Thematic Report

Storage session – October 2013

A report from the European CCS Demonstration Project Network

Public version

Proceedings from the Stavanger knowledge sharing event 23 and 24 October 2013

1. Introduction

This report gives an update from the leading European projects on the progress of the carbon dioxide (CO_2) storage component of CCS since the knowledge sharing event held in May 2013. It is a summary of key learning points that resulted from the thematic discussions held in Stavanger, hosted by the Sleipner project on the 23 and 24 of October 2013. The workshop was one of three sessions held in parallel during the European CCS Project Demonstration Network knowledge sharing event. Other thematic groups focused upon Regulatory Development and CO_2 Transport. The European CCS Demonstration Project Network has been setup to:

- Help fulfil the potential of Carbon Capture and Storage by creating a community of projects united in the goal of achieving commercially viable CCS by 2020.
- Foster knowledge sharing amongst the demonstration projects.
- Facilitate the identification of best practices.
- Accelerate learnings and assist the CCS projects to safely fulfil its potential, both in the EU and in cooperation with global partners.
- Leverage this new body of knowledge to raise public understanding of the potential of CCS.

Storage Knowledge Sharing Themes in 2013:

Two storage topics were selected by the European CCS Demonstration Project Network Steering Committee for the year 2013:

- Designing long term injection operations;
- Baseline monitoring.

Both topics have been addressed during the knowledge sharing event in May 2013. The October knowledge sharing event focused on operational progress, well injection, communication challenges and the Sleipner project operations. The location of the meeting offered the opportunity to visit Statoil's operational centre for Sleipner project.

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2. Project Status Update

Projects representatives gave an update on storage progress since the knowledge sharing meeting in May 2013 which was held in Doncaster[1], in the United Kingdom.

The below project status table presents a summary of the status of the storage sites under development (except for the Sleipner project for which all boxes would be marked as completed).

	Compostilla	Don Valley saline	ROAD	Don Valley EOR	Porto Tolle	Hontomin
Site screen	✓	✓	✓	✓	✓	✓
Site select	✓	✓	✓	✓	✓	✓
Feasibility study	✓	✓	✓	✓	✓	✓
Appraisal drill and/or seismic	✓	✓	n/a	n/a	○	✓
Baseline surveys	✓	☐	n/a	○	✓	✓
FEED	✓	○	○	○	○	✓
LT monitor plan	✓	○	○	○	○	☐
Storage License application	○	☐	✓	○	○	n/a
CO_2 Injectors	3-5	2-6	1	5-6	1	1
Injection backup	yes	yes	no	yes	no	no

○ not started ☐ in progress ✓ complete project suspended

(as of October 2013). In red: License application only after a positive FID is taken. In green: changes compared to progress reported in May. The Bełchatów project and the Porto Tolle project were terminated in May and October 2013, respectively. The Compostilla project and ROAD project are now waiting for FID to be taken. The Don Valley and Hontomín are in progress. The Don Valley EOR is focusing on restructuring and securing funding.

[1] Thematic report: Storage session - May 2013 http://ccsnetwork.eu/publications/thematic-report-storage-session-may-2013

2.1. The Compostilla project– Duero and Andorra sites

ALMACENAMIENTO GEOLÓGICO DE CO2
D2.10 BASELINE REPORT
CO2 STORAGE PROJECT

endesa generación
WorleyParsons
Schlumberger Carbon Services

ALMACENAMIENTO GEOLOGICO DE CO2
Compostilla CCS Project – Engineering Services

D2.10
BASELINE REPORT

ENDESA Doc. No:

Prepared by WorleyParsons

The project finalised the Front End Engineering and Design (FEED) for the Duero site in Sahagún, North West of Spain. The main focus since May 2013 has been on completing the FEED, the baseline monitoring and establishing the monitoring risk and management plan.

2.1.1. Monitoring Baseline

The baseline data acquisitions were completed, including thorough gas and fluid sampling and analysis for a solid hydro-geo-chemical baseline. The storage site is on the flank of a synclinal.

Data collection concerned the surface, the vadose zone and the deeper subsurface.

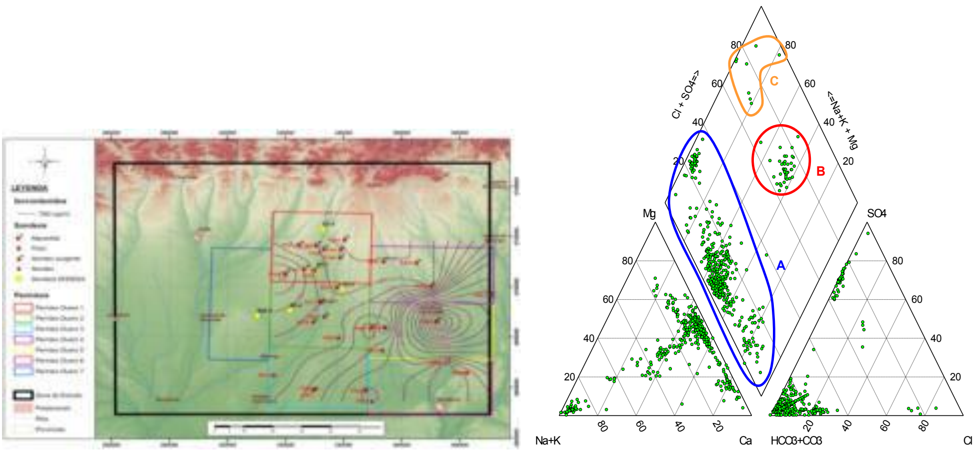


Fig 2.1.1.a. showing a surface mapping and water composition analysis.

In particular:

- Soil CO_2 concentration and flux were measured and mapped;
- Aquifer and superficial water quality and CO_2 levels were measured and mapped.

At all depths CO_2 contents, salinity, carbon ^{13}C and ^{14}C isotopes and anions contents were measured.

In the area, the hydrodynamic flow of dissolved CO_2 from outcropping Palaeozoic formations releases natural CO_2 into the overlaying Cretaceous Utrillas reservoir.

As a consequence, in the targeted Utrillas formation overlaying the Paleozoic, the average measured salinity value for the brine is of 10000 - 20000 ppm while salinity is in the order of 7000 to 8000 ppm in the Paleozoic. In the confining/caprock formation overlaying the Utrillas, salinity values of 47,000 ppm were recorded while values of around 32,000 ppm were recorded in the formation overlaying that confining unit. Thus salinity values in the order of 30,000 to 40,000 ppm are recorded above the targeted reservoir.

The storage complex is a closed reservoir with a fluid content that is millions years old. The chemical composition of the Utrillas reservoir formation and the overlaying Boñar formation shows that there is no connection between the formations.

Water composition was one of the key data analyses to comply with the Spanish laws and regulations.

In the vadose zone and at the surface, strong seasonal variations in CO_2 concentrations are being measured. Experiments to inject anthropogenic CO_2 from the Compostilla oxyfuel plant in the vadose zone will take place at the PISCO2 project test site.

Remote Interferometric Synthetic Aperture Radar (InSAR) data were acquired over the entire storage area to establish a baseline. Artificial amplifiers were installed on land to measure natural subsidence and the effect of wetcrops. Attempts were made to extrapolate the results to simulate the potential effects of a CO_2 release. Further work is planned in collaboration with the USA.

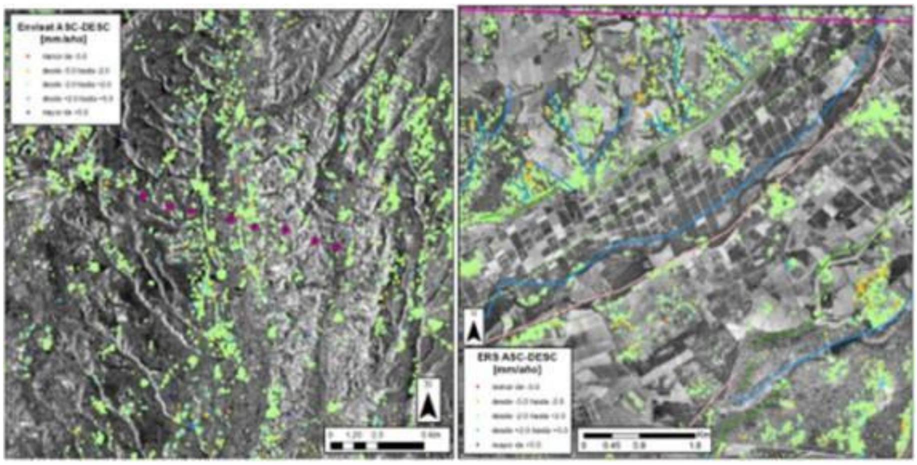
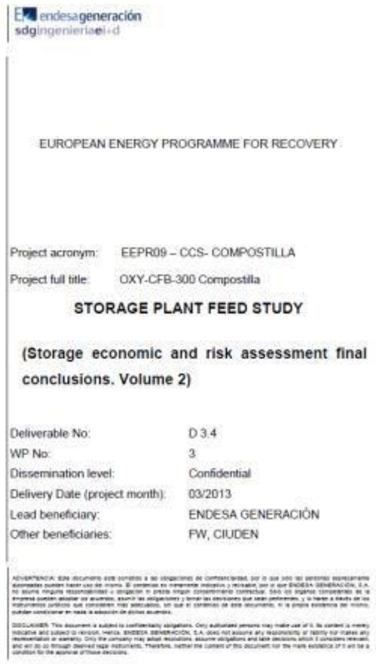


Fig. 2.1.1.b InSAR mapping

Ecological studies were conducted, including inventories of animal and plant species. A Natura2000 protected site (European habitats and Birds Directives) overlaps with the storage site zone.

2.1.2. Monitoring Risk and Management Plan

Risk assessment was performed using the approach recommended by the IEAGHG[2], the European Commission Guidelines[3] on implementation of Directive 2009/31/EC on geological storage of Carbon dioxide and adapted by the United States Department of Energy National Energy Technology Laboratory (NETL)[4].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sdg ingeniería el+d

EUROPEAN ENERGY PROGRAMME FOR RECOVERY

Project acronym: EEPR09 – CCS- COMPOSTILLA
Project full title: OXY-CFB-300 Compostilla

STORAGE PLANT FEED STUDY

(Storage economic and risk assessment final conclusions. Volume 2)

Deliverable No:	D 3.4
WP No:	3
Dissemination level:	Confidential
Delivery Date (project month):	03/2013
Lead beneficiary:	ENDESA GENERACIÓN
Other beneficiaries:	FW, CIUDEN

2.1.3. Economic and risk assessment studies

Estimations of the Capital expenditure and Operational expenditure have been finalised.

The Final Investment Decision (FID) process is now with responsible teams other than the Storage team. It requires establishing a price per MW for the plant (currently ranging from €6 to €7 per kW). With CCS the price would rise to €70 to €90 per kW. Such price level does not allow for entry into the electricity market, especially taking into account that the electricity consumption rates are falling compared to 2005.

FEED was completed with regard to following elements:

- Surface facilities.
- Subsurface: Injection and monitoring.
- Permits and environment.
- Public.

The current exploration licence remains valid for 4 years under current mining law and 6 years under storage law. To maintain it, monitoring activities such as geochemical and micro seismicity measurements need to be performed at site.

The storage licence application is pending and will only be submitted after a positive FID has been taken. Under the Spanish law, the project developer needs to make an upfront payment equivalent

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[2] IEAGHG, *A review of the international state of the art in risk assessment guidelines and proposed terminology for use in CO2 geological storage* http://www.globalccsinstitute.com/publications/review-international-state-art-risk-assessment-guidelines-and-proposed-terminology-use

[3] European Commission, DG Climate, Guidance documents http://ec.europa.eu/clima/policies/lowcarbon/ccs/implementation/documentation_en.htm

[4] NETL, *Risk Analysis and Simulation for Geological storage of CO_2* http://www.netl.doe.gov/File%20Library/Research/Carbon%20Seq/Reference%20Shelf/BPM/BPM_RiskAnalysisSimulation.pdf

to 10 to 20% of the total cost of the project (€100 milion) to the authorities when applying for the storage licence.

2.2. The Compostilla project – Hontomín Technology Development Plant

CIUDEN continued to carry out its plans at the Technology Development Plant. The Spanish government committed to 2 years of operations at Hontomín, thus until the end of 2015. Injection of some 20,000 tonnes of food grade CO_2 should take place in spring 2014. Baseline characterisation and monitoring continues.

The project completed drilling of the injection well and of the monitoring well mid-October 2013. Using a mining rig for the shallow drilling (percussion drilling at a progress rate of 8.5m per day) followed by rotary drilling (inverse & direct circulation, rates up to 70m per day) for the deeper part, allowing to save 60% on drilling cost compared to the original drilling budget with conventional O&G drilling rig (2.5 million euros per well instead of 7 million euros per well). 7m long cores were taken out of both the injection and the monitoring boreholes. The cores correspond to the reservoir limestone rock and the Liassic seal rock. Core are being analysed at present.

Upcoming work:

- Acquire 2 km of ERT and CSEM data in Q4 2013 before year end using 60 electrodes buried at 1 to 1.5 m depth and clipped to existing wells (baseline).
- VSP acquisition end of October 2013 (in the injection well and in a groundwater monitoring well).
- Hydraulic characterisation tests, including the use of tracers is to take place in March 2014.
- Auxiliary civil works will continue until end of December 2013.
- The PISCO2 project located near the Compostilla plant that is a part of the overall Technology Development Plant carries out experiments with soil from the Hontomín injection site.

2.3. Don Valley Power Project – Saline Formation

The Don Valley project planned to capture, transport and store 4.7 Mtpa originally (now adjusted to 2.5 Mtpa in Phase 1 – see section 2.4). The Humber Cluster pipeline to collect the CO_2 and transport it to store offshore is sized at 24 inches diameter – to accommodate 17 Mtpa (which include 2.6 Mtpa from the White Rose project and other emissions capture anticipated in the region). CO_2 emissions from power generation and industrial output in the area are in the order of 60 Mt/year.

2.3.1. Yorkshire & Humber project, UK - Transportation update

The formal consultation process along the proposed onshore pipeline route has been completed.

- Nine consultation events took place attended by around 500 persons;
- There was a range of media coverage - all coverage has been fair with no difficult questions or anti-CCS feeling.

A 1 km wide offshore survey has been conducted along the proposed pipeline route including environmental surveys and side scan sonar. The main queries during the onshore consultation were about:

- Location of the pipeline, including landowner queries mainly on drainage and easement payments;
- Design of the pipeline, installations and the offshore elements;
- Programme timeline.
- Start date of construction and further steps
- Traffic management.
- General questions on safety, without major concerns.

Theoretical and experimental R&D work is well advanced and is due for completion end of 2013. The Environmental Statement is currently being prepared. Offshore geo-technical and geo-physical surveys due to start in November 2013.

2.3.2. Yorkshire & Humber project, UK 5/42 aquifer storage appraisal

The first UK CCS Licence & CO_2 specific appraisal drilling took place in June and July 2013.

"*The goal of the characterization of the storage site and complex is to assess the site's containment, injectivity, capacity, hydrodynamics, and monitorability in order to ensure safe and permanent storage of CO_2*" Source: European Commission Guidance Document.

- The 2 month well operations were conducted with no Lost Time Incidents (LTIs) or environmental harm;
- Targets were met for very extensive data & sample acquisition programme within budget;
- Early indications, pending detailed post well analysis are very encouraging that the store is suitable.

National Grid's ambition is to be a leader in CO_2 transportation for the future CCS industry and attract new participants into CO_2 storage to help grow the CCS industry. National Grid is continuing with development work for the store and aims to use this project to help create a business model that attracts other players.

2.3.3. UK 5/42 aquifer storage appraisal - Location

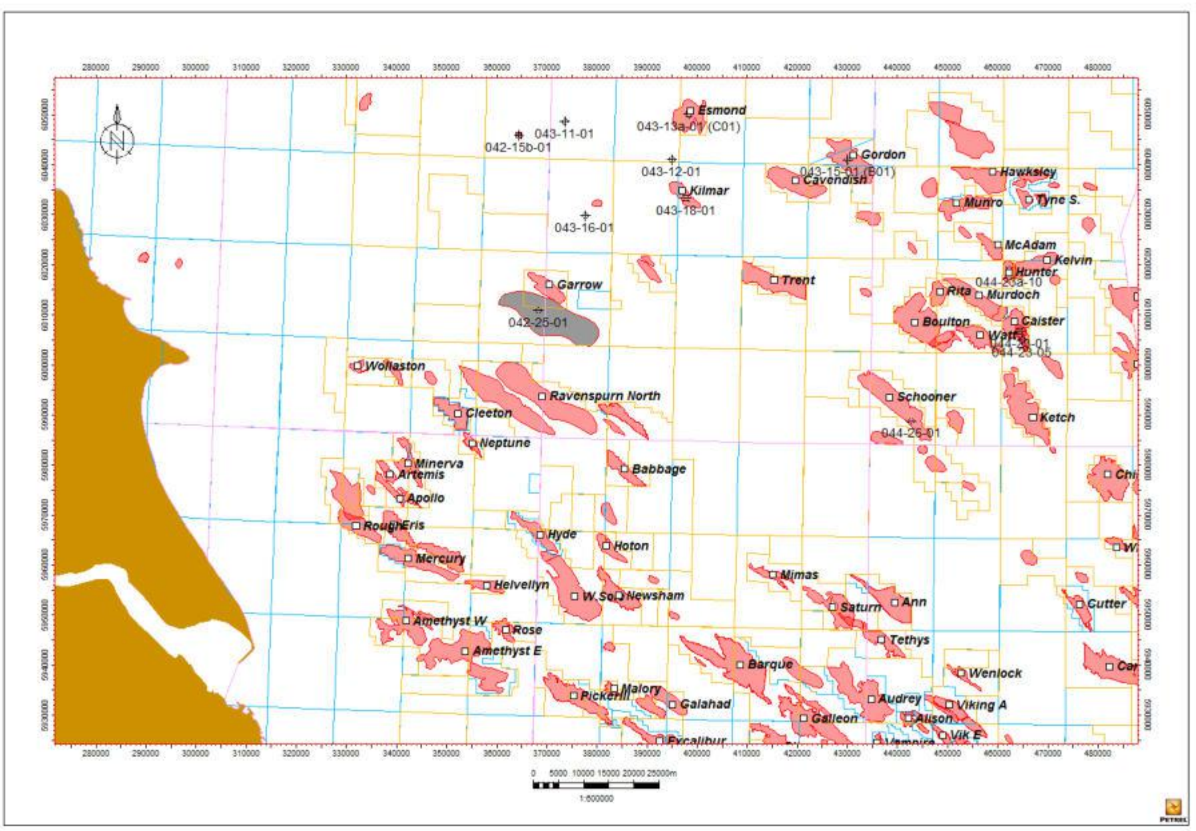


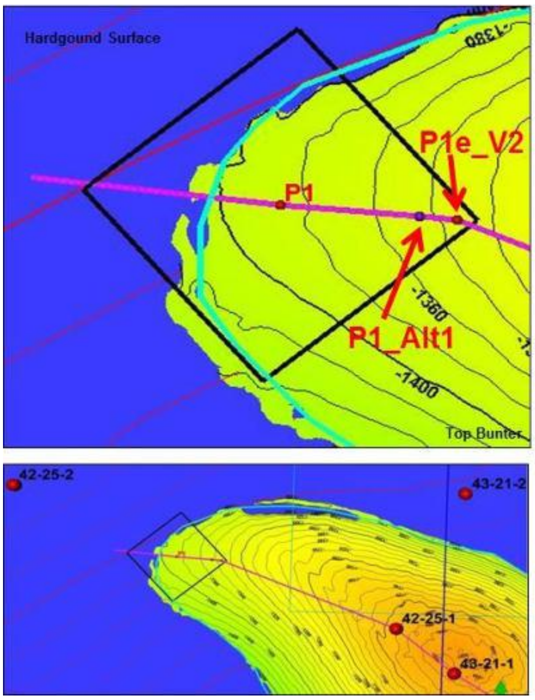
Fig. xx. Location of 5/42 and neighbouring gas fields'

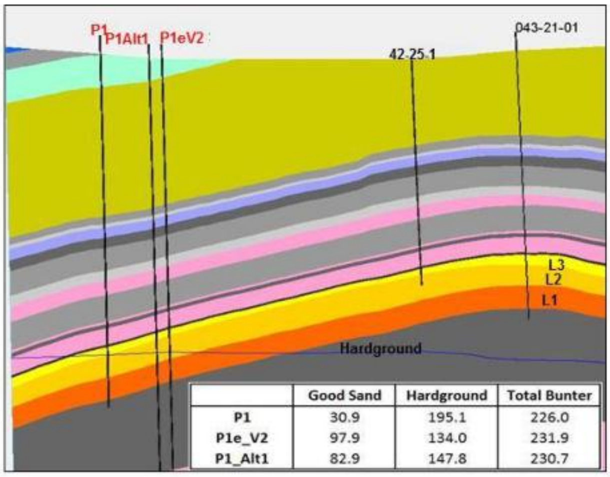
2.3.4. UK 5/42 aquifer storage appraisal - Need to know – pre-drill.

Prior to drilling the project applied a so-called traffic light preliminary evaluation of the data availability and quality; red standing for little knowledge, amber for significant knowledge and green for well understood:

- Containment
  - Seal characteristics, permeability, strength and continuity
  - Faulting
  - Well penetrations
- Capacity
  - Structure
  - Reservoir characterisation (porosity/permeability)
  - Depth
  - Compartmentalisation/connected volumes
- Injectivity
  - Reservoir quality
  - Near well bore effects

2.3.5. UK 5/42 aquifer storage appraisal - Well location





	Good Sand	Hardground	Total Bunter
P1	30.9	195.1	226.0
P1e_V2	97.9	134.0	231.9
P1_Alt1	82.9	147.8	230.7

- Location selected to confirm lateral correlation, depth model and to understand halite distribution
- Moved the location to P1_Alt1 to test a dipping hard-ground model hypothesis

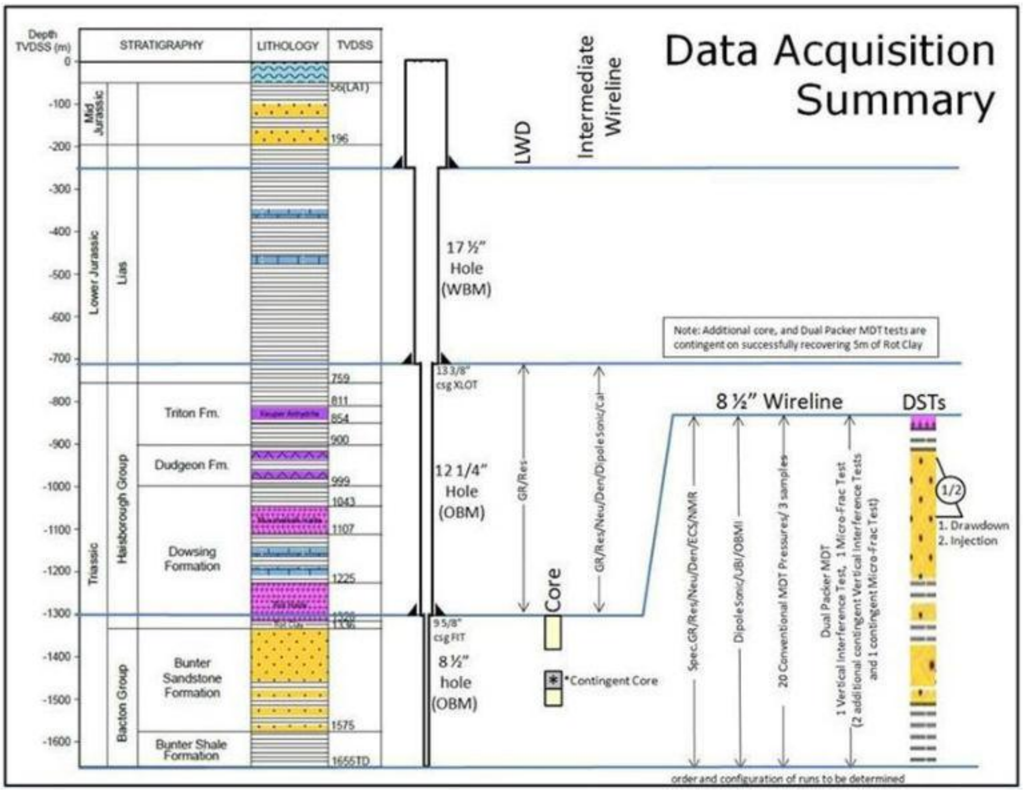
Fig. XX 5/42 appraisal well location (well drilled above the spill point of the structure)

Seismic modelling shows clearly the mapped phase reversal is related to reduction in porosity at top Bunter sandstone - most likely caused by presence of halite cement.

