though a feasible realistic target for future storage, is a concept:
  - Freedom to explore more challenging aspects of site characterisation and storage permit application than actual demonstration projects in the near-future
  - Reduces the risks associated with developing ‘dry-run’ storage permit applications and allows us to ‘learn by doing’
  - Very resource-constrained and recognise the limitations on the depth of the characterisation and associated storage permit application

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## Storage permit required components

- Components developed for SiteChar UK North Sea site are determined or informed by risk assessment
- Required components determined by risk assessment
  - Project description (injection strategy, site design & storage performance forecast)
  - Site description
- Informed by results of risk assessment
  - Preventative Measures Plan
  - Monitoring Plan
  - Corrective Measures Plan
  - Post Closure Plan

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## Role of risk assessment in site characterisation

- Site characterisation is about understanding the risks to secure containment of $CO_2$ at a specific site
- Characterisation is led by risk assessment to
  - anticipate risks,
  - reduce risks
  - mitigate risks
  - monitor unmitigated risks
- Determines what site characterisation activities are needed
- Ensures resources, time and effort are focused to meet the objective

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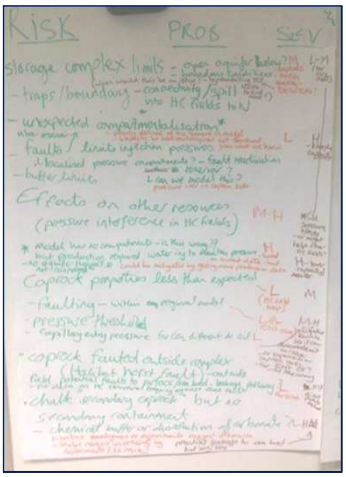
# Risk-led characterisation, UK North Sea site

Risk Assessment workshop

- First project activity
- Participation by all experts including technical and non-technical
- 'Brainstorming'
- Anticipate risks from existing knowledge and expertise
- Initial assignment of probability of a risk occurring
- Initial assignment of likely severity of consequence if a risk does occur

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# Risk-led characterisation – risk register

- Initial risk register (list of 79 risks)
- Each described and categorised,
  - 12 categories
  - 5 overarching risks
- Ranked by probability & severity
- Highest ranked risk addressed by SiteChar researchers
  - Containment risk
  - Adverse effect on other resources

| | |
|---|---|
| Containment risks | Migration / leakage of injected $CO_2$ |
| | Loss of injected $CO_2$ to biosphere |
| | Displacement or alteration of brines |
| Adverse effect on other resources | Hydrocarbon fields |
| | Others |
| Reduced technical performance | Reduced Injectivity |
| | Reduced capacity |
| Monitoring / Regulatory | Monitoring issues |
| | Regulatory issues |
| Economic / Environmental | Socio-economic |
| | Storage costs |
| | Environmental |

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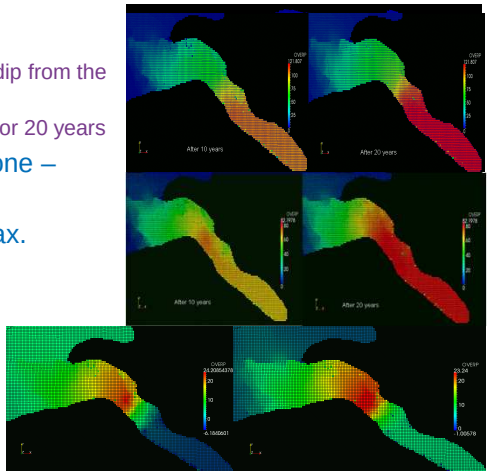
# Investigation of injection strategy to ensure containment

- Two well positions investigated:
  - Within the Blake Field
  - Within the Captain Sandstone down-dip from the field
  - Injection simulated for 5 Mt per year for 20 years
- Injection into the Captain Sandstone – max. pressure increase **122 bar**
- Injection into the Blake Field – max. pressure increase **82 bar**
- Simultaneous injection into the Blake Field and water production from the Captain Sandstone – max. pressure increase **23 bar** (~50 bar less than allowed pressure)



- SiteChar concept is to *maximise* storage capacity; further modelling would reduce and optimise injection rate to manage pressure

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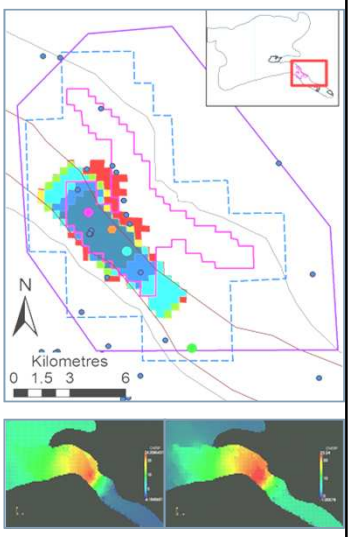
# Adverse effect on other resources

- Anticipated risk
  - $CO_2$ migrating to other fields
  - Pressure interference with other fields
- Risk reduction in SiteChar
  - Mapping of $CO_2$ plume migration
  - Modelling pressure increase 'footprint'
- Risk mitigation
  - Maximum plume extent, over 1000 years, within immediate vicinity of Blake Field
  - Little pressure change in Captain Field
  - Initial pressure drop in Cromarty and Atlantic then gradual increase to ~10 bar overpressure
  - Additional modelling could further minimise pressure impact

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## Site Characterisation

- Site characterisation should be driven by risk assessment process to
  - Identify and reduce priority uncertainty,
  - Enable project design
  - Develop monitoring plans and performance metrics.
- Both projects consider an injection test would be needed.
  - To assess proof on injectivity, reservoir connectivity and pressure response.

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## Storage Complex Boundary

- Complex defined by maximum extent of plume
  - including $CO_2$-saturated formation water
  - plus a margin to enable monitoring
  - to reflect inherent uncertainty in predictions
- Including the pressure footprint would require impractically large storage permit areas, since pressure responses can extend far beyond the plume.
- The pressure footprint has not been considered.
  - There is little consensus on the thresholds above which effects should be included.
- A clear and prior agreement with CA is needed on definition of storage complex

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## Storage Complex Boundary

- Informal discussion with regulators indicate that the pressure footprint might receive lower emphasis in defining the complex boundary.
- Storage complexes may overlap HC licences in the North Sea
- Storage complex can't include the surface
- 'Safety' margin around plume extent:
  - to allow for uncertainty in predictions
  - To enable monitoring beyond the plume (e.g. pressure and $CO_2$)
  - This would include both updip and downdip areas. Will need full justification

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## Interactions with other users

- The nature and extent of interactions with other users is a key consideration for regulators.
- Assessing future interactions may be challenging for operators
  - E.g. future operations (HC production and/or other storage) may impact on the risk profile of a project.
- The 'state owner of the resource' may be best placed to take an overview
- The CA(s) may need to undertake its own risk assessment and supporting investigations, to provide guidance to operators, including around third party access.

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## Pressure management & water disposal

- Disposal of water offshore is not considered particularly challenging, as it is widely practised in HC production.
- Volumes of produced water for pressure management in the North Sea have not been estimated.
  - For comparison, 175 million $m^3$ of produced water were discharged in UK waters in 2011
  - Moray Firth estimated similar volumes produced as $CO_2$ injected
- At Vedsted, pressure management was not necessary, since pressures were limited to 85% of lithostatic.
- Disposal of produced waters may be significantly more challenging onshore than offshore,
  - A key topic in the storage and environmental permits for onshore sites.

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## Permit performance conditions (PPCs)

- Define limits to site behaviour which, if exceeded, indicate that a significant irregularity or leakage has occurred.
  - Identified through Risk Assessment
  - Inform the Monitoring Plan
  - Trigger Corrective Measures if exceeded
  - Indicators will be in the Corrective Measures and Post-Closure plans
  - Enable site closure

| Blake Field | |
|---|---|
| PPC1 | **Environmental or human health will not be adversely affected by the storage operation** |
| PPC2 | **$CO_2$ will not pass beyond the Storage Permit Area boundaries** |
| PPC3 | **$CO_2$ plume shows migration within expected modelled behaviour** |
| PPC4 | **Pressure changes will remain within predefined/predicted ranges** |
| PPC5 | **Geomechanical integrity of site will be maintained** |
| PPC6 | **Cost per tonne will remain within a set limit** |

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## Recommendations on PPCs

- PPCs should be linked to the specific risks they address
  - To demonstrate that the risk register, PPCs, corrective measures plan and monitoring plan are closely integrated.
- PPCs should be written with positive phrasing as the permits will be public documents.

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## Additional conclusions for permit applications

- Clear evidence base must be included to support case for safe and permanent storage.
- Prime objective for Moray Firth was maximising storage potential
  - This may not always be the case with costs and risk reduction being additional objectives
- Justifications for locations and re-use of wells for storage must be carefully made as legacy HC production wells may be suboptimal.

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## Site closure and the storage permit

- Conditions under which permits should be changed (to reflect changes in operation) should be agreed.
  - This would not be predictions of alternative scenarios and open permits but rather the circumstances under which permits might need to be changed.
  - Provide a ‘master’ storage permit with additional permits for specific activities such as drilling wells

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## Post-injection period

- SiteChar permits have 20-year post-injection periods
- If sites are performing as expected, operators likely to wish to transfer responsibility as soon as possible.
  - Both sites predict reaching safe steady-states quickly.
- Any uncertainty in this may delay FID.
- Crucial to agree, during permit negotiations, exact evidence required to enable site closure and transfer of responsibility.
  - Challenging due to multiple CAs involved and may require initial experience from early projects prior to this.

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## Recommendations

- Make readily available data required for storage site characterisation
- Risk assessment should lead site characterisation from the very start
- Successful multi-disciplinary characterisation requires very close integration of all investigations
- The implications of emerging characterisation results in one discipline must be considered by all other disciplines
- Expect the project concept to evolve, reinforcing the need for close communication between disciplines, and anticipate revised planning of site characterisation activities.

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## Communication and management of uncertainty

- Uncertainty and hazard should be distinguished
- Site characterisation will always be associated with a degree of uncertainty.
  - How much is acceptable?
- Assessment by scenario development
- Focus should be put on assessing uncertainty related to parameters which significantly impact capacity and containment.
  - It will be for the operator to undertake the cost-benefit analysis to decide the appropriate level of risk reduction prior to permit application.

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## Communication and management of uncertainty

- It is likely that the available evidence would indicate that one interpretation is more likely than others and this will form the basis of the permit application.
- However other interpretations might be possible and these should be discussed to provide a full overview of the level of interpretation applied to the geological model.
- Contingencies should be included in the application.

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## Competent authorities

- Reviews of history matching between observation and predictions should be undertaken throughout the project.
  - May require specialist technical advice to support this.
- Under what conditions could other users challenge a storage permit application?
- It is currently assumed all sites will be closed and infrastructure removed.
  - It may be beneficial for some sites to be kept open. CA may wish to extend storage life.
- Data archiving requirements should be applied to hydrocarbon licence holders to enable storage permit applicants to demonstrate that past production does not lead to unacceptable risks for $CO_2$ storage.
- Over what periods should predictions of post-closure performance be undertaken?
  - 500-1000 years in SiteChar

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## Key learnings from the SiteChar experience

- A first-pass storage permit can be prepared from publicly available data
- 'Pre-characterisation' of a site highlights additional investigations and targets information and activities needed
- Even where there is abundant site-specific data, additional information will always be a sought
- Greater anticipation of risks and alternative site parameters will be required where data is sparse
- Pressure footprint and pressure management is a key issue in an area with other users of the pore space

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## Remaining issues/Challenges

- First iteration of risk reduction activities at pre-characterisation stage has reduced risk and uncertainties; many further iterations of risk reduction and risk reassessment will be needed for storage permit
- UK multi-store site concept is to maximise storage capacity; not addressed minimisation of project cost or optimisation of the injection strategy to manage pressure
- Pressure relief by water production from aquifer component; how would the environmental standards for hydrocarbon and what would the cost implication be to a storage project

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## Summary

- Site characterisation undertaken at varying levels on credible storage sites.
- Estimated 2-5 years with up to 200 person months of effort for storage permit applications
  - CAs will need significant resources and expertise to assess applications and during operation.
  - Several CAs likely to be involved.
- Site characterisation objectives:
  - Reduce risk and uncertainty: implies these should be known *before* detailed characterisation is undertaken
  - Provide sufficient evidence to demonstrate permanent, safe storage.
  - Enable cost-effective project design

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## Summary

- Dry-run permitting process has identified approaches to demonstrating safe and permanent $CO_2$ storage.
- Recommendations arising from the dry-run process provide guidance to operators and regulators on site characterisation and the SiteChar workflow.

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