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# Thematic Report

# Monitoring session (Storage) – May 2012

A report from the European CCS Demonstration Project Network

Website version

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Proceedings from the Cottbus knowledge sharing event 24th/25th May 2012

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# 1 Background

## Mission of the European CCS Demonstration Project Network

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 ensures that we can assist CCS 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 for 2012

Two topics have been selected by the European CCS Demonstration Project Network Steering Committee to be addressed during the year 2012 concerning storage: best practice in monitoring, and storage characterisation. The first topic to be considered was the monitoring theme. As monitoring and deciding on monitoring plans and strategies is an activity that occurs early in the project's process (particularly for obtaining licences), it was deemed to be of great importance and justified the swift consideration of this topic. The Network has a unique onshore-offshore mix and has the opportunity to highlight the differences and complementary methods that can be employed in the projects' monitoring activities.

Following from that high-level approach, in April a pre-meeting of the storage experts from the Network projects decided that there was the need for:

- A clear and agreed common definition of the project development phases/stages,
- A clear and agreed common definition of activities undertaken within each phase/stage (including monitoring and other domains),
- To exchange detailed information and technical reports,
- Clear and consistent status reporting across all of the Network projects,
- A detailed status of the projects.

# 2 Knowledge sharing event – Monitoring, 24 – 25 May 2012

## 2.1 Knowledge Sharing – Key Lessons Learnt

A number of fundamental lessons have been learnt by the projects within the Network, which range from projects considering onshore to offshore storage, and from planning to fully operational projects. From the presentation and expert discussions that took place at the knowledge sharing event, some key shared themes emerged.

Storage sites vary greatly, and monitoring tools, techniques and plans should reflect the specific circumstances of the area. It is important to take into account local conditions such as the geology, regulations and public concerns. As monitoring plans always aim to ensure the safe and permanent storage of $CO_{2,}$ detailed analysis of the benefits of each technique should be considered.

For example, repeated seismic surveys are not always useful or feasible in a number of offshore and onshore locations (obtaining permitting permission for repeated acquisitions onshore may be problematic; or the geology may not allow useful results to be obtained. Using a specific example, while 4D seismic is very useful in the case of Sleipner, it is considered of little benefit in the case of ROAD). The number of surveys and their frequency should also be considered: some North American projects carryout one baseline seismic survey at the start of project and one at the end of the project, while three surveys are planned for the Goldeneye field in the North Sea (Longannet/Peterhead project).

While there are a set of minimum monitoring requirements common to all sites, and these must be in place (usually as the result of regulation), it is possible to demonstrate that monitoring is a valuable investment in the lifetime of a project and will save the operator money and time in the long term. In particular, monitoring is important for a better scientific understanding of the overall system and its management (historic data matching).

Good and appropriate baselines and appropriate monitoring techniques are essential in order to build good models that will aid operations, but can provide tangible evidence to regulators, stakeholders and the public that storage of $CO_2$ is safe and permanent.

Similar messages were taken from a joint US, Canadian and European workshop focusing on monitoring. A detailed report from that event can be found at http://www.ccsnetwork.eu/index.php?p=publications.

## 2.2 Project Status Update and Monitoring tools

For practicality, the summary of the 2 sessions has been combined into one section and displayed per project.

### 2.2.1 Bełchatów

#### *2.2.1.1 Overall*

The first phase of the storage site selection for the Bełchatów project has been completed. This ran between 2009 and February 2012, and resulted in three sites being screened for their suitability for safe and permanent storage of $CO_2$.

- The Wojszyce structure has been investigated using a range of preliminary data acquisition techniques: gravimetric data acquisition, 2D seismic data acquisition and an appraisal well drilled to the depth of 2050m, with some well logging and coring.
- The Lutomiersk-Tuszyn structure has had its initial assessment undertaken using gravimetric data acquisition, 2D seismic data acquisition and 1 appraisal well drilled at 2884m, with some well logging and coring.
- The Budziszewice structure analysis has been based on modelling and archive data only.

