WHEN TRUST MATTERS

Lessons learned from international CCS projects, regulatory challenges and solutions, and certification of storage projects

CCS Technical Workshop - Tokyo

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24 January 2024

DNV in CCS – helicopter view

A global assurance and risk management company

Purpose: To safeguard life, property, and the environment

159	~13,000	~100,000	100+	5%+
years	employees	customers	countries	of revenue in R&D

Ship and offshore classification and advisory

Energy advisory, certification, verification, inspection and monitoring

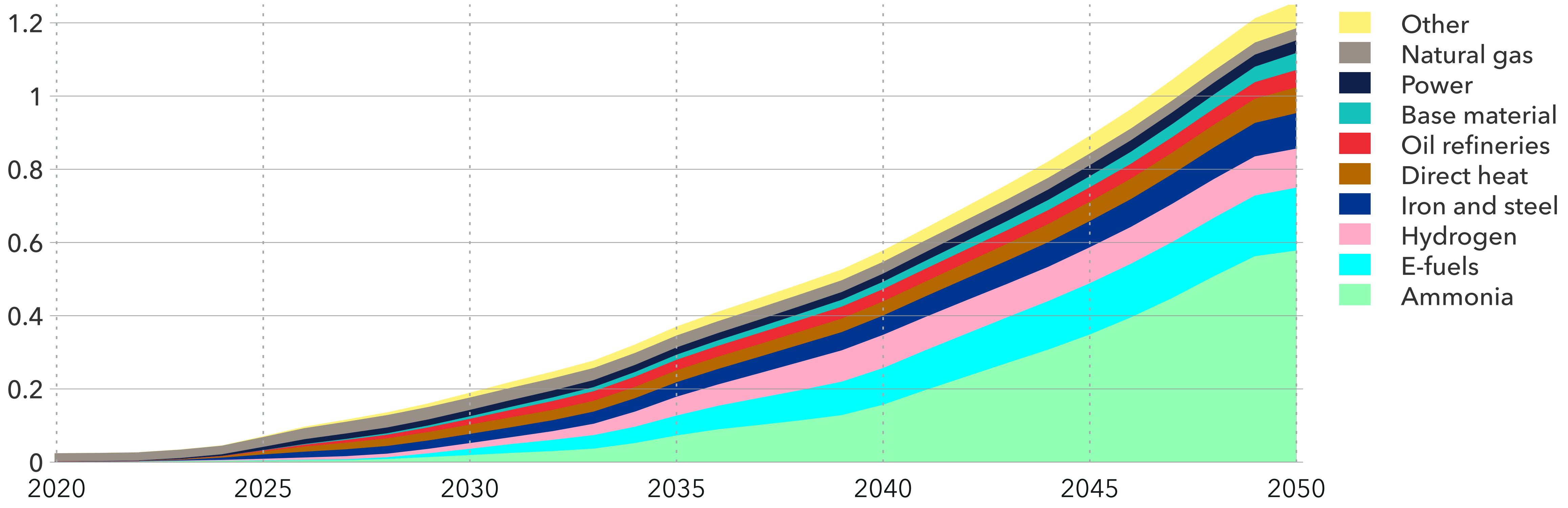
Software, cyber security, platforms and digital solutions

Management system certification, supply chain and product assurance

CCS captures 6% of emissions in 2050

World CO_2 emissions captured by sector

Units: $GtCO_2/yr$



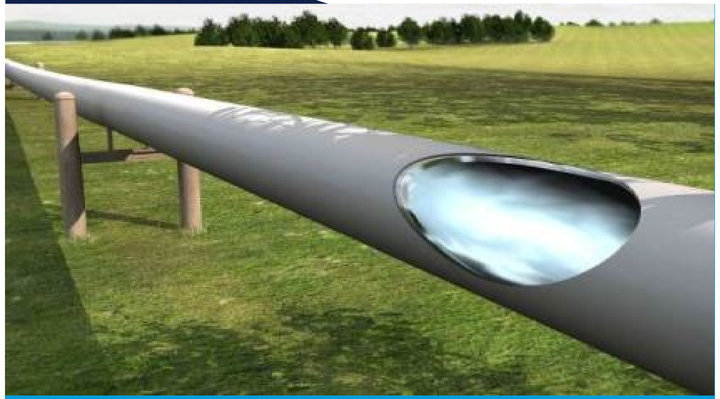
Helping scale CCS – 200+ projects in past 10 years

CAPTURE

- Fossil power plants
- Natural gas CO_2 reduction
- Other industrial processes

- Cost estimations
- Introduction of new technologies
- Technology review and benchmarking
- Up-scaling risk assessment
- HSE risk assessment
- Accidental release and dispersion
- Value of avoided CO_2

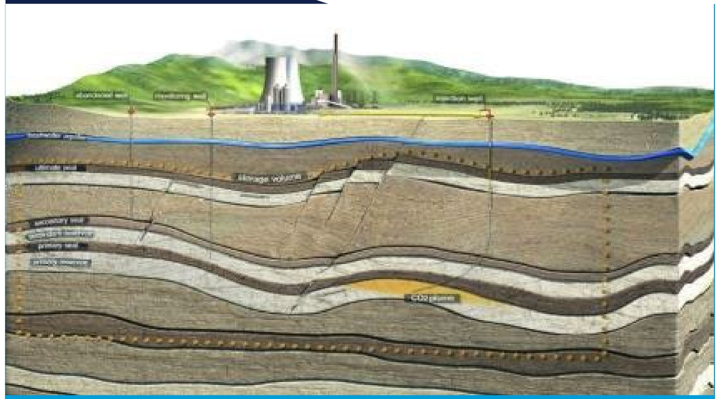
TRANSPORT



- Pipelines
- Ships

- Corrosion
- Material selection and structural design
- Flow assurance and operational issues
- Accidental release and dispersion
- Concept design for CO_2 ships
- Requalification of infrastructure

STORAGE



- Depleted oil or gas reservoirs
- Saline aquifers
- Enhanced oil recovery (EOR)

- Verification of storage sites
- Permanence of storage
- Risk management
- Monitoring and verification
- Public concern
- Transfer of responsibility

Driving development of first international CCUS standards

DNV RESEARCH/JOINT INDUSTRY PROJECT ↓	• CO2 RISKMAN – Guidance on CCS CO_2 Safety and Environment Major Accident Hazard Risk Management • CO2 PIPETRANS – Guidance on transportation component of CCS projects • CO2 SAFEARREST – Guidance on the efficient design of CO_2 pipelines • CO2 QUALSTORE – Guidance for the selection and qualification of CO_2 storage sites • CO2 WELLS – Guidance on the risk management of existing wells at CO_2 storage sites • CO2 CAPTURE – Guidance on procedure for capture technology qualification • HiPerCap – Development of novel Capture technologies • ECO2 – Best environmental practice for offshore CO_2 injection		
DNV RECOMMENDED PRACTICE	**DNV-RP-J201** Qualification procedures for carbon dioxide capture technology	**DNV-RP-F104** Design and operation of carbon dioxide pipelines	**DNV-RP-J203** Geological storage of carbon dioxide
INTERNATIONAL STANDARD	**ISO 27919-1** Carbon dioxide capture – Performance evaluation methods for post-combustion CO_2 capture integrated with a power plant	**ISO 27913** Carbon dioxide capture, transportation and geological storage – Pipeline transportation system	**ISO 27914** Carbon dioxide capture, transportation and geological storage – Geological storage
DNV FRAMEWORKS FOR ASSURANCE SERVICES	**DNV-SE-0160** Technology qualification management and verification	**DNV-ST-F101** Submarine pipeline systems	**DNV-SE-0473:** Certification of sites and projects for geological storage of CO_2 **DNV-SE-0617:** Qualification management for geological storage of CO_2

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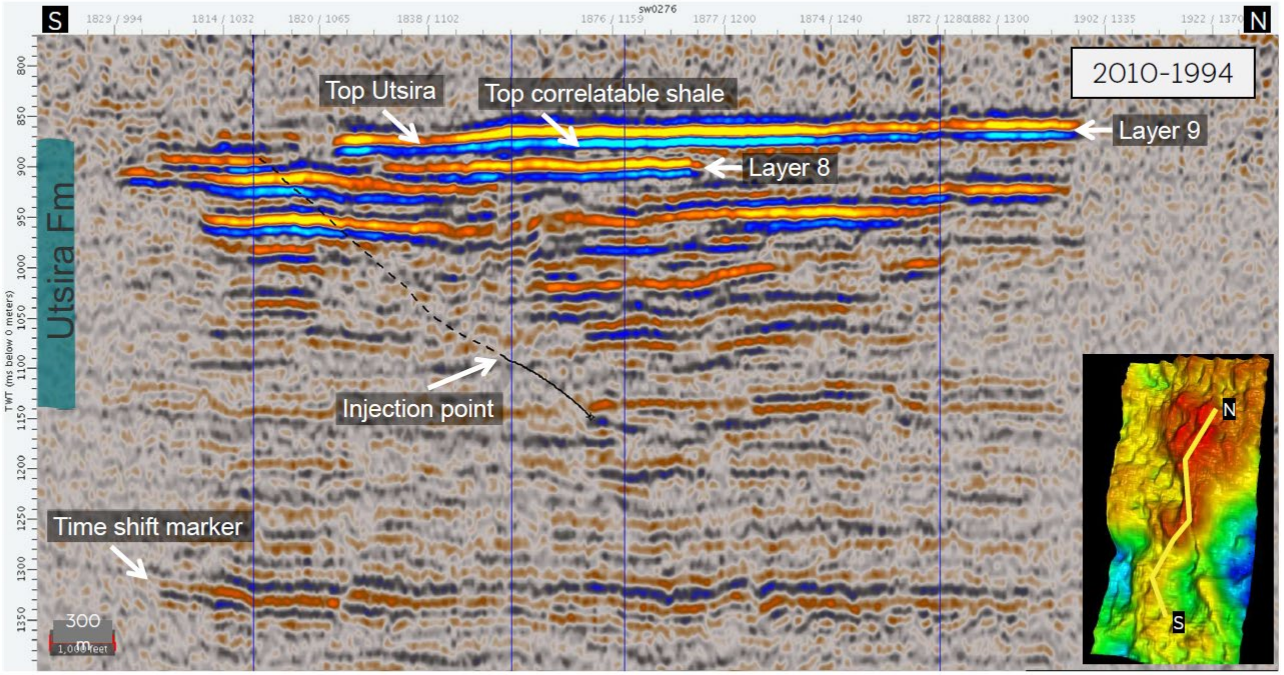
What have we learned from international CCS projects?

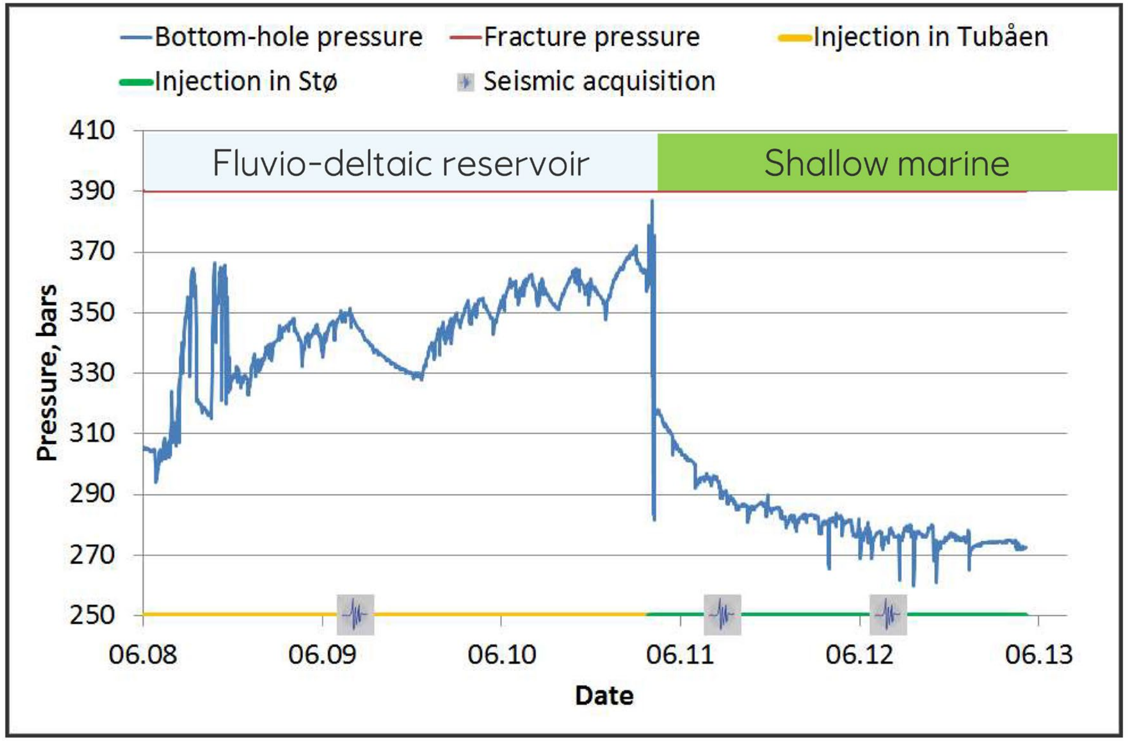
Lessons Learned - Sleipner
- Storage works, the value of seismic

- Sleipner was initiated in 1996 – will run out of CO_2 soon.
- Has demonstrated safe long term storage in aquifers.
- Has informed policy and regulators about the value of seismic monitoring to demonstrate CO_2 migration.
  - Conformance with models (migration through interbedded baffles occurred faster than initially modelled)

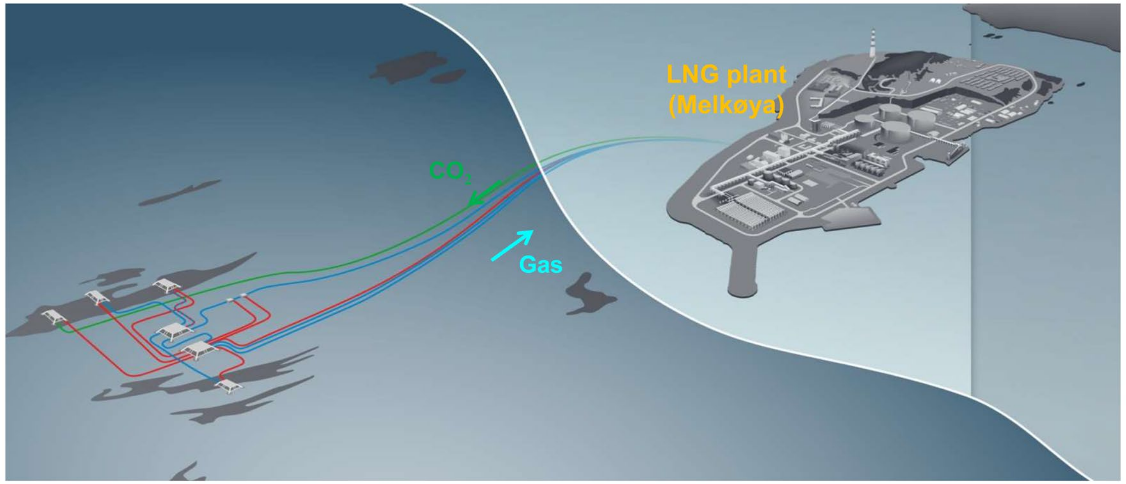


Lesson Learned – Snøhvit
First offshore CO_2 pipeline, compartmentalization

Down-hole pressure data



Hansen et al. 2013; Pawar et al., 2015



- Initial injectivity challenges due to salt drop-out + fines
- Rising pressure due to geological barriers
- Deployed back-up option in the injector (new completion)
- New well drilled to allow continued injection

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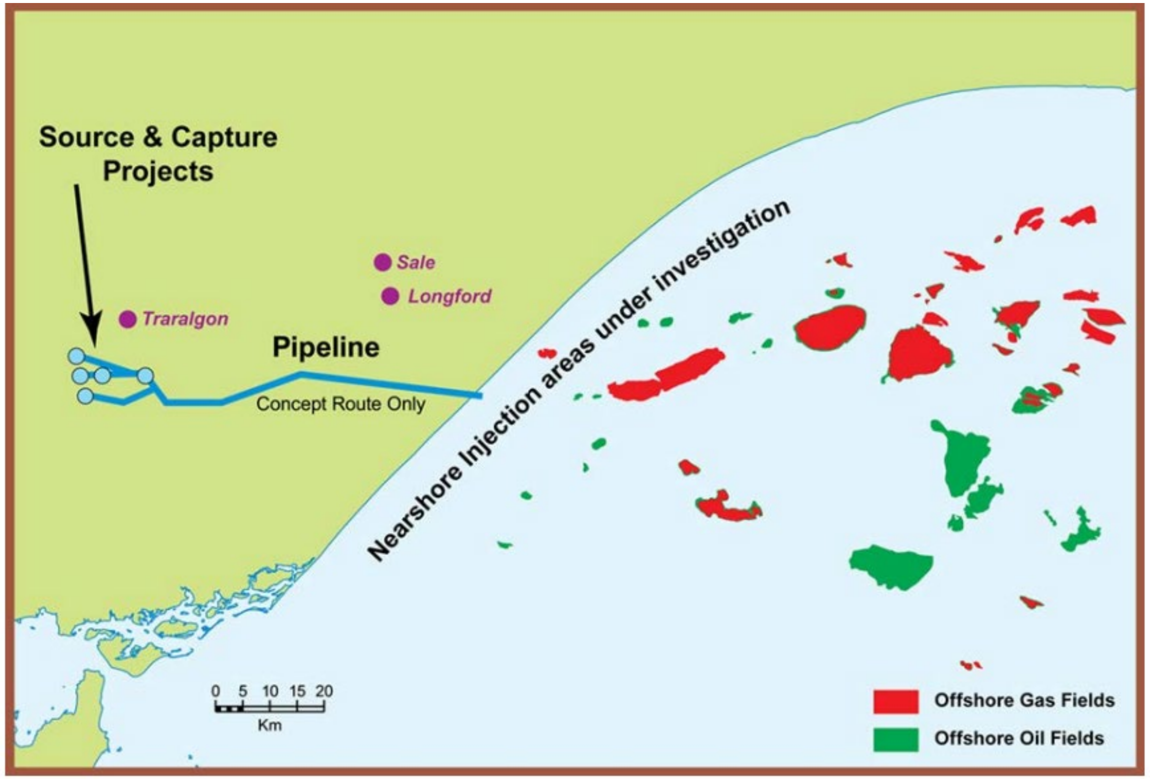
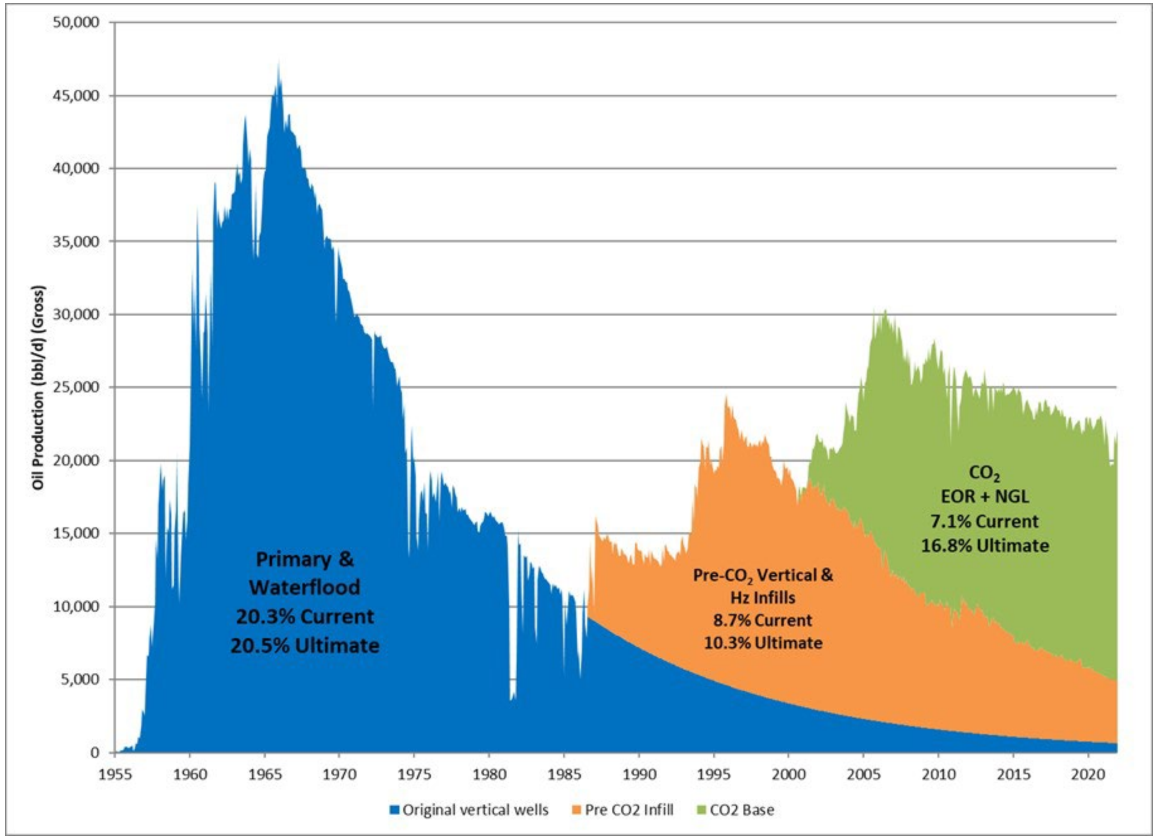
Lessons Learned – CarbonNet
Government led, regulatory challenges

- Storage first, then emitter contracts
- Built team within government
  - Needed clear separation with regulatory body
  - Dependence on government funding
  - Significant outsourcing of studies
- Regulations existed. But storage sites that straddled boundary between state boundary and commonwealth waters not legal.
  - Dialogues in 2012, resolved in 2021
- Testing SRSOAI meaning for CCS



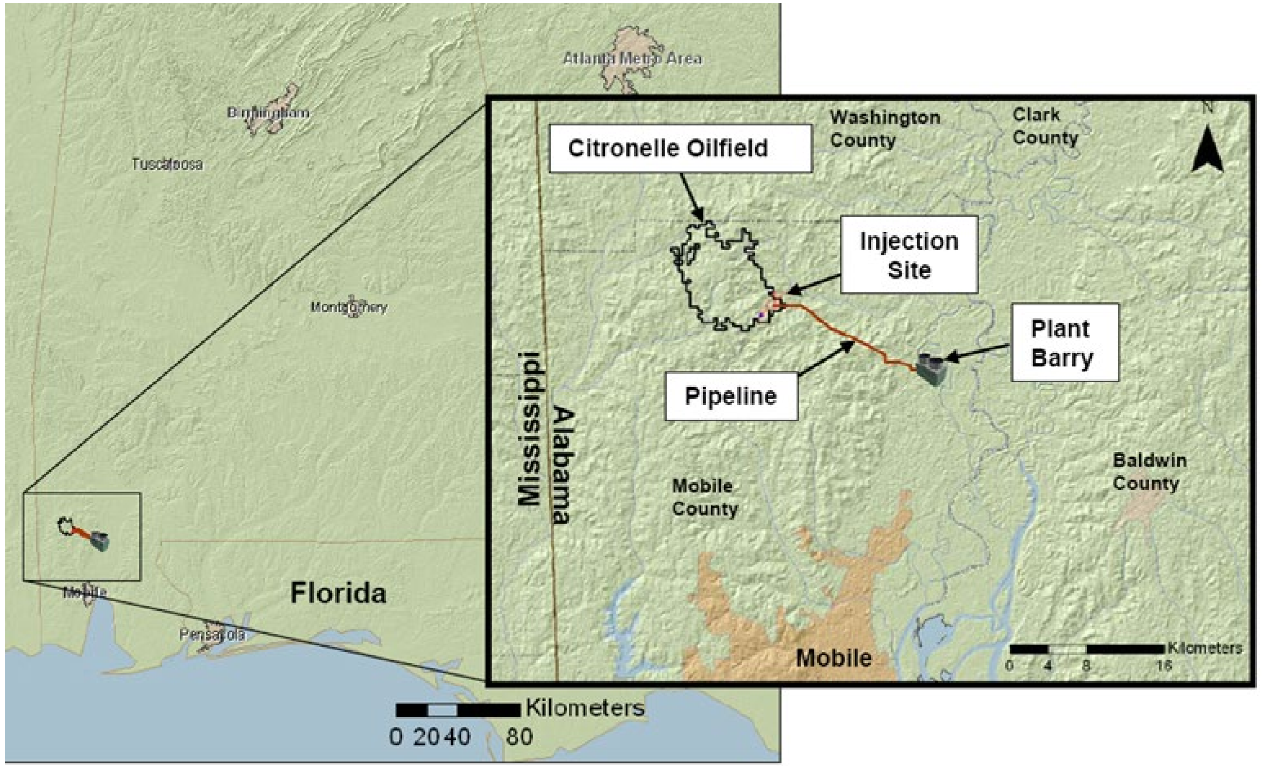
Lessons learned – Weyburn (+Midale)
CO2-EOR is CC(U)S, value of assurance monitoring

- Started in 2001
- Comprehensive monitoring and risk assessment delivered confidence in storage
- 1300+ wells (at Weyburn), many old.
- Petroleum regulations apply
- The One Stakeholder …
  - Kerr farm claims of leakage
  - Robust monitoring and scientific evidence provided to dispute claims
  - Operator may not have been home-free without support from IEA GHG M&S project



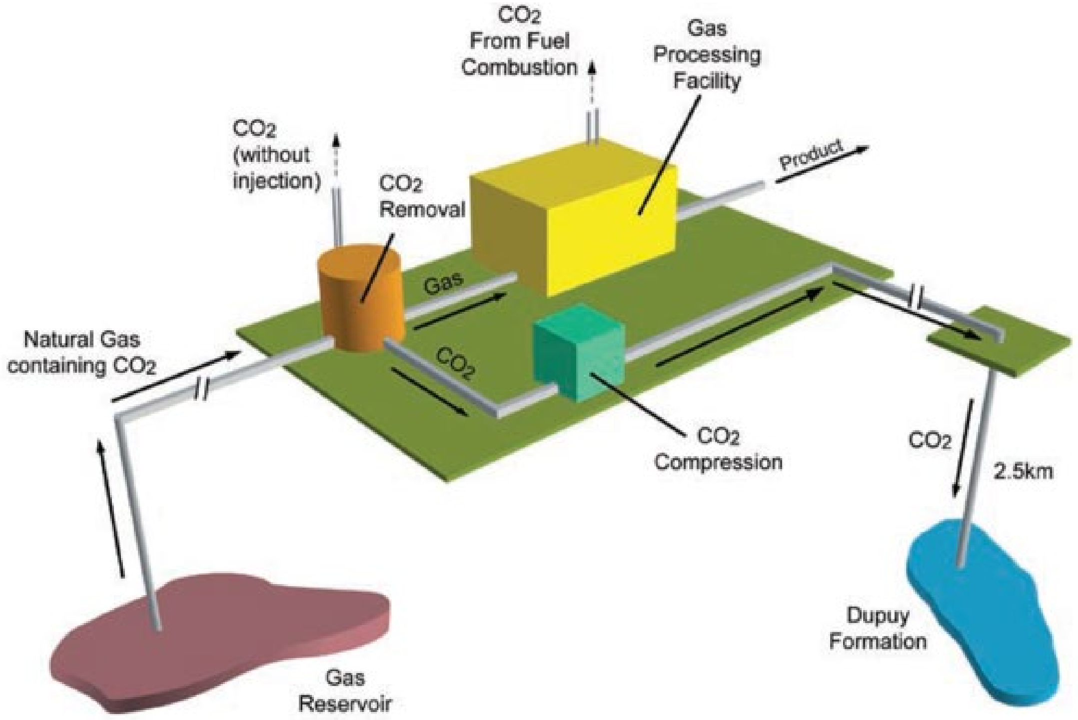
Lessons Learned – SECARB at Citronelle

- Carbon capture from Plant Barry (equivalent to 25MWe).
  - 12-mile CO_2 pipeline constructed by Denbury Resources. Injection into ~9.400 ft. deep saline formation (Paluxy) above Citronelle Field.
- Lessons learned
  - Regulatory process biggest risk (in hindsight). Last project to be permitted under Class V – experimental well regulation, with req. for 4.5” pipeline.
  - First major demonstration with intermittent injection (low gas prices led to coal plant being switched off and on). No issues.
  - Duration of project shortened due to lack of CO_2 – Denbury pulled out when their minimal contract commitment of 100kt was met.
    - Initial intent was to continue with CO_2 EOR after project, but low oil prices didn’t support business case. Similar for PetroNova.
- First integrated project with different entities for capture, transport monitoring and storage.
  - Risk mng challenge: Provide sufficient transparency to allow the risk assessments to be auditable and traceable across companies.



Lessons Learned – Gorgon
Barrow island act, pressure management issues

- Placed on a Class A Nature Reserve – allowed through barrow island act with many regulatory constraints
- Chevron is required to sequester at least 80% of the captured CO_2 from the LNG plant over a five-year period
- CO_2 injection started in 2019 (gas production in 2016) for next 40 yrs.
- Injection reduced, not meeting promised injection rates
  - Major fault system implied need for water production to manage pressure (away from fault system)
  - Injectivity reduction – due to sand/fines in water production led to issues implying reduced water injection



Lessons Learned – In Salah, Algeria (EOR) Risked based monitoring: value of satellite InSAR

Plan: Injected CO_2 through 3 new wells located in the water leg of the field; CO_2 was expected to migrate towards the gas field

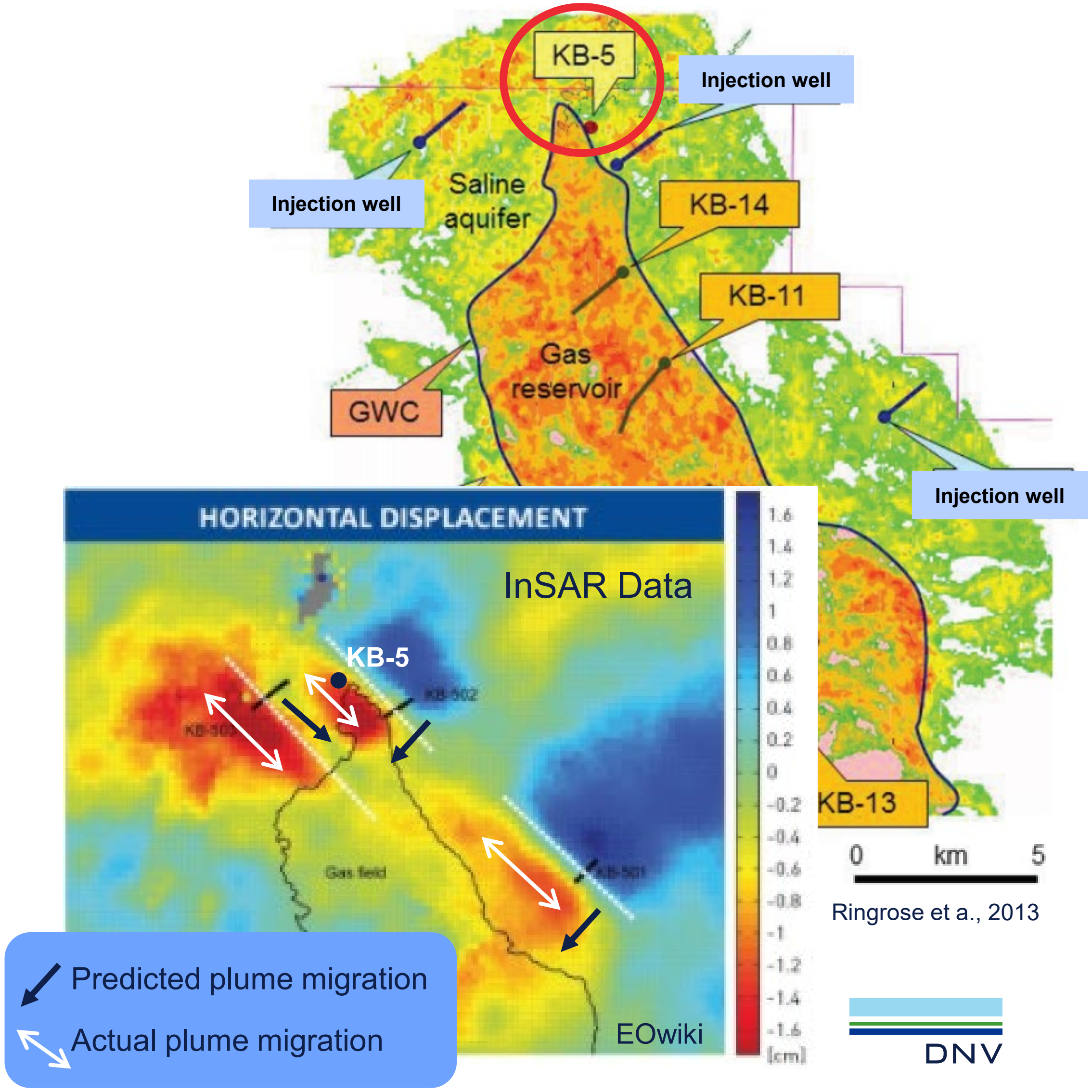
Event: CO_2 migrated *unexpectedly* in a northly direction and broke through at **KB-5** well (suspended legacy well)

- Detected by integrating a combination of geochemical, geodic and geophysical technologies – low-cost satellite InSAR was key

Result: Update to risk-based monitoring plan & injection strategy

Key Learning

- Inadequate understanding of subsurface structure
- Deployment of multiple monitoring technologies
- Adaptive risked based MMV plan



Ringrose et a., 2013

Quest – Shell Alberta Canada Public Acceptance (2008 to date)

- Quest - 1MT of CO_2 per year from 2015
- CCS was unknown to the community, objections centred on government funding which could have been used for other local activities
- Many non-believers in climate change

Approach

- Started public engagement 2 yrs. before drilling started in 2010
- Shell worked with local NGO to provide technical information
- Engaged with the community – local coffee shop sessions
- Set up a Community Advisory Panel to raise issues and present responses when drilling started
- Pipeline route selected to meet stakeholder requirements
- Got the project third-party verified prior to injection

Lessons learnt

- Engage at local level in an informal manner (no suits, local settings)
- Public acceptance won by building relationships and trust; not by providing technical info or trying to win people round to the purpose of the project.
- Do not over do it – local aquifer water sampling, farms got fed-up

Source: Shell

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Differing risk profiles of Saline aquifers vs. Depleted fields

Risk factor	Deep saline aquifers	Depleted fields
Containment - Well - Faults & seal	▪ Typically fewer legacy wells – primary anthropogenetic path of leakage	▪ Typically higher density of legacy wells, as the field has been explored developed and produced.
	▪ Faults and seals not geomechanically weakened through production	▪ Due to depletion of HC, fields may be geomechanically impacted ▪ Proven in the local area to hold HC
Capacity	▪ Regional capacity ranges typically higher due to large lateral extent ▪ Larger uncertainty range on capacity estimates, linked to limited data on reservoir (store) properties	▪ Typically offer smaller overall capacity, as the capacity is limited to the field size ▪ Uncertainty on capacity range less, due to better reservoir (store) knowledge
Injectivity	▪ Greater uncertainty due to lack of data, cannot be derisked until appraisal well conduct injectivity tests	▪ Production data gives you confidence on dynamic injectivity rates early on in CCS storage maturation phase ▪ Depletion can create high pressure differentials and lead to significant J-T cooling, and potentially form solids (ice and hydrates) which may have significant impact on injectivity. Well material (cements, casing) and the near-wellbore formation may also be impacted by the thermal and mechanical stresses, impacting well performance and integrity.
Monitorability	▪ Geophysical monitoring techniques inside and outside the storage complex are not hampered by the presence of residual HC	▪ If residual HC remain, especially gas, they can inhibit geophysical (seismic) techniques aimed at visualizing plume migration with the confines of the structurally defined ''store' (injection reservoir) unit. However, it does not preclude the use of seismic outside for detecting CO2 leakage or migration outside the defined store or storage.

Example technical issues and mitigations

- Salt precipitation
  - Principally an issue when injection into high salinity aquifers (QUEST, Bunter Sandstone UK)
  - Well stimulation may be required on regular basis to maintain injectivity
- Hydrates
  - Principally an issue caused by J-T cooling during blow-down, well blow-out or injection into depleted fields.
  - Injection: Heating of CO_2 and potentially start injection at lower rates.
- Pressure build up in closed structures (second target?)
  - Pressure build-up depends on hydraulically connected volume (to absorb injected fluids). This will constrain the capacity due to fracture pressure constraints. Vbulk/Vtrap = 5 ➔ Storage efficiency = 0.5-2.0.
  - Critical points: wells (plugs, near wellbore region), faults (reactivation), shallowest point (capillary entry pressure).
- Where does displaced formation fluids go?
  - To shallower units through off-structure legacy wells (mitigation: placement of plugs).
  - To seabed through outcrops (mitigation: produce formation brine and inject into other aquifer)
  - To nearby reservoirs (repressurized – mitigation may not be required).

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Regulatory challenges and solutions (in Europe)

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Regulatory challenges – a European perspective

- DNV coordinated update of guidance to support adherence to CCS Directive.
  - 3000+ stakeholder comments
- Challenges noted:
  - Establishing consensus on what constitutes significant vs. non-significant risk.
  - Coordination and permitting of multiple sites within same hydraulic unit, incl. X-border.
  - Enabling mineralization projects (storage in mafic rocks without traditional seal).
  - Transfer prior to 20 years post-closure.
  - Enabling transition from O&G license to storage license (without competitive process)
  - When is CO_2 EHR combined with storage?

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Proposed solutions

Significant risk (leakage + HSE): Cannot put into question the purpose of the CCS Directive.

- No assumption of zero risk or zero leakage (eliminating as far as possible (ALARP) risk) – Need to defend selection of risk treatment for individual risks.
- Guidance: Consider nature of the damage, relevant risk acceptance criteria in applicable regulations and corporate policies, ***and*** the benefits of the CO_2 storage activity.

Multiple sites in the same hydraulic unit: Pressure interference.

- Operators: Map and describe other *known* activities within the hydraulic unit that may impact pressure within the storage site.
- CA: Enable sharing of related information between operators and between CAs, and maintain records of pressure influence from previous operations.

Mineralization projects without a seal: Caprock and CO_2 stream

- Caprock should – in tandem with other trapping mechanisms – have sufficiently low permeability to deliver permanent containment of CO_2 and formation fluids, and prevent any significant risk in site-specific circumstances.
- CO_2 stream is not overwhelmingly CO_2. This gap is not resolved.

Proposed solutions

Handover prior to the end of a 20-year period following closure

- Operator: Specify in the post-closure plan quantitative KPIs for compliance with the criteria for transfer.
- Discuss and agree indicators with the CA as part of the evaluation of the post-closure plan.
- The indicators should be based on the site-specific context, and consider the evolution of containment risk over time.

Exploration permits are to be granted or refused on the basis of non-discriminatory criteria.

- O&G operators holding licenses for depleted fields may not require an exploration permit.
- Leeway to allow such project proponents to apply directly for storage permit, and will also have competitive advantage for exploration permits.

CCS Directive shall apply if CO_2 EHR (or potentially geothermal operations) is combined with storage.

- EHR is considered combined with geological storage of CO_2 when long-term storage of CO_2 is a primary objective.
- EU ETS accounting: Life-cycle emissions of the EHR operations, including from the combustion of incremental HC.

Certification of CO_2 storage

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Certification frameworks

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SERVICE SPECIFICATION

DNV-SE-0473

Edition October 2017
Amended October 2021

Certification of sites and projects for geological storage of carbon dioxide

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SERVICE SPECIFICATION

DNV-SE-0617

Edition February 2022

Qualification management for geological storage of CO_2

Certification against ISO 27914:2017

https://www.dnv.com/oilgas/download/dnv-se-0473-certification-of-sites-and-projects-for-geological-storage-of-carbon-dioxide.html

Certification against DNV-RP-J203

https://www.dnv.com/oilgas/download/dnv-se-0617-qualification-management-for-geological-storage-of-CO2.html

Addressing the trust issue: Benefits of Storage Site Certification

Stakeholder Assurance

- Subsurface CO_2 storage remains a novel and unfamiliar concept for many – stakeholder assurance is key.

Minimising and mitigating risk to developer

- Objective QA of storage site development by independent experts – brings key issues into focus.

Creates confidence with regulator

- General alignment between certification stage and permitting milestones – can accelerate permitting processes for early projects.

Enables implementation of CCS in countries without established regulations for CCS

- Certification can be used alongside regulatory E&P milestones to demonstrate alignment with industry best practice

EU Taxonomy compliance

- The EU Taxonomy requires compliance with ISO 27914 – Relevant for import of H2 and NH3 and for EU companies doing storage outside Europe.

Positioning for public funding

- Helps companies be positioned for public funding, e.g. EU Innovation Fund.

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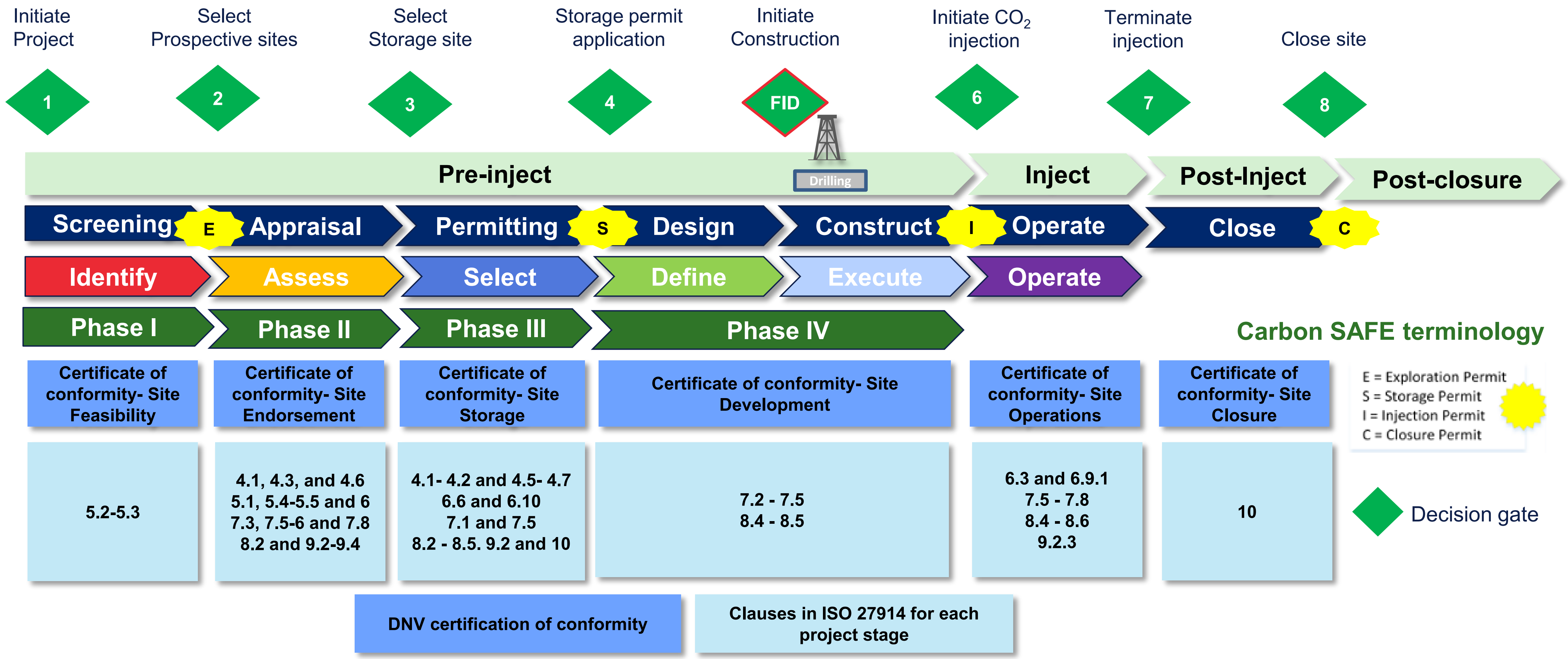
CO_2 storage certification framework

DNV-SE-0473 guides verification of conformity with ISO 27914 at generic milestones in project life-cycle

Requirements in ISO 27914 mapped to align with project milestone



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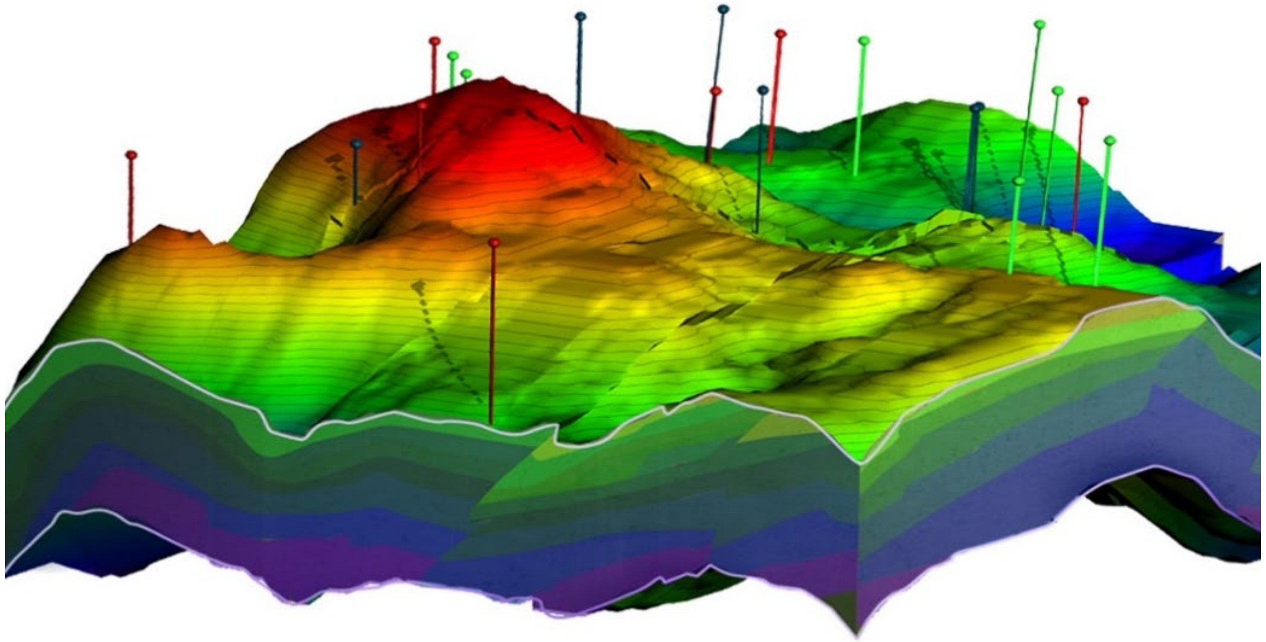
Independent review and certification of storage projects



- QUEST (CA) (2010-2011): 1 onshore site, aquifer
- CarbonNet (AUS) (2012-2019): 6→3→1 offshore aquifer sites
- Gorgon (AUS) (2013): 1 on/offshore aquifer site
- Greensand (DK) (2020-2022): 1 depleted field site
- NEP (UK) (2021-2023): 5 aquifer sites
- 3 confidential onshore projects in Eur. (2021-2023): 6 aquifer sites and 1 depleted field
- 2 confidential projects in Aus. (2023): 2 onshore and 1 offshore depleted fields.
- **Total: 23 sites**

General recommendations

- Structure documentation to align with requirements, or provide a document with pointer to relevant documents for respective requirements.
- It is highly recommended to have risk assessment at the core:
  - Site characterization activities are informed by the need to de-risk the site
  - Site ranking and selection is informed by qualitative risk assessment
  - Uncertainties are considered and managed in a risk assessment context
  - MMV plan developments are risk-based
- QC that the documentation does answer the full question being addressed.
  - Don’t lose sight of non-technical issues – often quick to de-risk, but can have substantial impact
  - Well integrity is normally “manageable” (at high cost and effort for many depleted fields), but does not mean site is preferable

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Thank you

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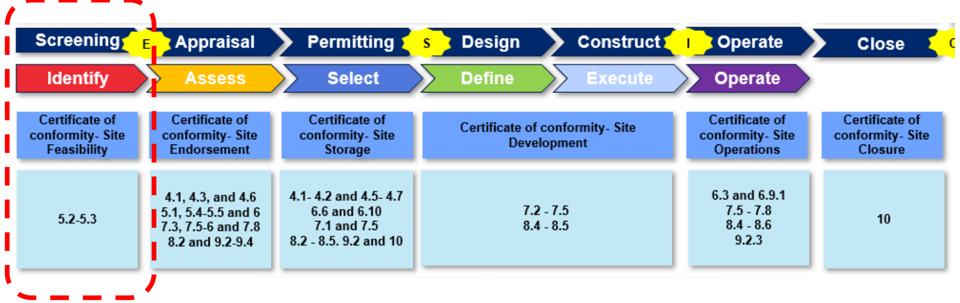
Screening / Identify Phase



Aim: Initial evaluation of site suitability. Screen for major technical & nontechnical showstoppers (containment, injectivity, capacity, monitorability, stakeholders) and surface access issues for the site

ISO sections: 5.2-5.3 (site screening, selection, and characterization)

Focus areas:

- Geological screening of area of interest for potential CO_2 storage sites.
- Qualitatively rank sites based on containment, capacity, injectivity, and project feasibility
- Screening for legal and regulatory requirements

Output:

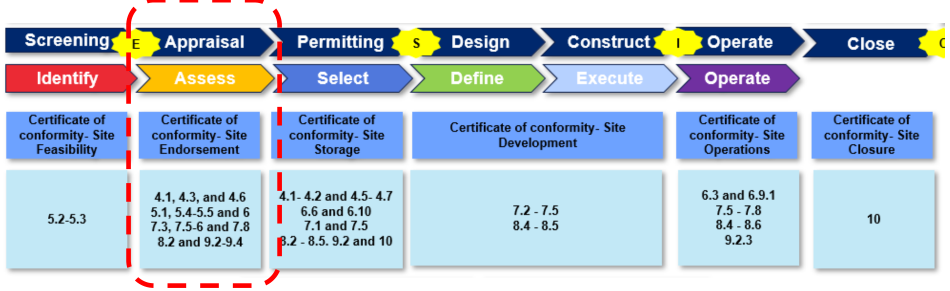
- List of prospective storage sites that fulfil the operator's site selection requirements and associated recommendations in ISO 27914

Decisions:

- Commit budget and resources for site characterization and apply for exploration permit or equivalent for prioritized sites.
- Stop progressing sites that cannot be de-risked further or have major showstoppers

Certification: DNV Certification of Conformity - Site Feasibility

Appraisal/ Assess Phase



Aim: Appraise prospective sites in detail and develop a well engineering concept that can deliver required volumes of CO_2 at an economic rate. At the end of this phase a storage complex(s) is selected

ISO sections: 4.1, 4.3, 4.6 (Management systems); 5.1,5.4,5.5 (Site Characterization); 6 (Risk Management); 7.3,7.5,7.6,7.8 (Well Infrastructure); 8.2 (Injection Operations); 9.2-9.4 (Monitoring and Verification)

Focus areas:

- Data collection and evaluation: Design & drill a characterization well (if required – aquifer stores), collect all data required for permitting, geologic modeling of storage complex
- Modeling and evaluation of containment, injectivity, capacity and monitorability
- Stakeholder engagement.
- Detailed legacy well review
- Risk assessment
- Initial planning & design for injection and monitoring (MMV feasibility work)

Output: Documentation that there is a feasible development opportunity based on ISO recommendations and TECOP principles, and all required information for permitting.

Decisions: Commitment of budget and resources for storage permit and public engagement

Certification: DNV Certification of Conformity- Site Endorsement

Process and deliverables

- Performed by a review team
  - Often consisting partly of non-DNV resources.
- Evaluation positive:
  - Certificate of conformity and verification report.
- Evaluation negative:
  - Verification report with nonconformity observations.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CERTIFICATE OF CONFORMITY – SITE FEASIBILITY

Statement No:

Project operator: XX

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CERTIFICATE OF CONFORMITY – SITE ENDORSEMENT

Statement No:

Project operator: XX

DNV·GL

CERTIFICATE OF CONFORMITY – STORAGE SITE

Statement No:

Project operator:	XX
Storage project:	<Name and organizational and operational boundaries (ISO 27914, Clause 4.2)>
Storage site:	<Name, location and boundaries>
Project goal:	<annual and total mass of CO2 to be stored>

This is to certify:

That DNV GL considers that the project operator has developed an appropriate storage development plan /3/ to allow safe and effective geological storage at the **<Name>** storage site in accordance with /1/ and project objectives. The storage development plan /3/ comprises the following project specific plans:
- risk management plan;
- Monitoring and Verification (M&V) plan;
- plan for public and stakeholder engagement;
- storage facility design plan;
- Operations and Maintenance (O&M) plan.
- provisional closure plan.

Certification involvement:

DNV GL has verified that the storage development plan /3/ is in accordance with /1/ and /2/, and checked conformity with the criteria listed in /2/ Section 3.2.3. The verification report /4/ includes a description of the verification process, conclusions from the evaluations, and deviations, if any, from recommendations listed in /2/ Table 3-3 and Table 3-5.

Validity:
This statement is valid on the date of issue.

DNV·GL

CERTIFICATE OF CONFORMITY – SITE DEVELOPMENT

Statement No:

Project operator: XX

DNV·GL

CERTIFICATE OF CONFORMITY – SITE OPERATIONS

Statement No:

Project operator: XX

Storage project: <Name and organizational and operational

DNV·GL

CERTIFICATE OF CONFORMITY – SITE CLOSURE

Statement No:

Project operator:	XX
Storage project:	<Name and organizational and operational boundaries (ISO 27914, Clause 4.2)>
Storage site:	<Name, location and boundaries>
Project goal:	<annual and total mass of CO2 to be stored>

This is to certify:

That the criteria for site closure in /1/, Clause 10.2 have been met for the **<Name>** storage site, and that the closure qualification process /4/ has been performed in accordance with /1/ and /3/. DNV GL thereby confirms that the risk of future leakage of injected CO_2 conforms to the following acceptance criteria established for the project in accordance with /1/, Clause 6.8 a):

<Acceptance criteria pertaining to risk of leakage of injected CO2 after site closure at the Name storage site>.

Certification involvement:

DNV GL has verified that the **<Name>** storage site is qualified for site closure in accordance with /1/ and /2/, and checked conformity with the criteria referenced in /2/ Section 3.2.6. The verification report /5/ includes a description of the verification process, conclusions from the evaluations, and deviations, if any, from recommendations listed in /2/ Table 3-10.

Validity:
This statement is valid on the date of issue.

DNV