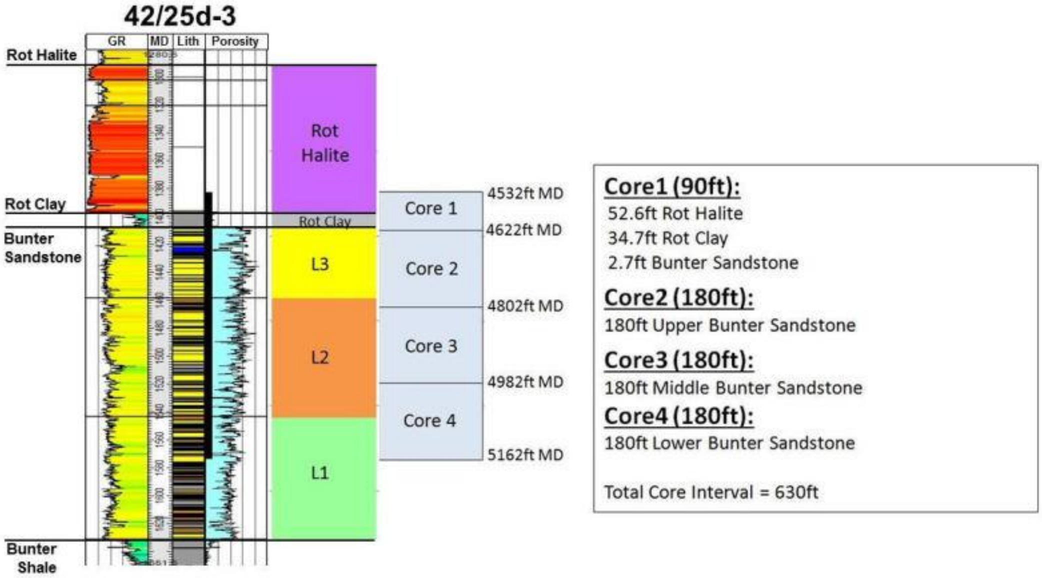
Appraisal well has shown it does not exist as a dipping plane beneath 5/42.

2.3.6. UK 5/42 aquifer storage appraisal - Data acquisition programme

An entire suite of logs was acquired, logging the reservoir and the overburden as shown in the following diagram.



2.3.7. UK 5/42 aquifer storage appraisal - Coring acquisition programme



Thanks to remaining contingency budget, it was possible to acquire more cores than originally planned (a total of 192 m of cores). Cores were taken through the cap rock and approximately 75% of the reservoir section in the Bunter formation with excellent recovery.

2.3.8. UK 5/42 aquifer storage appraisal - Production & Injection Test

A drawdown test was conducted followed by a 48 hour build-up and a multi-rate injection test with a 12 hour shut-in. No barriers were identified within a 1km radius of investigation. Preliminary test analysis shows an average k_h that exceeded pre-drill expectations. Three vertical interference tests were performed which measured k_v/k_h ratios of approximately 10%.

2.3.9. UK 5/42 aquifer storage appraisal - 42/25d-3 - first UKCS CCS appraisal

- Highly successful data acquisition programme;
- All baseline objectives achieved;
- Efficient drilling allowed acquisition of significant additional data.
  - Core total 192m recovered
  - Additional geo-mechanical data acquired in reservoir
  - Additional vertical interference tests (VIT)
- Well drilled, cored, tested & abandoned without incident.

Containment

- Structure confirmed;
- Cap rock cored and geomechanical tests demonstrate very competent and consistent with regional model.

Injectivity

- Reservoir quality confirmed and dynamic properties of reservoir excellent- proven injectivity;
- No evidence of significant halite cement.

Capacity

- Very large structure and good quality reservoir.

Hydrodynamics

- Excellent permeability from logs and test.
- Water samples recovered.

The well was plugged and abandoned using one single long (770ft) Portland Class G cement plug. CO_2 resistant Thermolock cement (Halliburton) was used for cementing the 7" liner to test its practical application but it was found that the setting time was unpredictable.

2.3.10. UK 5/42 aquifer storage appraisal - Post drill status

After drilling, the project applied again the traffic light evaluation (see page 13) of the data availability and quality

- Containment
  - Seal characteristics, permeability, strength and continuity
  - Faulting
  - Well penetrations
- Capacity
  - Structure
  - Reservoir characterisation (porosity/permeability)
  - Depth
  - Compartmentalisation/connected volumes
- Injectivity
  - Reservoir quality
  - Near well bore effects

The well acquired all the expected data and some extra data

- Stratigraphy confirmed;
- Reservoir quality confirmed and in excess of expectations at flank location- no evidence of significant halite cement;
- MDT and DST provide dynamic data and confirm injectivity;
- Vertical and horizontal permeability confirmed (Kv/Kh ~10% from VITs);
- In-situ rock strength tests and injection test confirm the geomechanical model (valid across basin) and show strong caprock;

- Core studies will provide definitive relative permeability and end point data.

The store is suitable

- Reservoir quality is comparable to crestal well 43/21-1 – with some deterioration with depth;
- Structure has a vertical relief of the order of 500 metres;
- In the absence of unforeseen results from post-well analysis a second appraisal well will not be required.

Polarity reversal still to be understood

- No evidence of halite cemented sands (cf. 42/25-2) (well water salinity in the order of 27,000 ppm. A DST investigated the possible presence of a halite wall some 1000m into the reservoir, 3 stages injection over 12 hours: no boundary was detected).
- No evidence for hydrocarbons in any of the three wells now drilled through the structure or from seismic data. Regionally hydrocarbons are only found in the Roetliegend formation.

2.3.11. UK 5/42 aquifer storage appraisal - Forward programme

- Water samples analysed;
- Considerable data being processed (sonic scanner & image logs);
- Core testing now underway but extensive programme could extend through to next autumn;
  - Conventional core analysis complete Q2 '14
  - Geomechanical testing complete end Q3 '14
  - SCAL complete approximately end of Q3 '14;
  - Special study to investigate halite precipitation complete Q4 '14;
  - Static and dynamic reservoir models will be rebuilt as experimental data becomes available.

Coupled reservoir simulation model will be rebuilt and calibrated with all available geo-mechanical data from core, tests and logs.

2.3.12. UK 5/42 aquifer storage appraisal - Post well analysis

Conventional core analysis has a test cleaning programme designed initially to understand the presence of halite.

- Permeability and entry pressure measurements on the cap rock with CO_2;
- SCAL core flooding with CO_2 and formation brine to get relative permeability, end points, etc. extensive programme to characterise the Bunter for use in reservoir simulation model;
- Special study using core flooding to evaluate the near well bore dry out and impact on permeability;
- Extensive geomechanical testing on cap rock and reservoir interval.

It is considered, based on early results, that at least 100Mt of CO_2 could be injected without pressure relief. Based on this initial post-appraisal assessment, with capture from each of the White Rose and Don Valley projects being approximately 2.5 Mt/yr, many years of production data would have been collected before any pressure relief would be envisaged.

2.4. Don Valley – CO_2 EOR

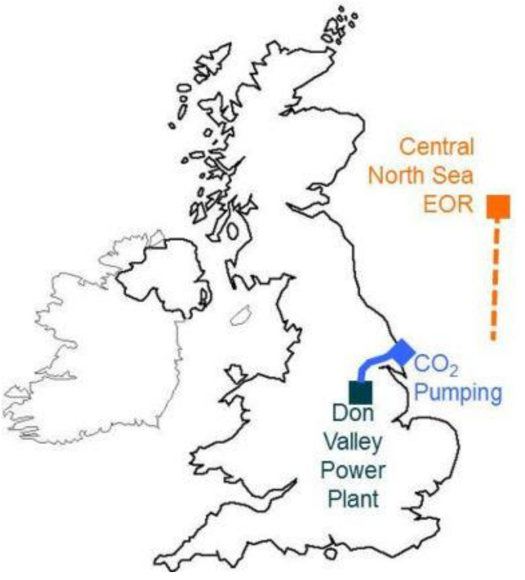
2.4.1. Project Status

- De-selection from UK competition has led to a 2-year delay – FID is now expected end of 2015 with commissioning late 2018.
- The project is being restructured so that it is financeable without capital grant from the current UK CCS Commercialisation competition.
- Inclusion of CCS on gas been recognised as an option for Don Valley Power Plant (DVPP) by both DG ENER and DECC. Technology provider and phasing of trains to be decided.
- NGC permitting of CO_2 pipeline and appraisal of 5/42 saline storage site continues.

2.4.2. Restructured Project Status

Don Valley Power Plant:

- Plant design with two trains of 450 MWe gross, each producing 2.5 million tonnes per year of CO_2;
- Construction phased to make financing possible;
- Investment decision timed to allow access to power price premium under UK Energy Market Reform.



Pipeline:

- New CO_2 pipeline constructed by National Grid Carbon between DVPP and initial storage site;
- Approximately 200km long;
- Offshore hub for future connections to EOR.

Initial Storage:

- Saline formation;
- Developed by National Grid Carbon;

- Synergy with other Yorkshire projects such as White Rose.

Ultimate Storage:

- EOR to be developed when more certainty on sufficient quantities of CO_2 available. Several fields in the North Sea have EOR potential;
- One train of DVPP is insufficient CO_2 volume for full-scale EOR.

2.4.3. EOR storage in the Restructured Project

- 2.5 Mtpa CO_2 supply from Don Valley Phase 1 would be insufficient for a full-scale EOR project of the type previously planned, so the base case for storage is now the 5/42 deep saline formation site.
- EOR storage of the smaller CO_2 supply could be enabled by:
  - Combining the Don Valley supply with CO_2 from another source.
  - Development of an EOR project matched to a smaller CO_2 supply – reduced capex, no new platform, extensive re-use of facilities and wells.
  - Longer timeframe to develop options.
- An initial CO_2 supply with saline storage offers advantages for later EOR developments:
  - CO_2 supply de-risked before substantial capital commitment to EOR.
  - Potential to divert CO_2 from the saline store to short-term injection tests of pilot developments (field satellites?) – this would probably require shipping capability.
  - Alternative storage to cover long-term outage of EOR storage.
  - 'Buffer storage' of CO_2 used later for EOR.
- However, later EOR development would have to balance additional costs for saline storage against reduced risk.

2.5. The ROAD project

From technical point of view, the project is in 'slow mode'. The project has been granted its storage permit, which is irrevocable. The application was filed in 2010 and the process took 3 years due to the time required to implement the CCS directive in Dutch law and the need to obtain the transport and storage permits in a package. The process of obtaining permit for transport slowed down the permit for the project. Finally, the decision was made that the storage element could be granted the permit separately. Injection could start in 2018 or before. It would take 8 years to fill the P18 reservoir, equivalent to 8 Mt of CO_2. The new power plant on the back of which the ROAD project will capture the CO_2 is being commissioned. The local community is supportive. The Dutch government is in favour of the project but has limited additional funding. It is trying to change the current grant agreement. Many efforts have been deployed at European level but the project stayed in slow mode for 18 months. Currently there is a considerable funding gap. The project received €180 million from the European Energy Programme for Recovery (EEPR), €150 million from the Dutch government. The challenge is that the electricity market is changing and the EUAs price is not increasing to the levels of €20 or €30 per tonne of CO_2 anticipated at the inception of the project.

2.6. Sleipner project

A special session was dedicated to the project operations (see Chapter 7 on Sleipner Operations). Operations continue since 1996 with demonstration of safe storage. Statoil is conducting a full storage system review.

2.7. Concluding remarks

- One of the major highlights of this knowledge sharing session on storage progress was the successful drilling, coring and testing of the offshore appraisal well by National Grid (Don Valley project).
- The Compostilla project has completed its FEED study. All elements have been presented to the decision-makers to take the FID.
- It is also positive news that Hontomín manages to progress as planned despite the major restructuring it went through after the change of government in Spain.
- Although the ROAD project is in a slow mode for 18 months, the storage permit has been granted. The project can start construction as soon as sufficient funding is secured.
- Don Valley CO_2 EOR has managed to maintain the project and to progress despite a major restructuring.
- And while it is taken for granted that operations at Sleipner continue smoothly, Statoil continues to successfully demonstrate storage and actively engage with R&D projects, institutions as well as with all active NGOs.