As a result of this first phase of site analysis, a site selection report was produced and the Wojszyce structure has been selected for phase II (site characterisation). On the 27 March 2012 a tender was published for the "Selection of a Phase II Coordinator". The result of Phase II will be used for the Final Investment Decision (FID).

#### *2.2.1.2 Monitoring*

A preliminary monitoring plan is included in the Phase I site selection report which includes details on the following techniques that will be employed:

- For the 2 to 3 injector wells, there will be downhole pressure and temperature (P & T) measurements, possibly microseismic technology, and distributed temperature sensing systems (DTS). At the well head there will be flow rate monitoring and P &T measurements,
- 1 to 3 deep monitoring wells will be used, with occasional sampling and analysis, reservoir saturation tool (RST) logging, possibly vertical seismic profiling (VSP) and occasional cement and casing corrosion monitoring,
- 2 to 5 shallow monitoring wells will be used with occasional fresh water aquifer sampling and analysis,
- Surface monitoring technologies will be employed including Interferometric synthetic aperture radar( InSAR), soil and air monitoring (4D Seismic Surveys are problematic due to the geological conditions),
- Surface metering will include injector well head flow rate and pressure and temperature (P&T) monitoring; and pipeline manifold entry point monitoring (flow rate, P&T),
- An Integrated monitoring data management system will be implemented.

Several monitoring technologies were analysed with respect to their applicability for the sites based on the characteristics known at the end of Phase I.
The design of a comprehensive monitoring system will be included in the phase III of the project, a phase which will include permitting, construction, and commissioning.

### 2.2.2 Compostilla

#### *2.2.2.1 Overall*

Compostilla has completed the assessment of the storage component, the first phase of the project. The preliminary site assessment work included a number of activities. Screening was conducted based on a number of technical and logistical criteria, which pre-identified 7 potential sites. Eventually two areas were selected for further assessment, one in the basin of the Duero River, region of Sahagun (province of Leon), referred to as the "Duero Site" and one in the basin of the Ebro River, province of Aragon, referred to as the "Andorra site". The relevant authorisations to assess sites in those areas were obtained and the following pre-assessment was performed:

- Outcrops structural analysis and stratigraphic studies for reservoir and caprock formations
- Hydrogeological studies
- Existing Wells and Seismic studies for structural, stratigraphic & hydrogeological models
- Isobath and isopach maps for reservoir and caprock formations. Seal cartographic studies
- Initial works for upgrading 3-D models
- Design of seismic surveys and wells for characterization of reservoirs, caprocks and seals.

Pre-assessment lead to the following activities:

- Up-grade of the geological studies
- Magnetotelluric surveys
- Existing seismic data reinterpretations
- Existing Wells: caprock and reservoir formation analysis
- Well drilling: SD-1 & SM-1
- Acquired 2-D Seismic at both Andorra & Duero Sites
- Up-dated/Up-graded structural and stratigraphic models
- Up-graded hydrogeological studies and models
- Earth static & dynamic models, scenarios definition
- Main risks definitions to be addressed in MVA plan.

Finally the Duero site was retained for a comprehensive appraisal program including:

- 2-D seismic survey (which has now been completed)
- Drilling 3 to 4 appraisal wells (ongoing); analysis (ongoing)
- 3-D seismic survey (which is ongoing, but about to be concluded)
- Upgrade & up-date structural and stratigraphic models (ongoing)
- Upgrade & up-date studies and models, including geomechanical model (ongoing)
- Reservoir performance assessment (ongoing)
- Risk analysis and monitoring assessment (ongoing)
- Base line campaigns (InSAR, $CO_2$ soil fluxes, groundwater and surface water monitoring) (ongoing).

In total the project has acquired 1000 km of seismic lines under the EEPR programme. There are appraisal wells being drilled at the moment with coring of the caprock and reservoir. The wireline logging campaign has been completed. Production and injection tests were conducted which gave an estimated porosity of 45 – 50% and a permeability of 1 to 5 Darcys for the Duero site

unconsolidated sandstone. In Carbonates permeability is in the range of 20 to 50 mD.
It has taken 8 years to reach the stage of drilling wells.

#### *2.2.2.2 Monitoring*

A number of activities are planned for the monitoring requirements of the project:

- $CO_2$ baseline methodology and procedures have been developed,
- The study area (20x30km) was divided into equal cells in a way that 99 measuring nodes/points were defined and located by Universal Transverse Mercator (UTM) coordinates,
- At the Duero site the first baseline monitoring campaign started 28 June 2010, and a second baseline campaign started May 2012. This surface monitoring has resulted in soil data (20cm below surface) and atmospheric data (1.5m above ground), temperature records, relative humidity and $CO_2$ concentrations measurements, and atmospheric pressure data. $CO_2$ gas samples will determine the pre-existing concentration and isotopes before any activity takes place,

The project is also currently developing future events models, and process procedures to establish all potential risks and further refine any monitoring requirements.

#### *2.2.2.3 Risk Analysis and Monitoring Plan*

The Monitoring Plan has been divided into three elements: Operational (Injectivity), Verification (Capacity) and Assurance (Containment) monitoring. The plan is also based on a comprehensive risk analysis which includes:

- Taking into account authorities' expectations, regulatory requirements, Natura2000 constraints, liabilities and public acceptance needs,
- Hazards identification at sites that have gone through the screening and ranking process,
- Hazard criticality qualitative assessment,
- Preliminary monitoring techniques identification,
- Evaluation of uncertainties (structure, reservoir, seals).

The appraisal program has been defined to reduce uncertainties and data gaps. The items that have been identified include potential impacts on freshwater bodies, environment, data for public acceptance, and potential conflicts with neighbouring Oil & Gas fields.

In addition there has been an update of the static, dynamic & geomechanics models used. These include site performance and quantitative risk assessments, and take into account prevention and mitigation measures. This has been accompanied by an update on the selection of monitoring technologies that will be used based, on their feasibility.  Finally forward modelling has been used to define characterisation and monitoring technologies.

### 2.2.3 Hontomin (underground research laboratory of Compostilla)

#### *2.2.3.1 Overall*

The Hontomin Storage Technology Development Center/Pilot (TDP) is a component of the Compostilla project, along with the Capture and Transport components and the biomonitoring component (PISCO2). Injection is limited to <100,000t.

The Technology Development phase, running from 2009 to early 2012 corresponded to the site characterisation phase. The studies that were included in this phase were:

- Geological and structural mapping,
- Petrophysical studies based on 4 existing wells,
- 3D Seismics (high resolution acquisition completed, required new processing techniques),
- 3D Electromagnetic survey,
- High resolution gravimetry,
- The creation of a 3D geological model.

Phase II (demonstration) from 2012 to 2015 has now started. Surface Civil Engineering work started in December 2011, and the drilling of three wells for injection and monitoring/sampling will start in December 2012. Injection operations are expected to start in spring 2013.

#### *2.2.3.2 Monitoring*

Extensive work has taken place to identify all of the project's monitoring objectives and challenges. It is to be noted that the Hontomin project's very purpose is to benchmark and develop technologies for $CO_2$ storage. The monitoring tools and techniques that have been employed include:

- Atmospheric measurements focusing on isotopes.
- Shallow boreholes/Surface & Near surface techniques:
    - hydrogeological monitoring,
    - water chemistry,
    - bio-indicators/biomonitoring (cf. 'PISCO2' another component of the Compostilla project),
    - soil gas flux,
    - Differential SAR Interferometry (DinSAR) and ground-based SAR,
    - SeisMovie ( a patented high resolution reservoir monitoring solution, 4D) (1 60m well with 2 sources and 10 receivers; 80 receivers at 10m depth),
    - Permanent seismic network with 20 digital recorders,
    - Controlled Source Electromagnetic Survey(CSEM)/Electric (4D),
    - Gravity Survey (3D).
- Deep boreholes/Subsurface: 3 wells of approx 1500m depth to be drilled in December 2012 (1 injection H5, 1 geophysical monitoring H6, 1 multilevel completion H7)
    - VSP (4D),
    - Electrical Resistance Tomography (ERT) (4D) H5,H6, H7,
    - Geochemical sampling of the reservoir (H7),

        - Distributed temperature sensing system (DTS) monitoring (temperature) and T & P sensors (fluids), H5, H6, H7,
        - Extensometers in the boreholes (H5, H6, H7).
    - Sensitivity analysis of baseline datasets: error bars in baseline parameters,
    - Benchmarking of technologies,
    - Cost evaluation,

Some of the specific challenges that have been indentified include:

- Joint Inversion geophysical data,
- Multiseismic 4D imaging,
    - High resolution noise interferometry,
    - Time reversal imaging,
    - Full waveform inversion,
- Electrical/CSEM for monitoring,
- InSAR/GBSAR,
- Bioindicators.

### 2.2.4 Jänschwalde

#### *2.2.4.1 Overall*

More specific information can be found in the summary of the project, and the FEED studies that have been released. All relevant documentation can be found on the website https://www.ccsnetwork.eu/index.php?p=publications.

In 2004 initial site selection activity commenced through the initial screening of the north of Germany. This was achieved by first of all defining pre-selection criteria such as: estimated storage volume, geology (reservoir and seals properties), potential conflicts with other users of the sub-surface and surface, and the distance from the Capture power plant. This was then followed by a period of reviewing the data available from years of intensive oil and gas exploration, mainly in the form of 2D seismic data and deep drilling logs. As a result of this work, three sites were pre-identified as potential suitable storage sites: the gas field of Altmark, the Neutrebbin structure and the Birkholz-Beeskow structure.

In 2006, Vattenfall started negotiations with oil and gas companies (Altmark). The Birkholz-Beeskow structure was finally selected for further exploration as the relevant permit was obtained first. No permit was obtained for Altmark.

The geology of the Birkholz-Beeskow structure indicates a storage reservoir in the Buntersandstone at approximately 1300m depth with 2 caprocks: 1 in the Bundsandstein made of a 100m thick layer of clay with a 10m thick salt layer at approximately 1000m depth. The second caprock is in the Keuper made of clay from 200 to 600m deep. The Muschelkalk at 800m – above the first caprock - is an indicator horizon that would have been used for monitoring. The Rupelclay (Oligocene) separates the fresh water from the salt water beneath the clay in Northern Germany.

Existing data was entered into a 3D geological static model, and an exploration programme was designed, but not carried out, which included:

- Seismic Surveys:
  - ~ 300 - 550 $km^2$ per structure: 3D-Seismics (330$km^2$ at Birkholz-Beeskow) with 9 additional (67km total) 2D-Profiles,
  - Expected duration: 6 Month (Winter).
- Drilling
  - 4+ drillings per structure (3 deep injection and monitoring and 4 shallow monitoring wells at Birkholz-Beeskow), for reuse as later injection or monitoring wells,
  - There was to be a high rate of core drilling.
- Hydraulic Tests
  - Extraction of brine,
  - Injection of brine.

No new data was acquired. Instead time was dedicated to obtaining exploration licences and designing the exploration plans. These plans were based on existing historic data, which was collected, reprocessed and reinterpreted. The project had to create a new company, a joint venture, for the transport and storage elements of the project.

#### *2.2.4.2 Monitoring*

Groundwater monitoring methodology was adopted for the development of a baseline and would have formed the basis for an operative monitoring plan.
In terms of the methodology used, the project undertook the following actions:

- Searched, reprocessed and interpreted old well data,
- Evaluated the outputs from the existing monitoring wells,
- Developed a description of the baseline situation (including the salinity),
- Created proposals for the development of an operative monitoring system.

It was intended that the baseline would be re-evaluated once a year, to ensure that there was a continuous process to reduce any potential risks.

The project used a Risk Assessment matrix (also called a criticality matrix) based on probability versus consequences, labelling the identified risks as low, medium or high. This was used to identify and quantify the highest risks – and make sure that efforts were made to mitigate any adverse events and ensure the safe and permanent storage of $CO_2$.

One of the most critical lessons learned by the project was that site selection is the most important factor in developing a successful storage site. The selection requires:

- Comprehensible and accepted selection criteria,
- Articulation and decision on who should be responsible for the selection criteria,
- Early public participation,
- A transparent procedure.

### 2.2.5 Porto Tolle

#### *2.2.5.1 Overall*

The site screening around the Porto Tolle project commenced with an analysis of publically available data, and then included an oil and gas company property data. The data included 3D seismic, exploration well information and cores. Preliminary 3D static geological and a petrophysical model were developed from this information. Following this a dynamic model, a geomechanical model, a geochemical model and a near-wellbore model were built by the different partners of the project. Analysis of the results of these models indicated that there were two sites with suitable structures.

A pre-injection baseline of the area's chemistry, biology and physical (microseismic, induced seismicity) parameters was planned, using the best available technology for both an onshore and offshore environment. The offshore water column and near-surface sediments were analysed to define spatial and temporal value ranges.

The project aims to drill an appraisal well to enhance the site characterisation work, and which could later be reused for injection.

#### *2.2.5.2 Monitoring*

Although the storage site is located 25km offshore the project will carry out offshore and onshore monitoring. Baseline data acquisition has been carried out at a regional scale (400$km^2$).
The monitoring program includes the following steps:

- Reviewing all available proven and potential monitoring technologies – and the project has already built a comprehensive table listing all monitoring tools.
- Selecting which monitoring techniques are required to achieve the required objectives. For the pre-injection baseline the following tools were selected for measurements which will be taken 4 times a year:
  Onshore:
  - Soil gas and diffusive degassing,
  - Shallow aquifer and dissolved gas,
  - Microseismicity.

  Offshore:
  - Physical and chemical characterisation of the column and dissolved gases,
  - Characterisation of sediment interface and water/sediment (coring),
  - Benthic communities (winter and summer analysis campaigns),
  - Oceanographic measurements,
  - Chemical-physical parameter continuous monitoring.
  - The project ran a multibeam echo-sounder to map the sedimentary structures under the seafloor and installed a deep lab station as well as a number of dissolved gas sensor stations.

(Detailed descriptions of the benthic analysis, sediment core sampling, chemical and biochemical analysis in the core sediments, water column sampling including dissolved $CO_2$, the instrumentation and the analytical methodologies followed are available. Please contact the Network for more details.)

These monitoring steps will be used to create bespoke monitoring plans (for example a specific seismic monitoring plan). These monitoring plans will include the design of appropriate field deployment parameters – an activity which will require significant modelling work and a comprehensive sensitivity analysis.

### 2.2.6 ROAD

#### *2.2.6.1 Overall*

The ROAD project is planning to undertake its storage operations in a small cluster of nearly depleted gasfields (P18-6, P18-4, P18-2) producing high caloric gas since 1993 from a Triassic Buntstandstein reservoir overlain by clays. The project is close to reaching a Financial Investment Decision (FID).

The depleted gas reservoirs in P18 are at a depth of around 3,500m under the seabed of the North Sea and are 20 km from the coastline. The $CO_2$ will be injected from a platform. The estimated storage capacity is approximately 35 million tonnes. The reservoir should be available for storage in 2014. Existing wells will be used for injection following a workover, i.e. replacement of the tubing, installation of downhole equipment and redesign of wellhead and wellhead controls. There are no abandoned wells in the area that could be used for access.

Historical production data was used to determine the storage capacity and injection rates of two different wells. The historical data including 3D seismic data were sourced from TAQA Energy B.V. currently exploiting P18, the NLOG website (oil and gas information portal of the Netherlands) and the DINO database operated by TNO.

The project has built:

- A geological model, using available petrophysical data from existing wells
- A dynamic reservoir model,
- A flow assurance model (well modelling integrating boundary conditions),
- A geomechanical model,
- A geochemical model.

The project plans to start injection in June/July 2013, and one of the injection wells will be equipped with downhole Pressure and Temperature sensors.

#### *2.2.6.2 Monitoring*

A monitoring plan has been prepared by the project, and will be approved after the final investment decision (FID) has been taken. The monitoring plan will take into account the neighbouring reservoir. It was noted that seawater monitoring will take place, similar to the monitoring plan described by Porto Tolle.

Based on the risk analysis, the plan incorporates a remediation plan in case of leakage as the time available in which to react would be very short. The risk is considered to be manageable (with an estimated maximum leakage time of 2 months) and the project has established a good dialogue with the regulator.

### 2.2.7 Sleipner

#### 2.2.7.1 Overall

Sleipner has been in operation since 1996. The project injects 0.9Mtpa $CO_2$ in the Utsira sand formation (Miocene-Pliocene) at approximately 1000m depth below sea level and overlain by thick Pliocene shales. 13Mt of $CO_2$ has been stored to date.

#### 2.2.7.2 Monitoring

A number of monitoring activities have been utilised since operations began. In particular some of the results and activities are:

- Operational Performance
  - Stable wellhead pressure ~65bar,
  - Wellhead temperature held at 25$^{o}$C.
- Monitoring Data
  - Wellhead pressure and flow rate are monitored continuously,
  - Gas composition samples are taken intermittently,
  - Seven time-lapse (4D) seismic surveys (1994 baseline, then 7 repeats),
  - Two repeat gravimetric surveys,
  - Electromagnetic survey (CSEM),
  - Seabed surveys (2006 & 2011).

As a result of this operating experience number of lessons learned has been acquired by the project since it began including:

- Differences in density and compressibility makes seismic imaging a valuable monitoring tool to locate the $CO_2$.
- When selecting a storage site, avoid well operations as much as possible.
- The seabed survey of last year identified a linear feature – fracture like – at 25km from Sleipner. This was over-interpreted by a newspaper as an active fault, which generated a rumour of potential leakage. No gas was detected and it can be demonstrated that this cannot be related to the Sleipner $CO_2$ storage. This demonstrates the need for good, routine monitoring data - and it can be shown that the plume is well constrained by the structure.
- This validates the current project procedure of only releasing raw data to academia after quality control (QC) has taken place.
- The total storage capacity is also dependent of the injection rates.
- By encouraging academic research the project facilitated the improvement of a high accuracy gravity surveying technique. The gravity data that has been obtained has been

used to calculate a maximum dissolution rate (upper limit of 1.8% per year). This data turned out to be a good complement to the seismic data.

Some key considerations for storage operators are:

- What constraints the propagation of the plume?
- What is the long term fate of $CO_2$? In the case of Sleipner simulations runs until 2030 show that the plume will remain within the storage reservoir.

### 2.2.8 Don Valley

#### *2.2.8.1 Overall*

The project is currently investigating both an offshore $CO_2$ storage operation in a southern North Sea saline formation, and an EOR operation in the central North Sea. The project has gone through the following steps in relation to the southern North Sea storage opportunities:

- Regional assessment and then site selection has taken place, firstly by identifying clusters of storage sites, and performing static and dynamic capacity assessments.
- Detailed site selection was then performed to select the best possible storage site. This was based on comparing the storage characteristics using preliminary models, and then ranking the sites.
- A database repository was built using existing seismic and well data. This allows for data validation, the creation of temperature and salinity maps, and a petrophysical evaluation.
- A static model was created to perform geophysical mapping, rock property distributions, analyse the effect of sensitivities, and perform detailed risk identification.
- Near wellbore models were created to evaluate the effects in wells and near wellbore areas (focusing on pressure /volume /temperature). These models were also used to assess the feasibility of injection into depleted gas fields, and detailed risk identification.
- Dynamic models were built to model Field Development Capacity and Injectivity, assess effect of sensitivities (for risk identification purposes), pressure modelling, assess plume migration prediction over time, and further risk identification.
- Coupled modelling was used to evaluate the effect on the overburden relating to injection (using output from the dynamic model), and for risk identification.

#### *2.2.8.2 Monitoring*

The project is preparing an initial design of a monitoring programme. The definition of the monitoring programme in relation to the saline formation will be informed by the next phase of development work which includes intrusive exploration (drilling) of the target structure.

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 commercially viable 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: