Providing assurance of storage capacity in open connected aquifers for multiple users:

a case study from the Moray Firth – Scottish CCS, SiteChar and objectives of the CO_2MultiStore projects

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Summary findings

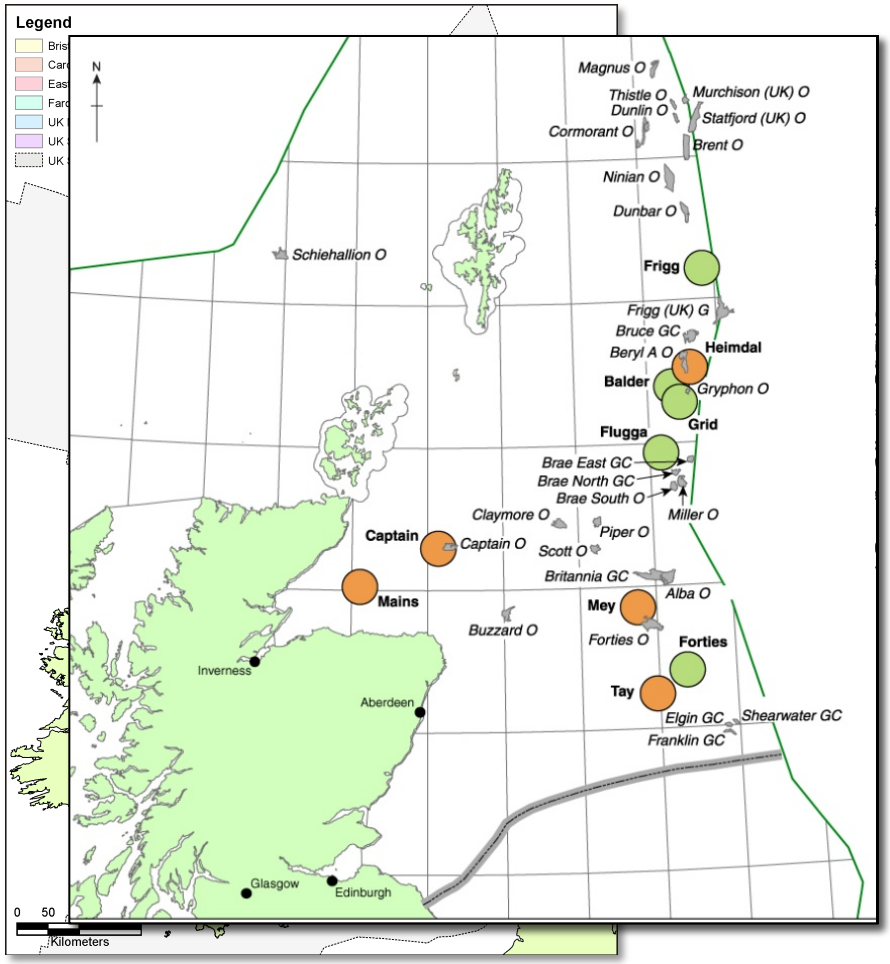
Lessons learned

- Can either inject CO_2 at multiple sites or achieve a high and continuous injection rate by managing pressure
- A hydraulically connected formation needs regional-scale appraisal
- Knowledge of boundary conditions is key information
- Greater storage capacity by CO_2 injection into a depleted field than injection directly into the surrounding aquifer
- The cost and effort to access and interpret existing data is worth it
- Can achieve a first-pass storage site assessment in a hydrocarbon province from existing publicly available and published data
- Characterisation should be guided by views by operators & regulators

Knowledge gaps

- Knowledge of the existing datasets and their availability
- Understanding of the effect of prospective storage operations on existing storage formation users

Theoretical storage capacity - UK central & northern North Sea



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Opportunities for CO_2 Storage around Scotland

Suitable basins are all offshore

- Central & northern North Sea (blue)
  - Depleted oil and gas fields
  - Saline aquifer sandstones
- Shortlist of 10 sandstones

  Geological characteristics

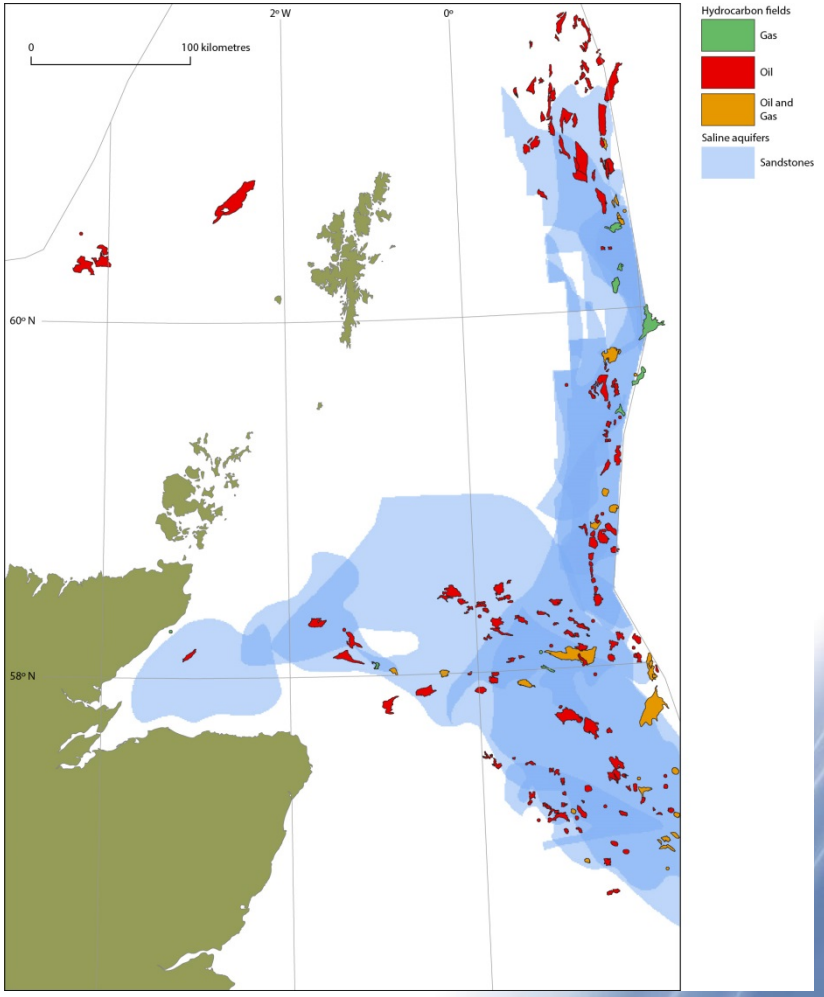
  Acceptable - orange

  Optimal – green

  29 suitable oil & gas fields - grey
- Theoretical storage capacity (2008)
  - Depleted fields ~1 300 million tonnes (Mt)
  - Sandstones > 4 600 Mt

Theoretical storage capacity – UK central & northern North Sea

- Shortlisted saline aquifer sandstones
- Very large extent, 1 700 to 17 000 km^2
- Many are overlapping
- Geological character is well known where they include hydrocarbon fields but less well known where brine saturated
- Storage efficiency assumed to be 0.2% to 2.0% of pore volume
- Total storage capacity for all 10 aquifers is wide ranging
  - 4 600 to 46 000 million tonnes
- Selection of a sandstone for CO_2 storage research



Sandstone extents from UKOOA

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Progressing Scotland's CO_2 storage opportunities

Captain Sandstone – criteria for selection

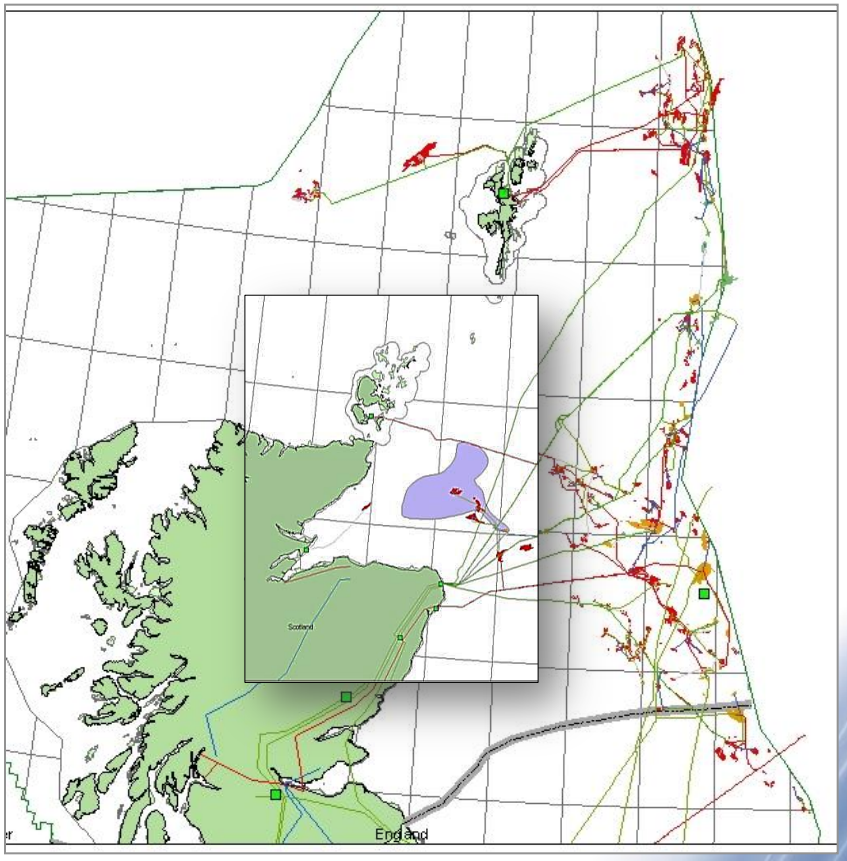
Non-geological criteria

- Proximity to CO_2 sources;
- Proximity to existing infrastructure, such as oil and gas pipelines;
- Presence of hydrocarbon field data
- Data availability

Geological criteria

- Depth <800 to >2000 m
- Permeability, mean 2000 mD (100 to 10 000 mD)
- Porosity, mean 30% (20-40%)
- Theoretical storage capacity 36-363 Mt CO_2

Two demonstrator CCS projects propose to store in the Captain Sandstone



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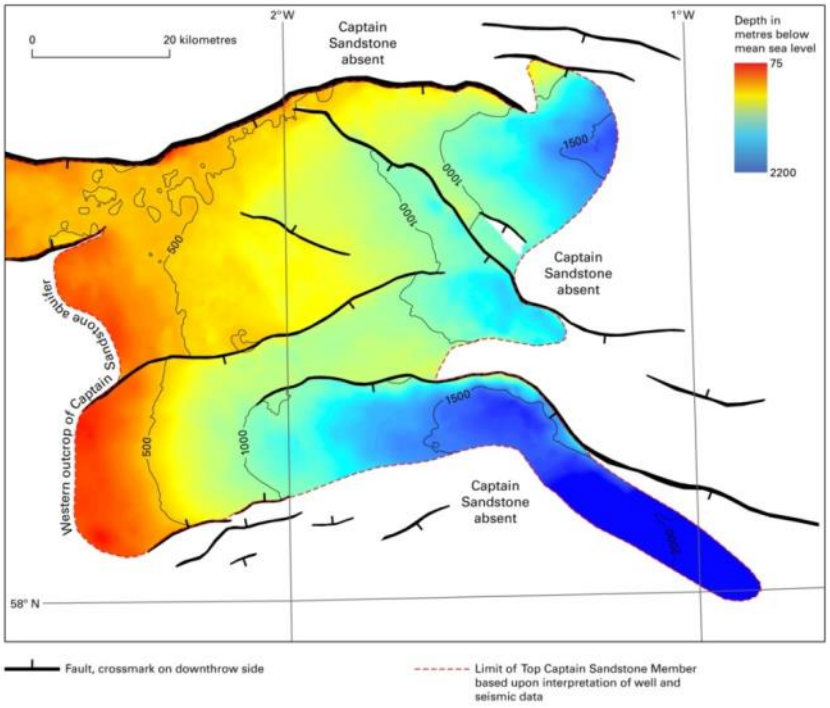
Captain Sandstone – storage research



- Revised mapping of the sandstone
- 3D geological model
- Attribute model cells with sandstone properties
- Selection of injection wells positions for dynamic modelling with constraints:
  - Retain CO_2 >800 m depth
  - Avoid localised increases in pressure
  - Avoid oil and gas fields

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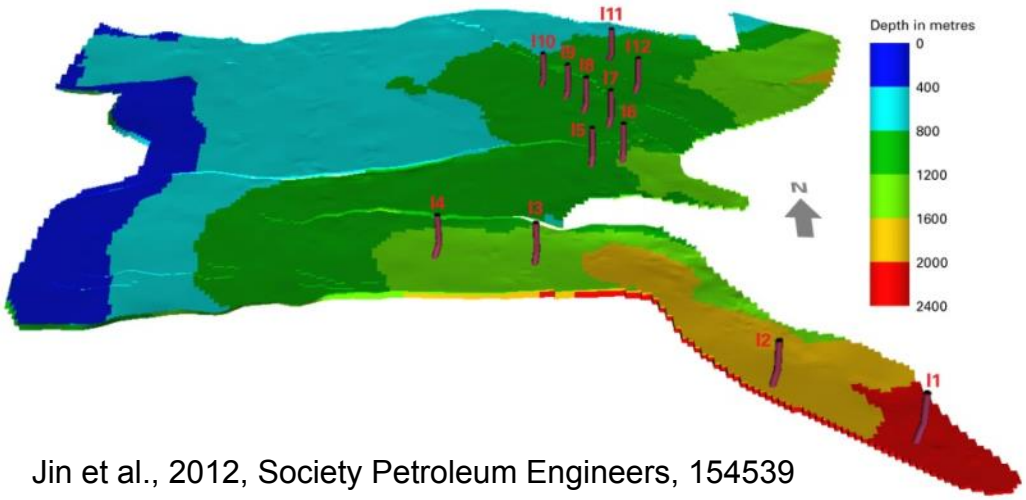
Captain Sandstone – dynamic capacity



Jin et al., 2012, Society Petroleum Engineers, 154539

- Tested 12 well sites.
- Simulated injection of 2.5 Mt CO_2 per year
- Constrained to a maximum 1.3 x initial pressure
- After 10 years injection the rate at all sites was < 2.5 Mt
- After 50 years injection at only the deepest well site

- Storage capacity of at least 358 Mt, theoretical maximum, up to 1.5 Gt
- Captain Sandstone is a single hydraulically connected storage unit
- Properties of the sandstone boundaries need to be understood
- Pressure needs to be managed to maximise the potential storage capacity

SiteChar project

Characterisation of European CO_2 storage

www.sitechar-co2.eu

Captain Sandstone - storage site characterisation

www.sitechar-co2.eu

Workflow for site characterisation tested at 5 sites

Assessment of a UK storage site, comprising

•A depleted hydrocarbon field: *early storage capability;*

•The surrounding Captain Sandstone saline aquifer: *greater storage potential, later in the storage cycle.*

Objectives

•Site characterisation sufficient for a 'dry-run' storage permit application

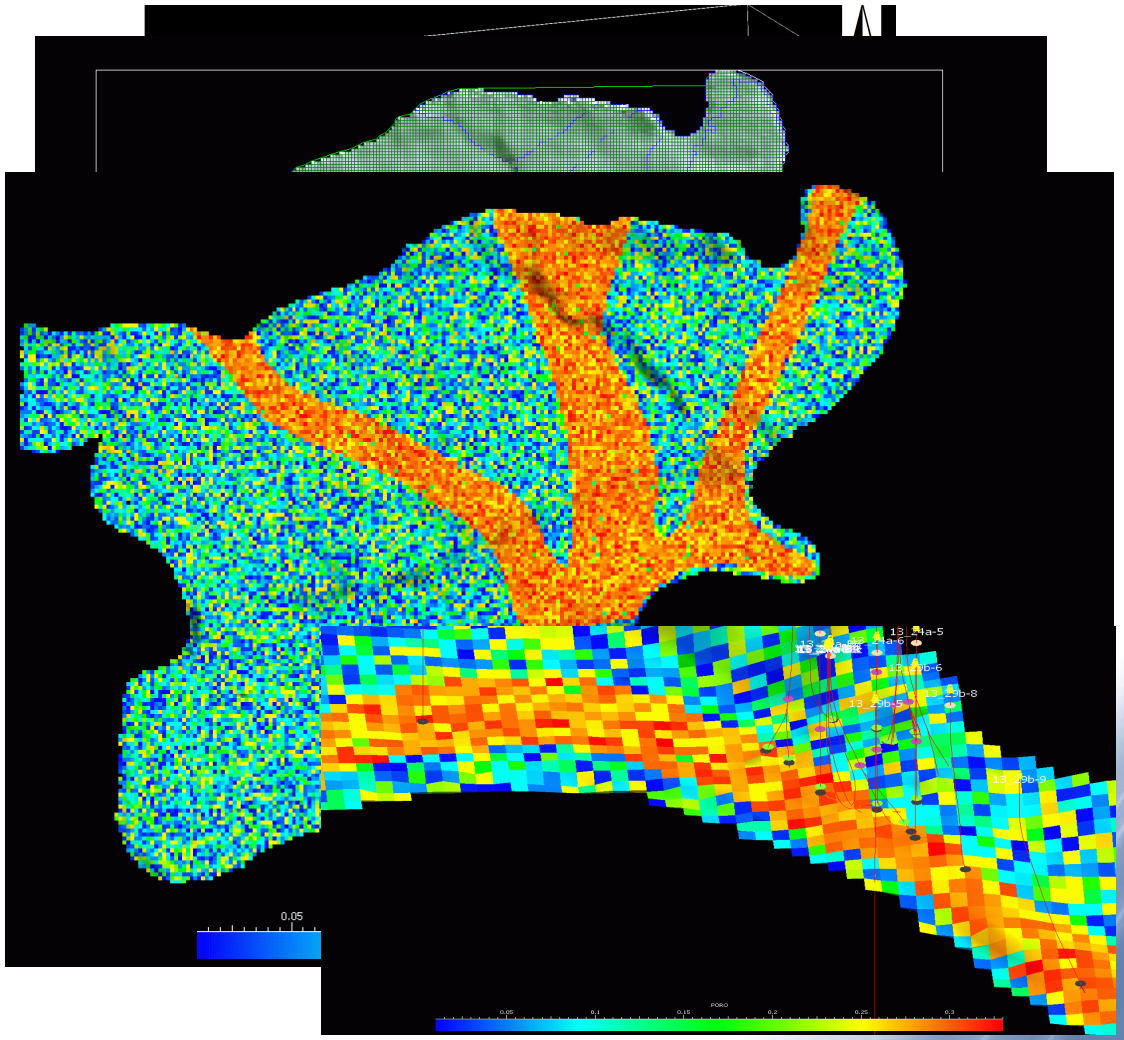
•Targeted to increase certainty and confidence in the storage resource

Injection scenario

- Continuous supply and 'commercial-scale' storage of 5 Mt CO_2 per year for 20 years – 100 Mt stored at a single injection site

Captain Sandstone - storage site characterisation

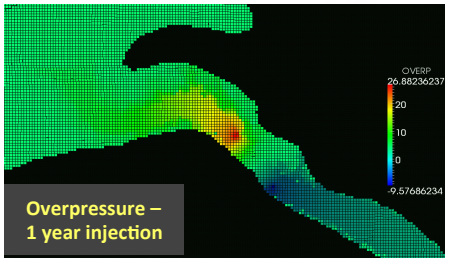
- Selected the Blake Field as a component of the store
- Modelled the site from high resolution 3D data
- Integrated into the regional geological model
- Mapped and attributed the geocellular model by facies Channel and Flank e.g. porosity
  - Stochastic modelling honours statistical distribution from core measurements
  - Average values from well data

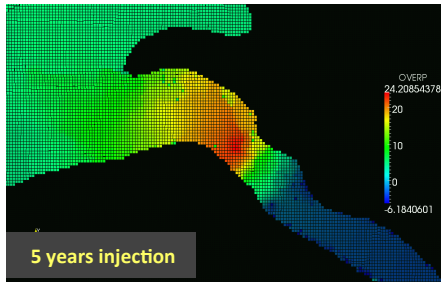


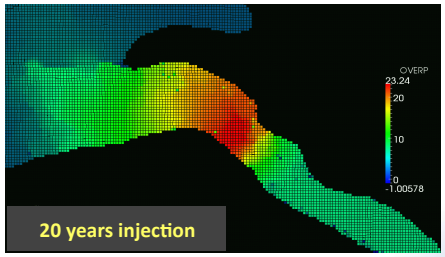
www.sitechar-co2.eu

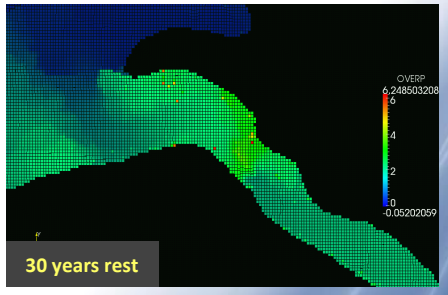
SiteChar - characterisation of a feasible and credible injection scenario

- Simulated injection of CO_2 into the Blake Field and into the Captain Sandstone saline aquifer
- 20 years of injection & 30 years post-injection
- In all scenarios:
  - Injected CO_2 gas was retained within the hydrocarbon field or immediate vicinity
  - Pressure 'footprint' was extensive
  - At this injection rate simulations indicated pressure management is needed
- Pressure management by water production was simulated
- Hydrocarbon fields are not adversely effected
- Pressure managed to remain substantially less (1/3) the modelled pressure threshold









Akhurst et al., accepted for publication, Oil & Gas Science and Technology Review

CO_2MultiStore - optimising storage potential by multi-user stores

- Informs development of multiple injection sites in a single extensive CO_2 storage sandstone
- Investigations follow SiteChar workflow
- Addresses:
  - Increased certainty for development of multiple injection sites hosted within a multi-user storage sandstone
  - Potential interactions between injection sites
- Informs the licensing and leasing of multi-user stores to optimise storage capacity
- Supported by the Scottish Government, The Crown Estate, Scottish Enterprise, Shell and Vattenfall
- Captures generic knowledge learned during the project transferable to other regional storage formations

Lessons learned

Scottish CCS studies

- Can inject CO_2 at multiple sites and sustain store integrity
- Can manage pressure by varying or reducing injection rate
- Dynamic modelling supports the maximum theoretical storage capacity
- A single hydraulically connected formation needs regional-scale appraisal
- Knowledge of boundary conditions is key information – for increased confidence in pressure prediction and storage capacity

SiteChar

- Can achieve a high and continuous injection rate to store 100 Mt at a single site by managing pressure, with water production
- CO_2 injection into a depleted field generates a lower pressure anomaly than injection directly into the surrounding aquifer with greater storage capacity
- The cost and effort to access and interpret existing data is worth it - greater confidence in prediction of store site performance
- Can achieve pre-characterisation for a first-pass storage site assessment in a hydrocarbon province from existing publicly available and published data

Lessons learned

- Perspective of prospective operators and regulators guides what would be needed to give sufficient understanding and confidence for a storage permit

Scottish CCS and SiteChar studies

- Increased understanding of the storage formation has not been associated with an expected decrease in storage capacity
  - regional dynamic modelling at twelve injection sites (358 Mt) supports at least the previous theoretical maximum capacity (363 Mt) and more
  - site-specific modelling indicates roughly one third of the minimum capacity from dynamic modelling can be stored at a single site

CO_2MultiStore

- Work in progress, findings announced Summer 2015
- Great benefit to have access to industry-derived storage site investigations, published data from the prospective UK demonstrator
- Integration of the views of prospective operators, regulators and lease holders to guide investigations substantially increases confidence in the practical operation of a multi-user store

Knowledge gaps

- Knowledge of the existing datasets and availability:
  - Maps or indexes of all data collected for other purposes
  - Detailed data against which to validate and confirm/ revise our model attribution and performance predictions
- How to access data
  - Access to data which is known to have been collected but not publicly available
- Understand the effect of prospective storage operations on existing storage formation users
  - Are predicted changes beneficial or not?
  - Anticipate & mitigate potentially adverse effects
  - Plan & manage beneficial effects