3. Validation, Verification and Certification of CO_2 geological storage sites and projects - Providing assurance to stakeholders

DNV representative accepted the invitation of the Network Storage group to present some of the recent work undertaken and tested on a number of international projects. DNV is an independent party that supports projects with demonstration and communication of compliance with regulations and industry best practice, publishing standards that ensure robust decision-making and credible verification of CCS projects.

3.1. Validation, Verification and Certification - What's the difference?

DNV's presentation started with the definition of the terminology

Validation:

The assurance that a product, service, or system meets the needs of the customer and other identified stakeholders.

- Does the site have the key characteristics of a suitable storage site?
- Is the project designed to meet the desired objectives/success criteria?

Verification:

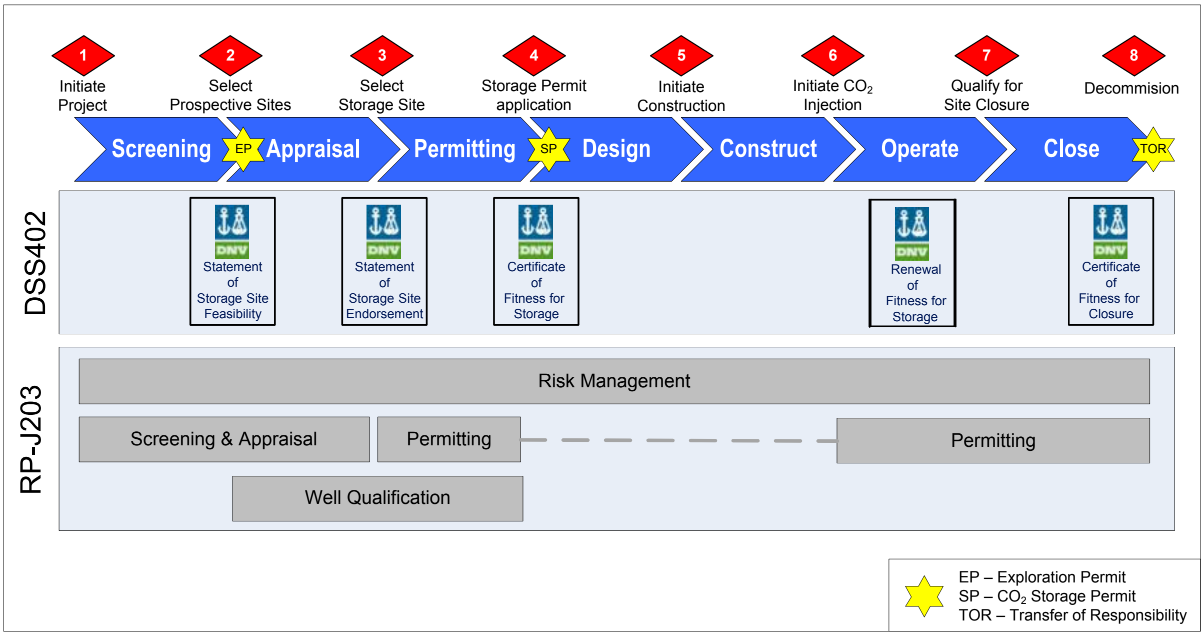
Evaluation of whether or not a product, service, or system complies with a regulation, requirement, specification, or imposed condition.

- Is the site/project in compliance with a defined set of requirements?

Certification:

Verification based on a pre-defined scope by a certification body.

3.2. DNV certification of CO_2 geological storage sites



DNV certificates:

- Statement of Feasibility
- Statement of Endorsement
- Certificate of Conformity (Fitness for Storage)
- Certificate of Conformity (Fitness for Closure)

3.3. DNV validation or verification of CO_2 storage projects

- Independent review of storage component of QUEST project in Alberta, Canada (2010)
- Independent review of ZeroGen project in Queensland, Australia (2010).
- Validation of Storage Development Plan for QUEST project (2011).
- Certification of feasibility of portfolio of candidate storage sites for the CarbonNet project in Victoria, Australia (2012).
- Independent review of Gorgon CO_2 injection project (2013).
- Confidential project (2013): Scoping of project to verify readiness for site closure.

3.4. QUEST CCS Project

- Joint venture by Shell, Chevron and Marathon Oil.
- Northeast of Edmonton.
- Capture of ~1 Mt CO_2 annually from 3 hydrogen manufacturing units.
- CO_2 transport by pipeline (< 100 km).
- Injection into a 2000 m deep saline formation.
- Injection to start in 2015.

Validation of Storage Development Plan for QUEST:

The QUEST Storage Development Plan (SDP) is suited to establish and maintain confidence in the following metrics:

- Injectivity and capacity are sufficient and the injection and operating plans are suitable to meet the project's system capacity objectives;
- The storage site will provide containment;
- Relevant risk scenarios are comprehensively assessed and documented and plans are in place to ensure that risk is appropriately managed;
- The MMV plan is fit-for-purpose to demonstrate containment; and
- The MMV plan is fit-for-purpose to demonstrate conformance.

Containment - Stored volumes of CO_2 and formation fluids from the BCS will be contained within the QUEST storage complex.

Conformance - Actual storage performance will conform to predicted performance within range of uncertainty (based on predictive modelling).

Statement ("Certificate") of fitness for purpose of the QUEST SDP accompanied by five tables, one for each metric.

Fit for Purpose Statement:

The Panel agreed that they will have confidence in all metrics when significant actions are implemented. There is no obligation for operator to implement recommended actions. Additional scrutiny may be applied to significant recommendations if "Certificate" is used in external communication.

A decision to not address a significant recommendation may impose a burden on the operator to justify that decision.

Shell's reasons for seeking and independent validation by DNV

- Public support (local to storage) for CCS has been challenging in early demo projects, and was identified early as key for QUEST.
- The storage area communities need Shell to answer the simple question 'Is it safe?'
- DNV secured a world class panel of leading academics in fields relating to CCS, thus providing a level of technical assurance greater than that Shell could do themselves.
- A DNV 'safe storage' certificate would therefore help both external public acceptance and internal technical assurance".

3.5. The CarbonNet Project

The project was led by the Department of Primary Industries for and on behalf of the State of Victoria.

- Screening studies were carried out in the Gippsland basin.
- Numerous oil and gas plays.
- 60+ Mt CO_2 emissions per annum from coal fired power plants in the Latrobe Valley.
- An assessment permit was granted in 2012 but does not cover the whole screening area.

Certification of feasibility for portfolio of candidate storage sites for CarbonNet project:

- Three candidate sites were evaluated relative to requirements in Section 4.2 of the DNV-RP-J203 – Geological Storage of Carbon Dioxide.
- Requirement to define Screening Basis:
  "List of requirements that candidate sites should fulfil in order to be regarded as prospective and qualify for further appraisal."
- DNV concluded that:
  - The Screening Basis was appropriate for the CarbonNet project; and;
  - Sufficient data was gathered to enable a feasibility evaluation for the respective sites against these criteria;
  - The portfolio of candidate storage sites fulfilled the requirements for a statement of feasibility.

Screening criteria (Titles)
Capacity
Injectivity
Injection depth
Primary seal
Well records
Natural seismicity
Faults and flow-paths
Access
Proximity to CO_2 sources
CO_2 mass rate
CO_2 composition
Lifetime of CO_2 sources
Natural Environment
Other uses of the subsurface
Land Use
Protected and Sensitive Areas
Drinking Water Sources
Social and Cultural Context
Legal and Regulatory Environment
Expectations of Operator, Regulators and Stakeholders

This implies that at least one of the sites, or a particular combination of the sites, qualify for a "Statement of Feasibility" in accordance with DNV-RP-J203 and the corresponding DNV Service Specification DNV-DSS-402.

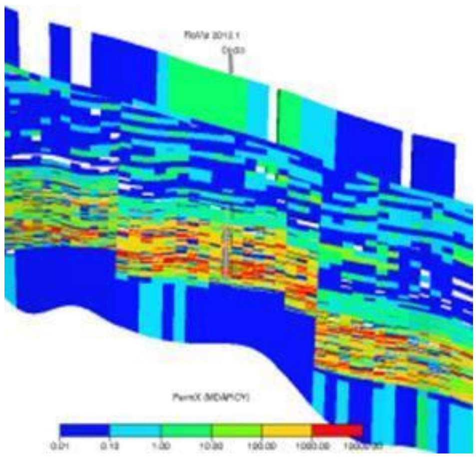
4. Thematic session: Well injection

This workshop was designed as an interactive session based on a presentation of the well design and completion by the Compostilla project.

4.1. Reservoir Performance

Full modelling results:

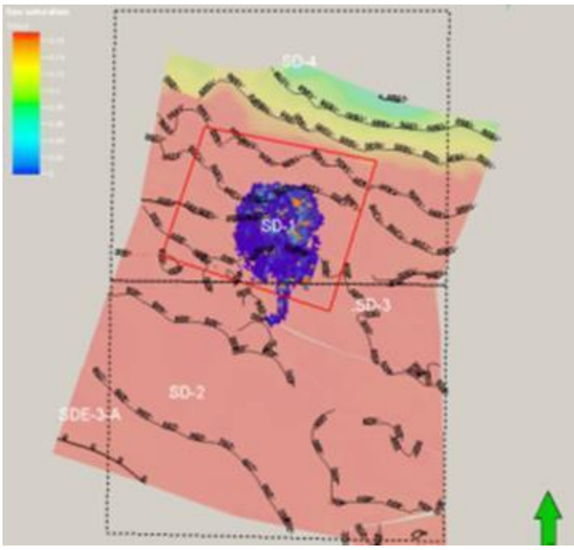
- Capacity, Injectivity and containment;
- Plume extension;
- Several scenarios definition from base case to worst case;
- Risk Analysis.



Injection Strategy

- Injection target: 1.4 Mt/year during 30 years, which corresponds to a cumulative injection of 42 Mt.

- 2+ 1 injection wells.
- 35 – 23 kg/s injection rate.
- Injection tubing -> 5'' or 5.5'' to increase WHT increase to 29ºC.



4.2. Injection

Injection Specification

- Well Type: 3 Vertical wells
- Injection parameters:
    - Max rate 35 kg/sec;
    - Average rate 23.3 kg/sec;
    - On time: expected 64% (5606 operating hours / year). Possibility of 100% (8760 operating hours/year);
    - Max BHP at 90% frac gradient;
    - Target injection life: 30 years (+10 years optional).
- Completion:
    - Perforate across the Utrillas formation;
    - Tubing size: 5 ½ inch OD based on apparent critical erosion fluid velocity in tubing;
    - Packer;
    - SSSV;
    - BPV;
    - Specs: tubing & completion fluids should accommodate instant flashing / blowdown of the well expect -40 °C possible for top tubing parts + wellhead.
    - Monitoring sensors: DTS + downhole P, T measurements.
    - Metallurgy & Elastomers: compatible with CO_2 injection (notably, 25Cr steel is recommended for all parts exposed to CO_2). Details of materials to be defined in detailed (FEED) design.

Team members and expertise required for this work:

Subsurface:

- Geologist; Hydrogeologist; Reservoir, drilling, completion; civil engineering expertise.

Surface:

- Geologist; Hydrogeologist; Environmental Specialist; Biologist; Lawyers; Permits, Civil Engineering, Mechanical; Electrical, I&C Engineering expertise.

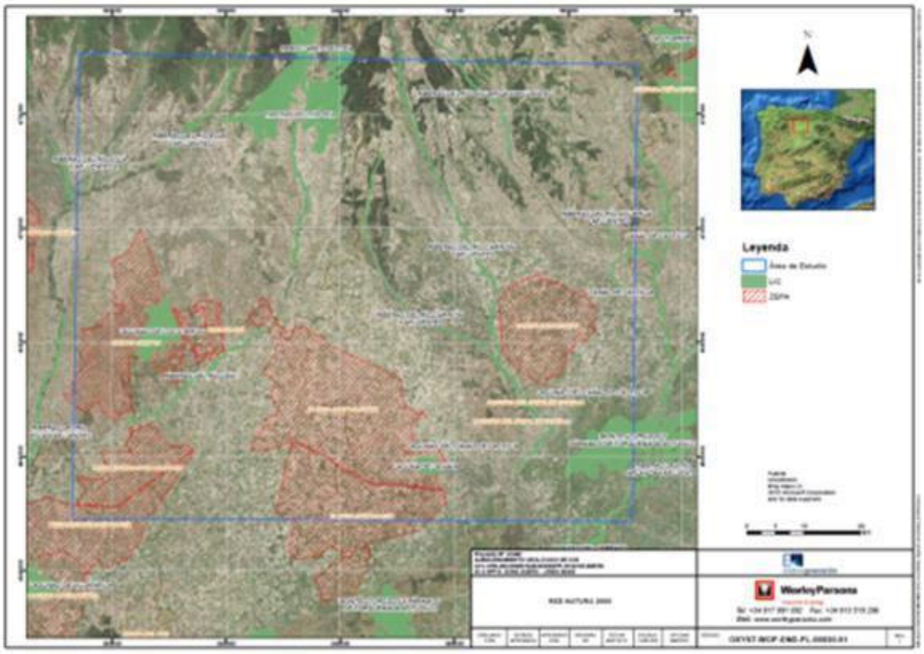
Transport:

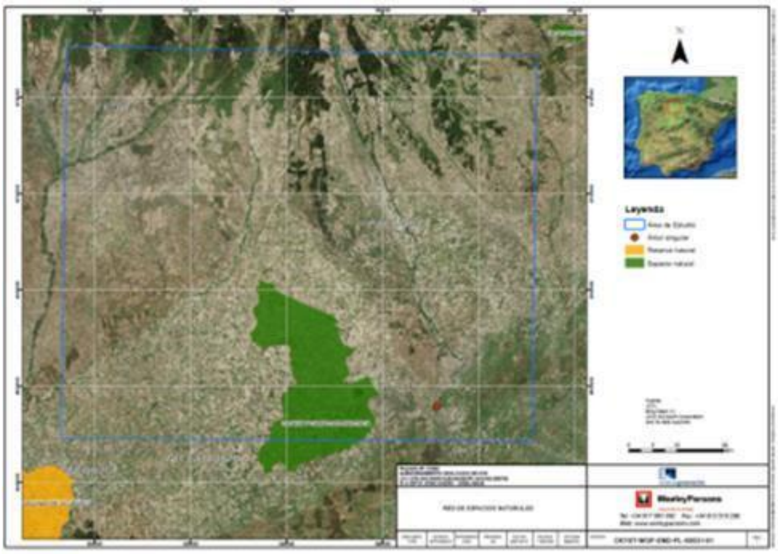
- Specialist Engineering; Civil work.

Injection strategy: engineering design

Working teams defined a criteria sheet including the below elements to select the most suitable sites for injection wells:

- Environmental constraints
- Natura2000 sites
- Birds protection areas
- Population and local economic aspects.
- Civil engineering constraints
- Connection to power grid -> 110 kW.





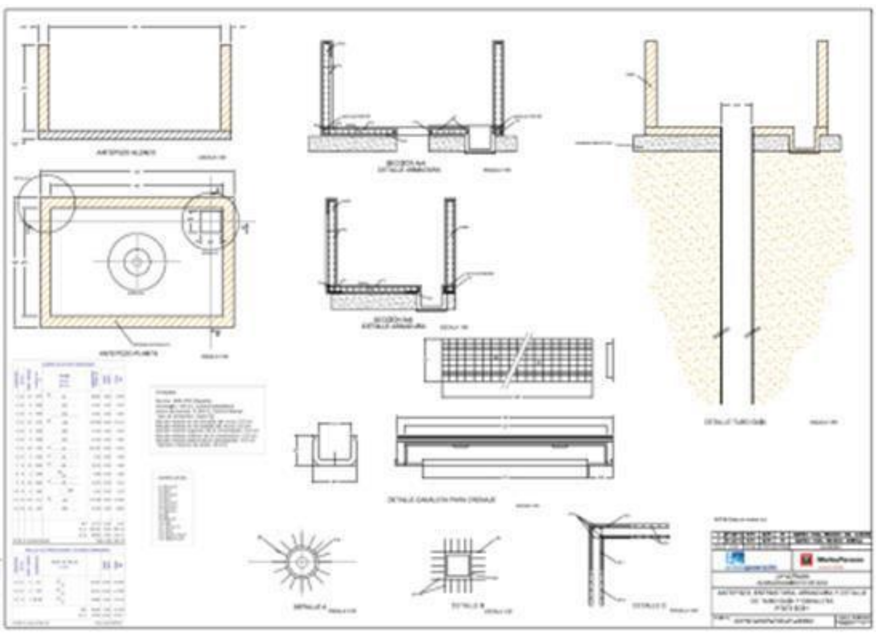
- **Criteria for defining the locations of injection wells**:
    - Proximity to the appraisal wells
    - Distance to the faults
    - Distance to fresh water zones and 800 mTVD contour depth of the top Boñar
    - Geological constraints: some technologies may not reach detectability depending, for example, on the porosity, permeability or depth of the reservoir. This has been addressed through the monitoring feasibility study
    - Risk related to CO_2 injection
    - Costs as a major factor to take into account; careful cost and benefit analysis has to be performed for each monitoring technology.
    - Public perception and confidence.
- **Selection scenarios**.
    - Three potential scenarios were selected.

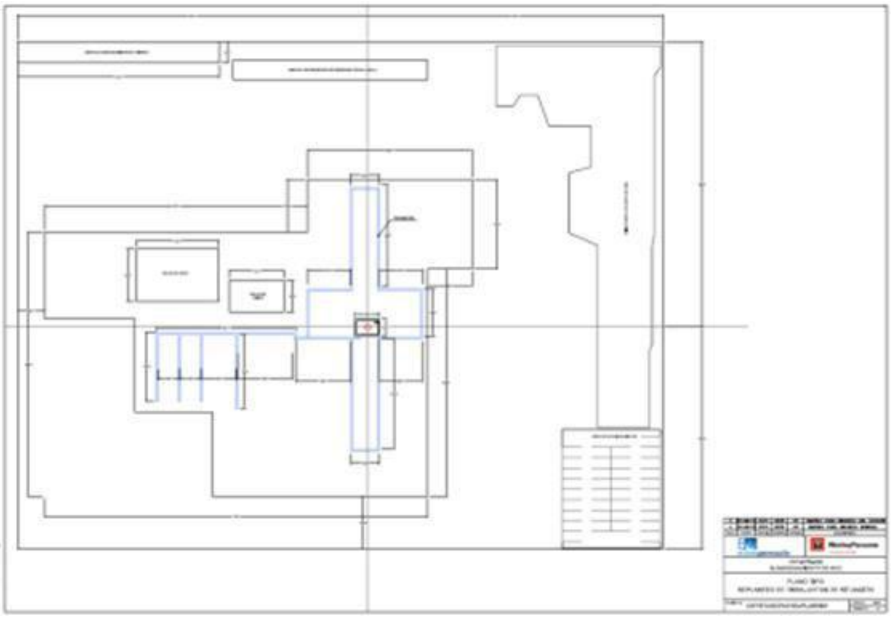
    - Reservoir performance: Full model run for selected scenarios.
    - Case base definition and worst case.

- Injection parameters verifications:
- Three scenarios were defined. Three different sites for the injection well locations.
- Well injectivity is not constrained by the reservoir, it is constrained by tubing deliverability.
- Average rate 23.3 kg/sec.
- On time: expected 64% (5606 operating hours / year). Possibility of 100% (8760 operating hours/year).
- Max BHP at 90% frac gradient.
- Target injection life: 30 years (+10 years optional).
- Risk analysis verification
- Monitoring plan definition for selected locations.

4.3. Injection strategy: FEED

- **Surface.**
    - Environmental study for :
        - Storage complex defined.
        - Each injection well
        - Each monitoring well.
        - >= 800 mTD.
    - Public perception and communication plans
    - Civil works engineering
    - Mechanical, electrical, I&C engineering tasks
    - Administrative permits. Not submitted -> FID.



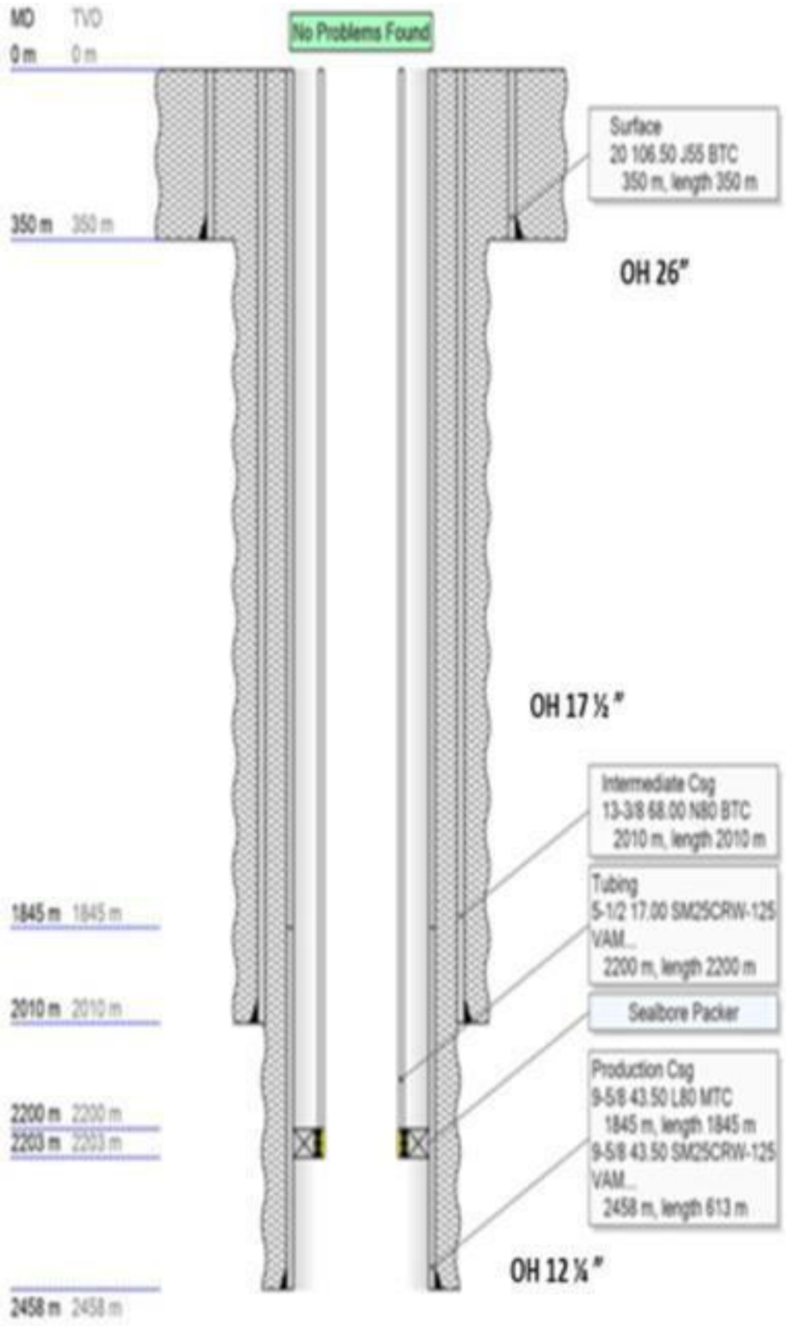


- **Subsurface**
  - Conceptual design of injector wells:
    - Max rate 35 kg/sec
    - Average rate 23.3 kg/sec
    - On time: expected 64% (5606 operating hours / year). Possibility of 100% (8760 operating hours/year)
    - Max BHP at 90% frac gradient
    - Target injection life: 30 years (+10 years optional)
    - 9 5/8 inch Cr25 casing for the bottom 600m of the well, across the Utrillas formation
    - 5½ inch Cr25 tubing, appurtenances and elastomers suitable for CO_2 injection service
  - Offset data analysis.
  - Drilling hazards:
    - Drilling problems
    - Pore pressure profile
    - Fracture pressure profile
    - Drilling and geological risks

- **Injection wells design**
  - Casing design and hole size :
    - 20” into a good claystone – sand with good consolidation. J55 BTC
    - 13 3/8” at the base of caprock. N80 BTC
    - 9 5/8”, main objective isolate reservoir formation, and drill ± 40m into Paleozoic. L80 MTC
    - The last 600m of 9 5/8 will be special steel, SM25CRW duplex stainless steel material, where the main objective will be to prevent CO_2 corrosion effects. SM25CRW – 125 VAM – TOP FE.

- The casing setting depth will be adjusted according the actual geology encountered

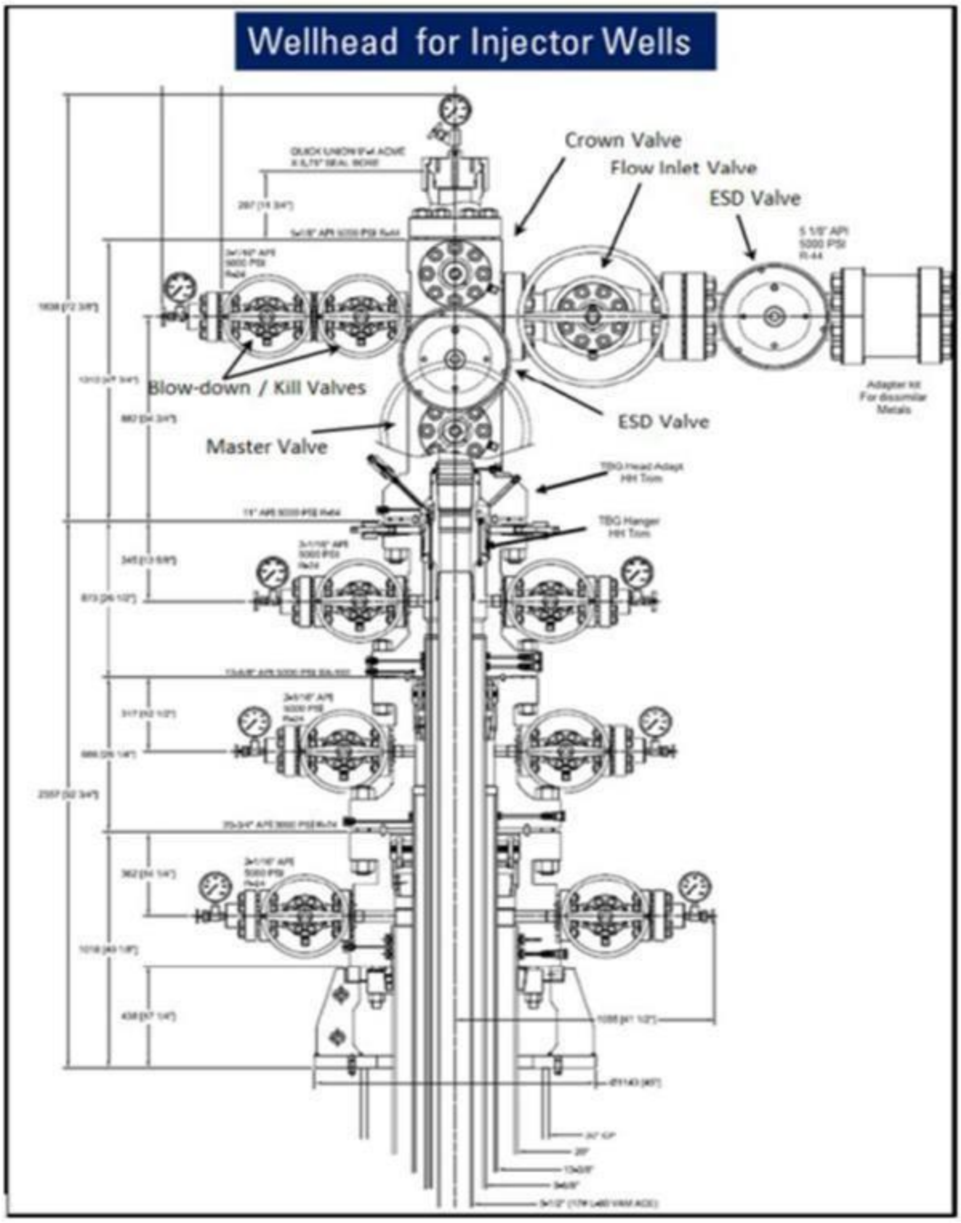
- The SM25CRW section will have a premium gas tight connection such as the VAM TOP FE.
- The 5 ½ Tubing will be designed with SM25CRW considering the effect of the CO_2 injection.
- The injection tubing will have a premium connection such as VAM TOP FE or equivalent such as in the marketplace at the time of drilling.
- Metallurgy is based on flow stream constituents provided by Endesa.



- Directional drilling:
  - MWD/LWD is considered for first well.

- Anti-collision plan is defined
- Torque/Drag Analysis has been performed
- Generic assemblies for 26” BHA, 17 ½” BHA, 121/4” BHA
- Technical specifications and requirements
- Drilling fluids:
  - 20” CSG -> Gel mud
  - 13 5/8” CSG -> KCl Glicol mud.
  - 9 5/8” CSG -> Biopolymer mud; KCl. Completion KCL – Brine.
- Well control.

- **Injection wells design**.
  - Well head:
    - Blowdown.
    - Kill
    - ESD Valve X “.
    - Master valve.
  - Open hole logging - Program defined.
  - Well testing:
  - Brine Sampling: performed with Wireline tester and slick line (before injectivity testing).
  - Injectivity test in the reservoir: brine or CO_2 injection test across Utrillas.
  - Leak-off tests: Extended leak-off in cap rock and below the intermediate section shoe.
  - Mini-frac test (for in-situ stress determination): not included, but feasibility to be verified in 12 ¼” hole for Utrillas and Boñar formations.
  - Data transmission:
  - DTS and Downhole P/T gauges.
  - Permanent monitoring of Tubing and Annulus pressures (Injectors)



4.4. Completion design

- Goal:
  - Provide for the safe and economic injection of CO_2
  - Maintain simplicity of installation and operation
  - Reliable design to afford required longevity and minimize total life of well costs
  - Selectively measure or control in real time the pressure and temperature as CO_2 is injected into the reservoir
  - Minimize intervention
  - Maintain an adequate means of isolation between reservoir zones, bore hole and cased hole
  - Minimize risk of CO_2 leaking

        - Reduce risk associated with using material; tubular, surface equipment, or completion supplements that is not proper for CO_2 Injection
    - Supporting data:
        - Temperature profile.
        - Pore pressure.
        - Initial injection strategy: Vertical flow modelling.
            - Two Injection rates (23 kg/s and 35 kg/s) were investigated for steady state, shut-in and restart with the transient simulations.
    - Conceptual design:
            - Injectors will require a 5 ½" tubing based on apparent critical erosion fluid velocity.
- **Completion design**.
        - Injectors will require a 5 ½" tubing based on apparent critical erosion fluid velocity.
        - 9 5/8" production casing. Completions will include the following:
            - Perforate across the Utrillas formation: zones and length to be defined after drilling and log evaluation to achieve completion capacity of 8000 md-m.
            - Tubing size: 5 ½ inch OD based on apparent critical erosion fluid velocity in tubing
            - Packer
            - SSSV
            - Monitoring sensors: DTS + downhole P, T measurements
            - Downhole Chemical Injection.
            - Cements: G, LiteCrete & EverCrete.

4.5. Technical and Regulatory Guidance Documents

List of relevant guidance documents:

- European Commission, Directive 2009/31/EC on geological storage of carbon dioxide.
- Gobierno de España, Ministerio de medio ambiente, rural y marino. Ley 40/2010, de 29 de diciembre, de almacenamiento geológico de dióxido de carbono, December 2010.
- European Commission, DG CLIMA. Guidance Document 1 - CO_2 storage life cycle Risk management framework.
- IEAGHG, A Review of the International State of the Art of Risk Assessment Guidelines and proposed terminology for use in CO_2 Geological Storage. IEA environmental Projects Ltd, 2009. p. 79.
- Det Norske Veritas (DNV), CO_2QUALSTORE Guidelines. 2010.
- NETL, Risk Analysis and Simulation for Geological storage of CO_2 - DOE/NETL-2011/1459.
- Thiercelin M.J et al. Cement Design Based on Cement Mechanical Response. 1997. SPE 38598.
- Barlet-Gouédard, Mitigation Strategies of CO_2 Migration through Wellbores. SPE 98924.
- Schlumberger, Guidelines for corrosion management in CO_2 injector wells.

4.6. Monitoring

Monitoring in Injection Wells. Real Time Monitoring and Modeling.

- As per legal requirements, monitoring in injection wells should include:
    - Fugitive emissions of CO_2 at the injection facility;
    - CO_2 volumetric flow at injection wellheads;
    - CO_2 pressure and temperature at injection wellheads (to determine mass flow);
    - Chemical analysis of the injected material;
    - Reservoir temperature and pressure (to determine CO_2 phase behaviour and state).
- As a consequence,
    - A moisture and gas composition analysis devices will be present at the beginning of the pipeline;
    - A leak detection system will be installed at the injection sites.

- The acquisition of new monitoring data will trigger a better understanding of the subsurface, and of its behaviour related to CO_2 injection. These data need to be used regularly to update the available modelling:
    - Static model.
    - Dynamic model.
    - Geomechanical model.
- Many monitoring data are acquired continuously in real-time monitoring:
    - Temperature/pressure measurements at well head, and downhole;
    - Flow rate;
    - Annular pressure;
    - H_2O, CO, CO_2, H_2S content of the injected fluid.
- A Supervisory Control and Data Acquisition (SCADA) system will be used to analyse these data in real time. Thresholds are defined to distinguish between expected and abnormal behaviour. These thresholds should be used to generate appropriate alarms when required. These data should also be screened regularly by an expert, to check for abnormal behaviour that could not have been identified automatically.

Other goals

Geological / Reservoir Goals

- Confirm stratigraphic information: Stratigraphy (see prognosis below) is well constrained by the presence of offset well SD-1 and the acquisition of a 3D seismic survey over the area, but local variations in lithology may impact formation thickness here.
- Confirm porosity and permeability estimates of Utrillas formation to validate property model and define suitable intervals for perforation.
- Confirm estimate of pore pressure, fracture pressure and temperature gradient to validate dynamic model.
- Confirm properties of overlying formations: notably porosity, permeability and natural fracturing in Boñar carbonates, Garumn claystone and Tertiary claystone).

- Confirm well injection potential: quantify injectivity, determine and remediate initial formation damage, if any.

5. CO_2 Storage, CCS and Communication

The Regulatory Development group joined this session of the Storage group which allowed for a broader discussion on CCS and communication, looking at ways to improve the interface between the project CCS experts and the general public and at communicating about the project by public relations specialist.

Five short presentations were given followed by a group discussion and brief CO_2 storage communication demonstration.

5.1. Summary of the last Network Communication Workshop in May

Representative of the Global CCS Institute gave a summary of the Communication and Engagement workshop held on the 22nd of May 2013, back-to-back with the knowledge sharing event in Doncaster.

The workshop brought together international experts that were interviewed for the report supported by the Institute on managing risk and maintaining the trust of stakeholders[5].

The report author and the panellists reflected on the findings of the report and their experiences of communicating and engaging on CCS, then went on to discuss - from a project proponent's point of view - the key communication and engagement issues facing the deployment of CCS. The discussion was focused on European context - recognising that the communication and public engagement issues are somewhat challenging in this region.

- Workshop follow up:
  - The Global Status of CCS 2013[6] report featured all of these key issues in the Public Engagement chapter along with features on a number of initiatives attempting to improve practices.
  - A number of best practice reports and social research findings have been published to help address some of the challenges identified in this session:
    - Social site characterisation and stakeholder management (see 5.3)[7]

[5] Global CCS Institute, *Communications for carbon capture and storage: identifying the benefits, managing risk and maintaining the trust of stakeholders* http://www.globalccsinstitute.com/publications/communications-carbon-capture-and-storage-identifying-benefits-managing-risk-and

[6] Global CCs Institute, *The Global Status of CCS: 2013*, http://www.globalccsinstitute.com/publications/global-status-ccs-2013

[7] Global CCS Institute, *Social site characterisation & stakeholder engagement* http://decarboni.se/sites/default/files/publications/119186/social-site-characterisation-stakeholder-engagement.pdf

- CCS social research[8]
- Communications for carbon capture and storage[9]
- Weyburn-Midale CO_2 Monitoring and Storage Project and the technical best practice manual[10]

- The Institute has published a full suite of infographics and education resources that are free to download from the Institute website. The use of the materials requires a reference the Institute.

A video summary of the Communication and Engagement workshop is available on YouTube[11]

[8] Global CCS Institute, CSIRO, *Synthesis of CCS social research: Reflections and current state of play in 2013* *http://www.globalccsinstitute.com/publications/synthesis-ccs-social-research-reflections-and-current-state-play-2013*

[9] Global CCS Institute, *Communications for carbon capture and storage: identifying the benefits, managing risk and maintaining the trust of stakeholders* http://www.globalccsinstitute.com/publications/communications-carbon-capture-and-storage-identifying-benefits-managing-risk-and

[10] The IEAGHG Weyburn-Midale CO_2 Monitoring and Storage Project http://ptrc.ca/projects/weyburn-midale
[11] http://www.youtube.com/watch?v=r8P_ssf2OW0

5.2. Statoil and the FP7 ECO_2 project - dealing with leakage allegations from a technical and public communications perspective

Representative of Statoil (Sleipner) introduced ECO_2 an FP7 R&D project, which assesses the likelihood of detecting CO_2 leakage and its potential effects on benthic organisms and marine ecosystems.

ECO_2 studies the sedimentary cover at active and potential CO_2 storage sites (Sleipner, Snøhvit, B3 field) using novel geophysical baseline studies, monitoring and modelling techniques.

In 2011 and 2012 the research expeditions in the North Sea, in the region of the Utsira CO_2 storage formation (Sleipner) used new Autonomous Underwater Vehicle (AUV)-technology to detect gas seeps at seafloor. Numerous microsensor and optode profiles, benthic chamber and pore fluid measurements were conducted to determine the fluid flow and the fluxes of oxygen, nutrients, dissolved inorganic carbon and dissolved trace metals across the sediment-water interface.

In the region many so called ‘seismic chimneys’ type vertical features can be detected on the seismic data cross-sections as well as numerous seafloor pockmarks. 25 km north of the Sleipner area, what appears as a ‘fracture’ like feature on the acquired seafloor data was detected in 2011. The 2012 expedition went back to that feature using a high-resolution synthetic aperture sonar (HiSAS) mounted on the AUV Hugin as well as a photo camera for high resolution imaging of the seafloor.

In 2012 gas analysis showed that no CO_2 that could have been in any way connected to the Sleipner CO_2 storage project was detected. In this region, the seafloor is covered with large glacial moraine deposits, displaying crack-like features at the edges of the deposits.

However in 2011 a press release that connected the ‘fracture’ like feature to the Sleipner project caused considerable damage in public opinion.

The ECO2 research group acknowledged the difficulty of dealing with this kind of situation.

Recommendations:

- The general recommendations that emerged from the group discussion were to be as aware as possible of different stakeholders (like research groups and NGOs) with the potential to influence perception. It is important to establish relationships with these stakeholders early, keeping them informed of project progress and monitoring their behaviour and reactions to a project. Often, simply maintaining strong lines of communication with these groups is enough to prevent non-intentional issues.
- In terms of being prepared to respond quickly and effectively to something like a CO_2 leakage allegation, it is vitally important that projects develop and agree a crisis management plan that clearly identifies approved project spokespeople, clear, consistent messaging around the project and common areas of misunderstanding and also contact details and protocols for quickly briefing influential external experts/ advocates likely to be approached for comment.

5.3. Introduction to the Social Site Characterisation and Stakeholder Engagement Case Studies developed by the ULCOS project

The storage expert from the Global CCS Institute gave a brief introduction to the report highlighting some of the preparatory public engagement work undertaken by the ULCOS project in the North East of France prior to this year's restructuring.

To set up the optimal conditions leading to social acceptance, a methodological process was followed, distinguishing 1) an assessment phase, or so called 'social site characterization' phase and 2) a stakeholder engagement phase.

The process must be carefully planned and deployed for a successful outcome. Each phase includes a series of key steps intended to prepare the stakeholder engagement phase, during which the conditions of acceptance mentioned above are negotiated between different actors.

Social site characterisation phase: Detailed characterization of the projects context and stakeholders.

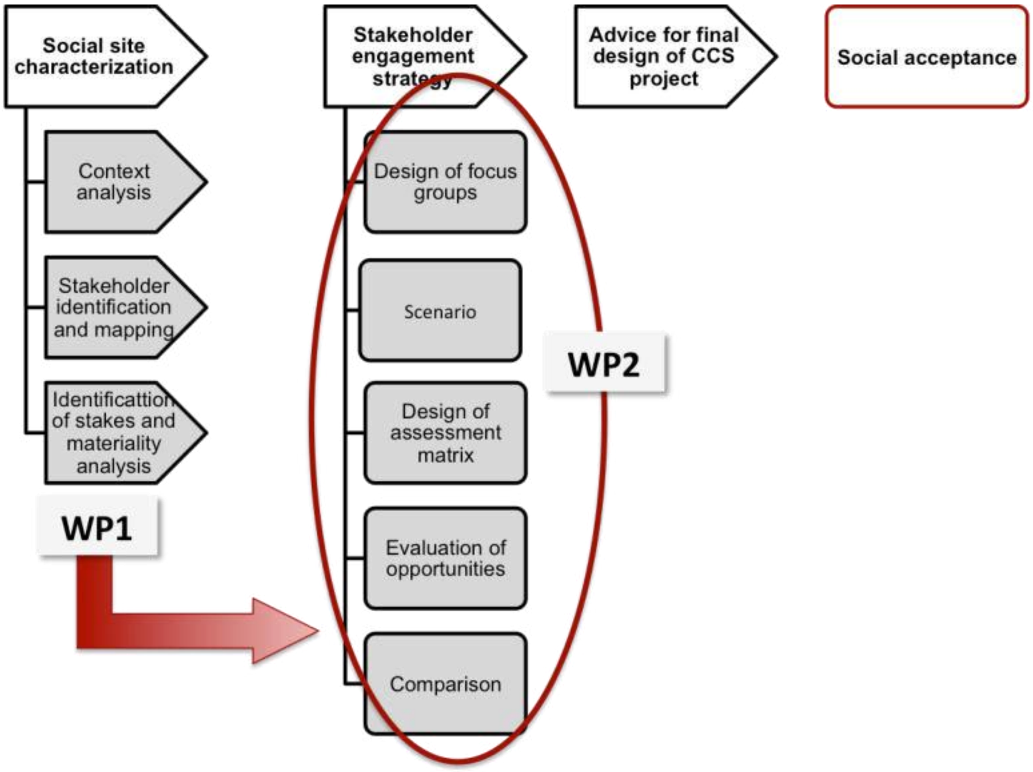
- Step 1: Obtain a deep understanding of the main regional challenges, in particular those that are likely to influence the stakeholders' perceptions of the project
    - Establish a baseline: used PESTEL to analyse the project context (6 key factors are reviewed: political, economic, social, technological, environmental and legal).

- Step 2: Stakeholder Analysis:
    - Stakeholder identification (spatial scope and during the lifetime of the project) and project-related issues (incl. tangible and intangible impacts)
    - Stakeholder 3D mapping: their positioning with respect to the project: power, attitude, interest to define profiles and map the intensity of the relationship for a first understanding of behavioural intentions.

- Step 3: Materiality Analysis of project issues

  This consists of:
    - Identifying the most significant concerns and/or expectations expressed by the most important project stakeholders.
    - Comparing between the external stakeholders' and the project developer's concerns or expectations about the project.

For large industrial projects, these issues or concerns can be classified into three broad categories: (1) Environment, (2) Society and communities, and (3) Industrial sector, company and project related.



Test of the stakeholder engagement methodology phase:

Once the ‘social site characterization’ phase is completed, the next step is to draft a stakeholder engagement strategy, starting with step 1 - the design of focus groups.

Step 1: A focus group is a group of people assembled for a moderated discussion. Focus groups are usually set up for qualitative research. Focus group design depends on the project or research characteristics and objectives, and combines the use of qualitative and quantitative methods.

- For the ULCOS project, stakeholder focus groups were formed according to their attitude towards the project; the evaluation framework consisted of 12 storage options, identified by stakeholders, and 3 evaluation criteria were selected for each issue (techno-economic, environmental, socio-economic), with a total of 9 indicators; the 12 options were evaluated for each of the 9 criteria.

Step 2: co-construction of scenarios

- The evaluation framework consisted of 12 storage options identified by stakeholders, with 3 evaluation criteria selected for each issue (techno-economic, environmental, socio-economic), and using a total of 9 indicators.

Step 3: Evaluation

- The 12 options were evaluated for each of the 9 indicators.

Step 4: Analysis and interpretation

– The involvement of stakeholders in a co-construction process that reveals and asserts their expectations, and takes into account their positions and demands;

– The evaluation of project options according to a set of criteria that is validated by all stakeholders, in their diversity and with their specificities;

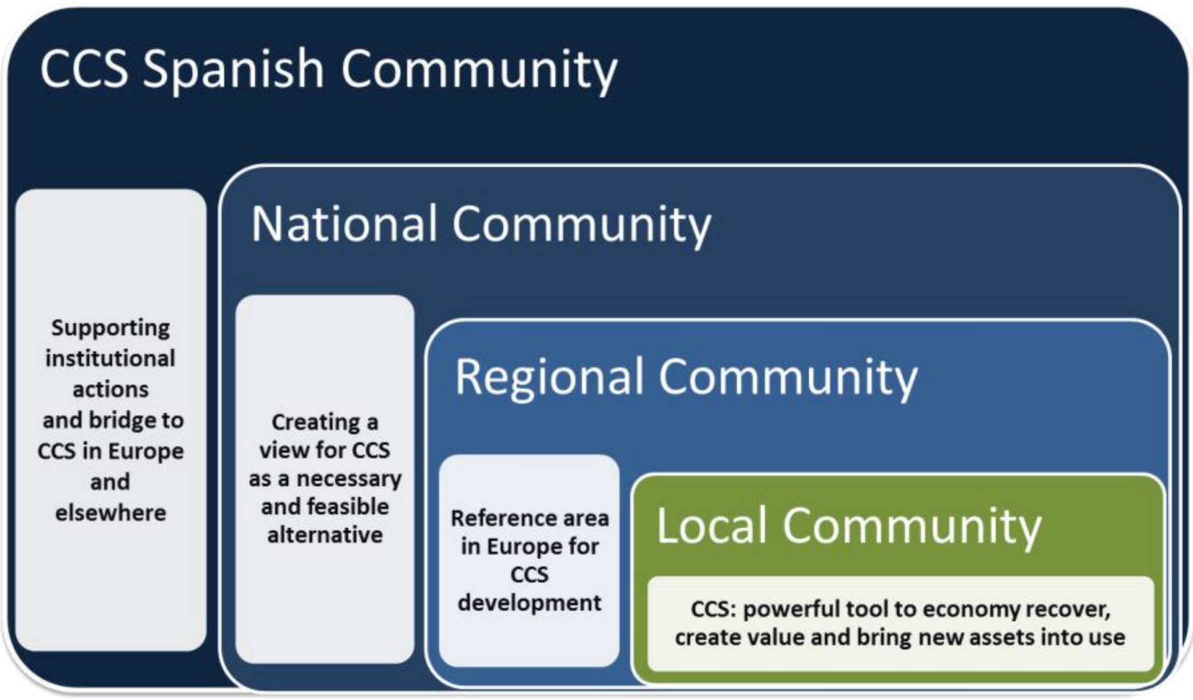
– An objective comparison of the different design options for a project.

The results of the evaluation process provide strategic information to the project developer, by identifying the most acceptable options with the highest probability of meeting stakeholder acceptance. As a corollary, the project manager can identify dissatisfied actors very early on, along with their potential reasons for blocking the project.

5.4. Communication with local government- Hontomín Experience

Representative of the CIUDEN CO_2 Geological Storage Programme gave a brief overview of the key components of the Hontomín CO_2 Communication Plan, followed by a more in-depth insight into the successful outreach and communication programme that the project has developed for their local community stakeholders in partnership with Local Councillors.

From the very early days, the project has been building a strong strategy to successfully engage with the public. This was supported by a strong public outreach team developing a plan, materials and monitoring protocols, inscribed in an integral communication plan covering the CCS community at national and local level.



The outreach programme included a range of activities: face-to-face meetings, workshops and technical meetings, educational programmes, TV Micro-documentaries and other informative videos, open days with site tours, press releases. The programme was enriched via engagement with the local community through participation in the local festivals promoting science and innovation. In September 2012 the Project team joined forces with the Local Council on a project promoting Scientific Culture and Innovation. This year-long project received extra funding in April 2013 and has proven to be a hugely successful partnership.

The Hontomín Project and CIUDEN were featured in all community communication materials; townhall website, activity leaflets, posters and regular detailed reports of project progress were provided to a local magazine.

A program of community education activities co-ordinated with the Local Council included:

- Photography and drawing competitions
- Cooking with CO_2 classes as part of the local 'Blood Sausage Festival'
- Fun science workshops on CO_2 for young people
- Sustainability workshops held in community centres for young people and the elderly
- Site visits and geology lectures 'The magical rocks of Hontomín' for adults and children
- Wine and CO_2 and Geology and CO_2 workshops were held with wine experts.

All these activities were designed to engage with the local community, increase understanding of the properties of CO_2 and some of the elements of the CO_2 storage, in an entertaining, accessible way and in a context that was relevant for their community.

The result of this work has been a greater sense of local pride and awareness of the Hontomín Project.

5.5. The Weyburn 'Creating Core Messages' Project

Principal Manager for Public Engagement from the Global CCS Institute provided a short update on on-going report being developed by the Institute and the IEAGHG Weyburn–Midale CO_2 Monitoring and Storage Project in Saskatchewan, Canada.

CO_2 storage, in particular the onshore storage and the effects of CO_2 storage on water supplies, was the most frequently voiced community concerns in the Institute's 2012 and 2013 CCS Project Surveys. As a result, the Institute has supported the research team attached to the Weyburn Project to create a simple question and answer resource[12] aimed at those communicating with the public and policy makers on CO_2 storage.

[12] Final 'What Happens When CO_2 Is Stored Underground?' report was published in May 2014. It covers 46 of the most frequently asked questions about CO_2 storage and answers them in a relatively short simple manner, using 12 years' worth of monitoring research that came out of the Weyburn Enhanced Oil Recovery project. The report is available for download at: http://www.globalccsinstitute.com/publications/what-happens-when-co2-stored-underground-qa-ieaghg-weyburn-midale-co2-monitoring-and

6. Sleipner Operations

A half-day session was dedicated to the Sleipner Operations, sharing Statoil's experiences and insights into CO_2 storage.

6.1. Latest data acquisitions and upcoming activities

The latest 4D seismic survey was acquired in January 2013 and is currently being processed. Another acquisition is planned for the future, probably around 2016, equivalent to another 2 Mt injected.

A microgravity survey was also acquired over the summer of 2013, and is being prepared for processing. No further microgravity is planned at present, though Sleipner East gas field surveys are likely during field operations. These will probably allow for further storage site monitoring.

6.2. General overview

A reservoir production engineer from Statoil gave an overview of the day-to-day operations at the Sleipner field, related to the storage of CO_2. By mid-2013, the cumulative amount of CO_2 injected was about 14 Mt (98% pure CO_2 and trace methane). The injection of CO_2 in Sleipner West is completed. The operator is now focusing on Gudrun and Gina Krogh as possible tie-ins, which should add 1 to 2 Mt of CO_2 to the storage. Other small volumes may be added later. With the Gudrun field tie-in, the prognosis is that about 17-18 Mt will get stored in total. The Sleipner West gas field and Gudrun contain about 9 mol% CO_2 while the Sleipner East gas field contains little CO_2. The commercial export stream must be less than 2.5% CO_2.

The injection rate has been very stable over the years. The injection well has a near-horizontal section towards the bottom of the well, with a 40 m perforation interval. When the well was drilled and completed, sand collapse into the first perforation interval required a recompletion and second perforation interval about 100 m behind the first, which has successfully injected CO_2 since 1996. This is the reason why the injection point is about 100 m from the end of the well bore.

The project injects CO_2 into the Utsira Formation, an Upper Miocene-Lower Pliocene sandstone reservoir at 800-1100 mbsl depth, almost 2 km above the deeper gas condensate Sleipner East field. The Utsira Formation is thought to be a shallow marine deposit. The net/gross ratio is 0.98. Porosity is of 35-40 % and permeability 1-4 D; the formation water salinity is low, similar to seawater, at a TDS of 30,000 ppm. The Utsira Formation within the vicinity of the storage site is roughly 300m thick with some local variations.

A number of data acquisition campaigns were performed, including baseline and repeat seismic surveys, gravity measurements, seafloor mapping and Controlled-Source Electromagnetic surveying (CSEM). An overview of the seismic monitoring results was shown. The seismic sections show that the plume, on average, has been moving at a speed of about 1 m/day, in the horizontal direction along a north-south trend which conforms to the subtle topography of the caprock, and apparently similar morphology of the intra-formation shale barriers.

Seismic data does not give an exact volumetric assay, but a highly accurate estimation of the spatial location of the stored CO_2. There are clear indications that the reservoir includes multiple shale barriers and the CO_2 is distributed as a number of layers. Deep layers are more difficult to interpret since the upper the layers of CO_2 mask the lower CO_2 on the seismic data.

CSEM gives a good survey image of the pipelines on the seabed but, in this case, is of little value when monitoring the CO_2. Shallow waters and pipelines are challenges to overcome when using this technique. CSEM acquisition in the Barents Sea where waters are deeper gave better results.

Over the past couple of years, four microgravity surveys have been collected, to study the value of gravity data in monitoring the behaviour of the plume. The gravity data have been used to estimate the density of the CO_2 in free phase in the Utsira Formation, using the disitribution of the plume in the seismic data as a constraint. The resulting average density in the plume agrees with the expected density of around 600 kg/m^3.[13]

6.3. Monitoring and characterisation: the latest on subsurface monitoring and seafloor characterisation

A senior geophysicist from Statoil discussed the role of subsurface monitoring and regional seafloor characterisation in rebutting press allegations of CO_2 leakage from the Utsira Formation.

Normal bubble-train methane seeps have been observed around old, abandoned wells. Isotope analysis has proven the biogenic near-surface origin of the gas; the methane reflects normal bacterial activity in shallow sediments, and is unrelated to the deep gas fields.

The ECO2 project has been disseminating reports in the press on sea bed ‘features’ – long crevasses in the sea bed, that were interpreted as the surface expression of faults in the shallow sediments. A connection with the Sleipner project was suggested. The sea bed features have been reported before, emphasising their ubiquitous existence in the North Sea. These are typical surface features of a continental margin.

The seismic acquisitions over the lifetime of the injection project confirm that the CO_2 is in place; with gravity measurements independently supporting the seismic data and providing density information. The seabed data acquisitions confirm there is no leakage. Emerging dual sensor streamer technology provides higher resolution imaging of the CO_2. While broadband seismic would attempt to record higher and lower frequencies, several current high-resolution methods are simply smart ways of dealing with the surface multiple.

Permanent cabling introduces flexibility in monitoring. There is no need to mobilize a seismic vessel. All that is needed is a gun boat. A permanent seismic array is thus faster to mobilize, roughly within a week. However, data handling is an issue regardless of survey type: it requires a team to process all the data. Permanent cabling is also expensive. The use of ocean bottom cables (OBC) was discussed. OBC, once installed, make it possible to shoot a seismic survey on short notice, at

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[13] Details of the study can be found in *Results from Sleipner gravity monitoring: Updated density and temperature distribution of the CO_2 plum,* Alnes et al., 2010 available at: http://www.sciencedirect.com/science/article/pii/S1876610211008150

relatively low cost. However, the installation costs are high, quite probably prohibitively high for a CO_2 storage project. Another disadvantage of OBC is the inflexibility to changes in the area covered; in case the CO_2 plume migrates in an unexpected direction, the location of the OBC may well have to be reconsidered.

A discussion evolved around whether the Sleipner project should have used high resolution methods earlier, and if less repeats would have been possible. It was noted that the technology has matured over the life of the project (almost 20 years) and will continue to improve. The pioneering nature of the storage site justifies the frequent surveying. A good baseline is essential and early monitoring, followed by a decrease in survey frequency assuming plume conformance to expected behaviour. Some of the seismic data has been optimised for the gas field, i.e. a target depth below the Utsira Formation. Seismic surveys dedicated to the CO_2 storage site would have been acquired with a slightly different configuration. The question of acquisition method is always a trade-off between requirements and cost. The proximity of an operating gas field has allowed for cost-share, but the results are deemed adequate.

Survey	**1994-2008**	**2010**	**2006**
Streamer	Conventional/hydrophones	Dual Sensor	Conventional/hydrophones
N# of streamers	4-10	12	1
Tow depth	8	15	3
Source tow depth	6	5	3

6.4. Injection, PVT and flow

The modelling work of the injection process was presented by a researcher from the Norwegian University of Science and Technology. With only few injection parameters measured and logged, the bottom-hole injection conditions are uncertain. Measured parameters include injected volume and well-head pressure. The composition of the CO_2 is not precisely constrained, although it is 98% pure CO_2. Nevertheless, the remaining 2% impurities are predominantly methane, and can give rise to PVT behaviour that differs from pure CO_2. Over the length of the injection well, this may have a significant effect on the bottom-hole conditions. The well-head pressure, also logged, has increased by 1-2 bar since the start of injection.

Modelling work was undertaken with HISYS and PROSPECT. HISYS allows inclusion of heat flow into the well and the definition of PVT properties of the fluid. The injection well was modelled in a number of sections. The CO_2 in the well ranged from pure CO_2 to 95% CO_2, with fractions of CH_4 and N_2. Various well head temperatures were used.

The conditions at the well head can strongly affect the bottom-hole conditions. For example, a change of one degree Celsius at the well head can result in a doubling of the bottom-hole pressure. The absence of tubing head parameters results in large uncertainties in the bottom-hole conditions.

A second set of modelling results was shown, for the Snøhvit field. The Snøhvit injection wells are much better equipped with sensors, providing the opportunity to test the HISYS modelling results. The results show that the HISYS model predictions agree well with observed pressure and temperature down hole, with only a few degrees centigrade and a few bar difference. The implication for Sleipner is that even though the uncertainty is high, the accuracy is high as well.

Injection problems at the Snøhvit site may have been caused by salt precipitation, which were solved by monoethylene glycol injection (MEG): a mixture of the diol with water often used to suppress hydrate formation. MEG injections were repeated at typically a weekly interval, for several months, and resolved the injectivity problem into the Tubåen Formation; however, a general increasing trend in required injection pressure indicated that the chosen location was a compartment with limited capacity. The well was recompleted with a shallower perforation into the Stø Formation. CO_2 injection has continued successfully since the recompletion.[14]

6.5. Storage site simulation and plume prediction

Principal researcher in CO_2 Storage at Statoil presented the Sleipner plume development case as a benchmark for reservoir engineering models. A complete description of the Sleipner Benchmark, and related data, are covered in a paper published by Society of Petroleum Engineers.[15] The presentation covered the matching of CO_2 plume development in the Utsira Formation using reservoir simulations: black oil simulators and percolation models. The black oil simulators failed to reproduce the rapid migration of the top of the plume towards the North; the percolation models, on the other hand, overestimated the amount of CO_2 that arrives in the northern tip of the plume.

A near perfect agreement between observed plume behaviour and model prediction was obtained when the black oil simulator, at each target year (the years the seismic surveys were shot), was allowed to reach pressure equilibrium. The conclusion of this is that the plume apparently always is at dynamic equilibrium, which in turn implies that when injection is ceased, the plume will not migrate further. This, at least for the Sleipner project, suggests that within a few years of injection ceasing, the storage system is effectively stable. This also indicates that simple reservoir simulations of CO_2 storage in open formations are likely to have strong pressure artefacts that distort the timing and distribution of a plume.

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[14] For further details consult: *Snøhvit: The History of Injecting and Storing 1 Mt CO2 in the Fluvial Tubåen Fm* Hansen et al. 2013 http://www.sciencedirect.com/science/article/pii/S187661021300492X

[15] *Reservoir Modeling of CO2 Plume Behavior Calibrated Against Monitoring Data From Sleipner, Norway* Singh et al. 2010 https://www.onepetro.org/conference-paper/SPE-134891-MS

The European CCS Demonstration Project Network was established in 2009 by the European Commission to accelerate the deployment of safe, large-scale and commercially viable CCS projects. The Network that has been formed is a community of leading demonstration projects which is committed to sharing knowledge and experiences, and is united towards the goal of achieving safe and CCS. The learnings that are gained will be disseminated to other projects, stakeholders and public to help gain acceptance of the technology –and support CCS to achieve its full potential as a vital technique in our fight against climate change.

Network support provided by: