ECCSEL Svelvik CO_2 Field Lab

CONTENTS

SINTEF

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CO_2 CAPTURE AND STORAGE (CCS)

CCS is an important tool for CO_2 emission reduction based on capture of CO_2 from fuel combustion or industrial processes (e.g. steel and cement production), followed by transport by ship and/or pipelines, and finally underground storage in deep geological formations like saline aquifers or depleted gas fields.

The International Energy Agency (IEA) and the UN Climate Panel state that it is "extremely probable" that climate change is connected to man-made CO_2 emissions. To avoid the most extreme effects we must reduce residual emissions of CO_2 to the atmosphere to near zero by 2050. CCS can contribute to eliminating 14–17 per cent of the emissions, or around 5 gigatons per year (equivalent to the CO_2 emissions from about ten thousand factories and power stations).

HISTORY / THE CO_2 FIELDLAB PROJECT (2009–2015)

The Svelvik test site was initially developed by the SINTEF-coordinated CO_2 FieldLab project and is located in a non-active part of the sand and gravel quarry of Svelviksand. The aim of the project was to contribute to safe underground CO_2 storage by investigating technologies for CO_2 monitoring in a well-controlled and well-characterized permeable geological formation.

The site area was characterized through a series of surveys comprising drilling, sampling and logging of a 330-m deep appraisal well (Svelvik #1), analyses of core and flow-line samples, geophysical surveys including resistivity, seismic reflection and ground penetrating radar along two 2D lines and hydrodynamical, geochemical and soil gas surveys. A second vertical well (Svelvik #2) was drilled in 2012 to test the injectivity of the sand layer located at 60–70 m. The sand layer was found suitable for future injection experiments.

At the end of the CO_2 FieldLab project in the test site was closed and preserved for future activities.

Funding for a revitalization was secured in 2017 and the field labo was re-opened as the ECCSEL Svelvik CO_2 Field Lab in 2019.

ECCSEL ERIC

ECCSEL ERIC is the European research infrastructure for CO_2 capture, utilization, transport and storage (CCUS). Its objectives are to "Coordinate, operate and develop a world-class distributed CCUS Research Infrastructure in Europe", "Provide access to integrated, upgraded and newly constructed CCUS research facilities", "Enhance European science, technology development, innovation and education in the field of CCUS", and "Enable spin-off activities and generation of new business", thereby "Enabling low to zero CO_2 emissions from industry and power generation to combat climate change". The consortium currently provides open access to more than 100 world class CCS research facilities across Europe. The Norwegian part of ECCSEL Is supported by the Research Council of Norway. Svelvik CO_2 Field Lab is one of several Norwegian infrastructures related to CO_2 storage. (Source: www.eccsel.org)

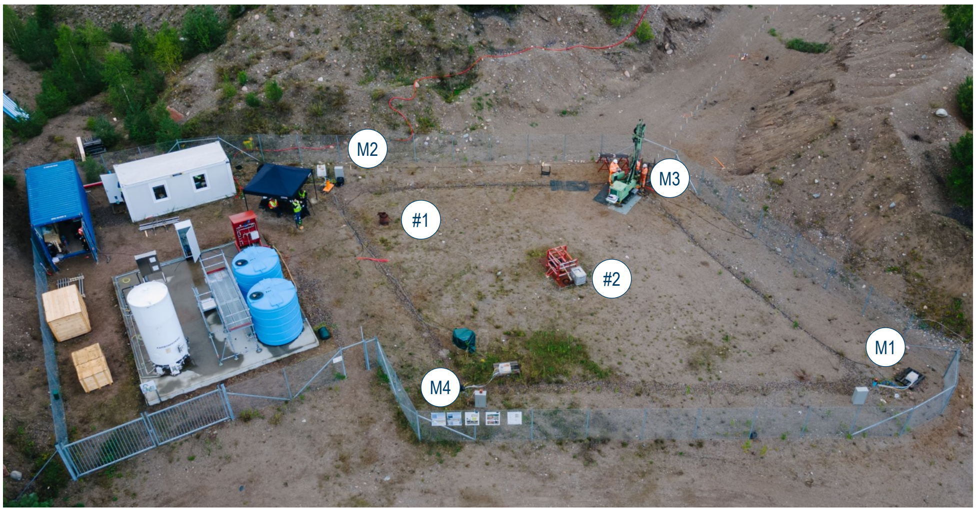
SVELVIK CO_2 FIELD LAB

Svelvik CO_2 Field Lab is one of several Norwegian ECCSEL research infrastructures related to CO_2 storage. This field lab offers unique possibilities for rapid and cost-efficient development and testing of technologies for quantitative monitoring of CO_2 storage.

The test site consists of an injection well (Svelvik #2) surrounded by four monitoring wells (M1–M4). The injection well and associated infrastructure facilitates injections of CO_2 and brine at 64–65 m depth. The injection well is instrumented for temperature and pressure measurements at packer level and with a fibre-optic cable for recording of the acoustic signature of CO_2 flowing in the injection tubing and migrating vertically outside the casing. The monitoring wells are 100 m deep and have been instrumented outside the casing with electrodes for resistivity tomography measurements and with fibre-optic cables for temperature, strain and acoustic measurements. Pore pressure transmitters are installed at injection depth for three of the wells. The casings are sealed downhole, preventing fluid communication with the surrounding formations. The casings of the monitoring wells are further “empty” (only filled with water) making it possible to immerse instrumentation and logging tools.

With the shallow injection and CO_2 accumulation depth the absolute changes in geophysical parameters are different from an actual field case for CO_2 storage. The general pattern of the changes are, however, comparable, as the table below shows. The differences between the field lab and an actual field case can be taken into account using appropriate rock physics models. It can be mentioned that analysis of data from past experiments indicate that we actually can use rock physics models quite similar to those used for the Sleipner injection project into the Utsira sand stone.

geophysical parameter	from brine to supercritical CO_2	from brine to gaseous CO_2	from brine to dissolved CO2	references
compressional wave velocity	↓↓	↓↓	↓	Myer (2001), Ghaderi and Landrø (2009), Mavko et al. (2009), Pride et al. (2004), Carcione et al. (2006), Lepore and Ghose (2015)
resistivity	↑	↑	↓	Hoversten and Gasperikova (2005), Kummerow and Spangenberg (2011), Szecsody et al., (2014),Myer (2001)
density	↓	↓	↑	Ghaderi and Landrø (2009)



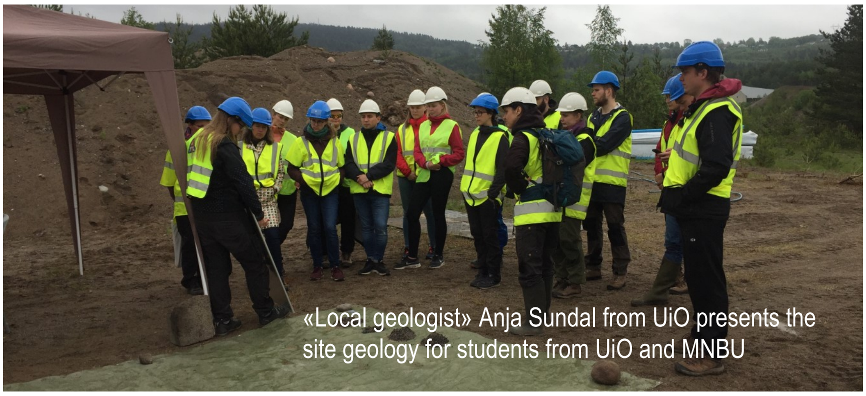
The distance between the injection well (#2) and the monitoring wells M4/M3 is 9.9 m. The distance is 16.7 m for M1/M2.

Instruments and data storage systems for downhole sensors are located in the control- and instrument cabin seen in the upper left of the photograph.

SITE GEOLOGY

The test site occupies a non-active ("depleted") part of a sand and gravel quarry, located at the premises of Svelviksand AS. The geological reservoir of the field laboratory is comprised within an east-west running sandy ridge of recessional moraine, fluvial and marine sediments deposited in Holocene (10 500 years BP). Sediments transported from the north were deposited at the ice front into a deep, narrow fjord during a pause in glacial retreat. The area has been uplifted due to isostasy, and part of the ridge is now above sea level, nearly damming the north-south oriented Drammensfjorden. The sandy aquifer is more than 200 m thick in parts, with its geometry locally affected by undulating bedrock topography. The uppermost, phreatic aquifer holds fresh groundwater, while deeper parts are brackish and thought to be influenced by seawater.

The site characterisation for the two field lab projects, with seismic surveys logging of deep wells and analysis of sediments sampled has aided in a revised geological interpretation of the area. For the four monitoring wells drilled in 2019 measurements of mud density and viscosity were performed every third meter. Sediments were, in addition, collected from the drilling mud each meter and analysed, in order to provide a detailed geological description of the test site.



«Local geologist» Anja Sundal from UiO presents the site geology for students from UiO and MNBU

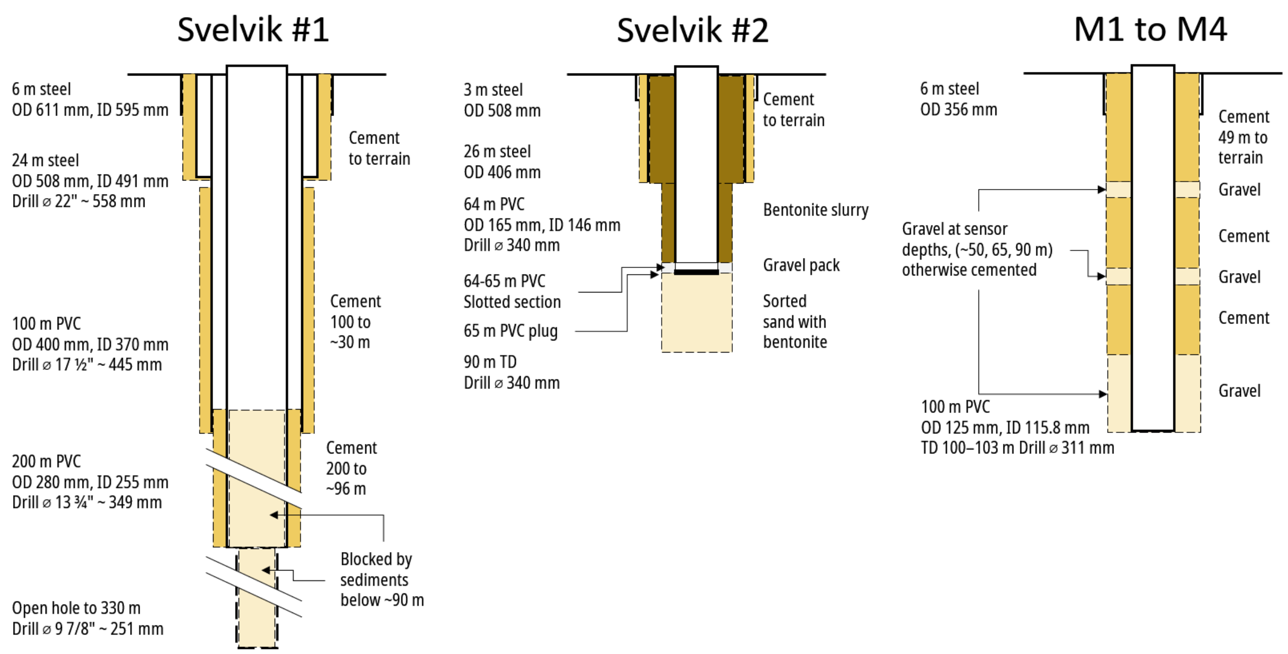
The Svelvik ridge in Drammensfjorden. View from south-west. House roofs in the town of Svelvik at the lower left .

WELLS

The central injection well (Svelvik #2) of the field lab is completed to 65 m, with an injection screen at 64–65 m depth. The four monitoring wells (M1 to M4) are completed to 100 m depth. In addition, the initial deep exploration well (Svelvik #1) can be accessed down to about 90 m. All wells have a steel ground casing to 6 m (Svelvik #1 and M1–M4) or 3 m (Svelvik #2) depth. Svelvik #1 and #2 have intermediate steel casings to 24 and 26 m depth, respectively. All wells have PVC casing from ground to total depth. Svelvik #1 was initially drilled to 330 m depth and has two PVC casings; one to 100 m and the innermost to 200 m depth. Sketches of the completion principles for the wells are shown in figures below.

For M1–M4 the annulus outside the PVC casing is filled with cement except for three depth intervals where instruments are installed. The annulus was filled with gravel for these depths in order to facilitate communication with the surrounding formations.

PVC casing	
Svelvik #1	255 mm ID
Svelvik #2	146 mm ID
M1–M4	115 mm ID



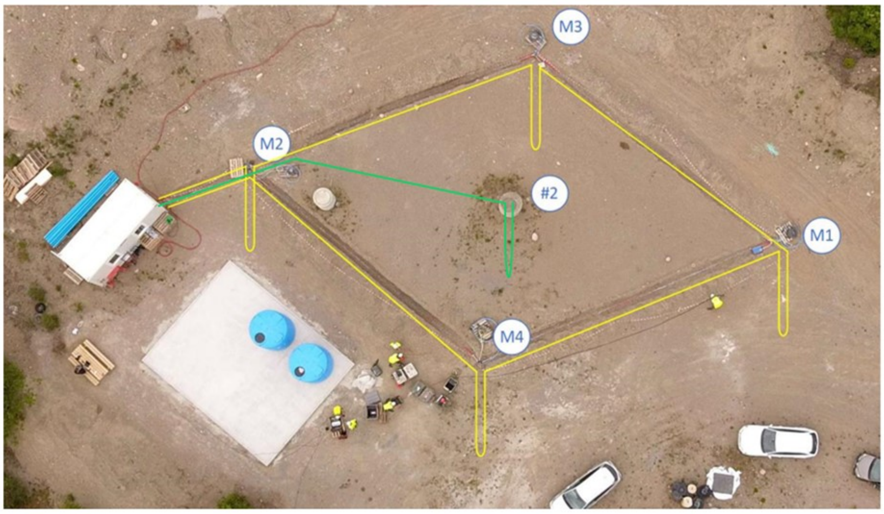
From the drilling and completion of the monitoring wells in 2019.

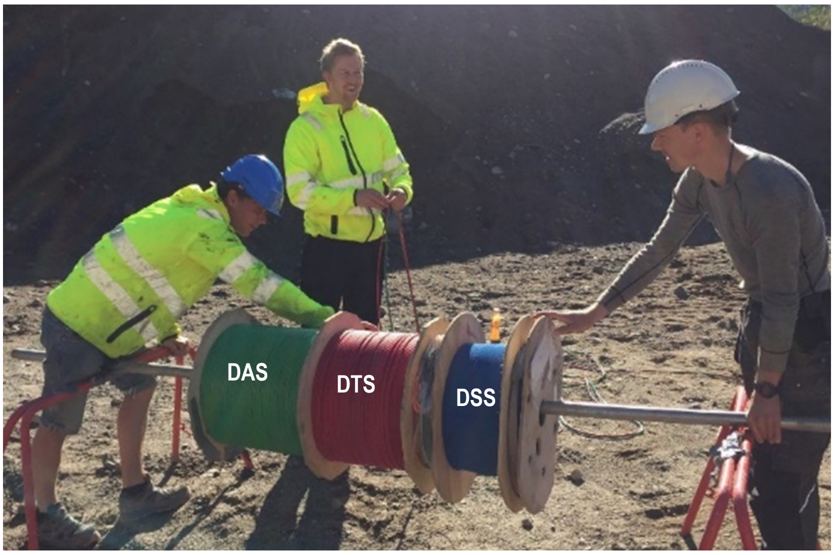
INSTRUMENTATION OF MONITORING WELLS

The monitoring wells (M1–M4) have instrumentation installed outside the casing making the inside of the casing available for non-permanent instrumentation and logging tools. Behind casing instrumentation includes:

- Pore pressure sensors in the injection layer (65 m depth) for three wells (M1–M3)
- Electrodes at 16 depths enabling cross-hole Electrical Resistivity Tomography (ERT) measurements
- Commercial fibre-optic cables (straight fibres) in a loop covering all four monitoring wells (see illustration)
- Research fibre-optic cables (helical and straight fibres)

In order to install cables and wires flush along the casings, spacers were mounted about every 10 m. Centralisers ensure that the casing with instrumentation is placed in the centre of the borehole.



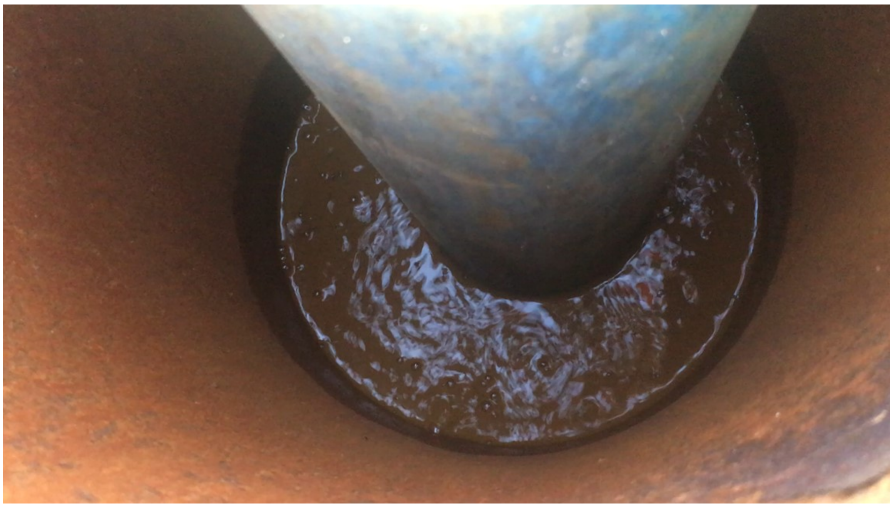


INSTRUMENTATION OF INJECTION WELL (SVELVIK #2)

The injection well is completed to 65 m depth. An injection screen is installed between 64 and 65 m. The bottom of the injection packer is at 63 m. The packer is instrumented with sensors measuring the temperature and pressure of the injected gas/fluid at injection depth.

The annulus between injection tube and casing is spacious enough to allow (temporary) installation of hydrophones, for more complex setups. Currently, a fibre-optic cable is installed in this annulus to record the signature of CO_2 in the injection tubing and in the near-well area on geophysical monitoring data.

During injection, leaking is CO_2 is pushing ground water up above the gravel surface in the annulus between PVC casing and steel ground casing.

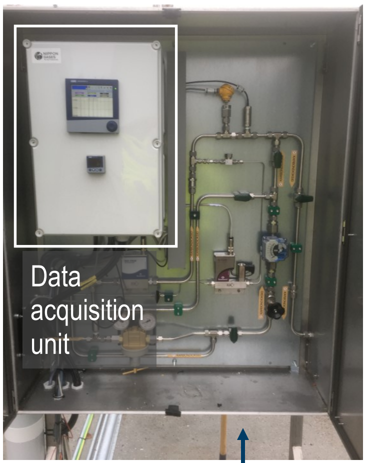


CO_2 INJECTION INFRASTRUCTURE

The infrastructure for CO_2 injection consists of a 6 m^3 tank (max 6 500 kg), an evaporator and a control cabinet for pressure and flow control. In the tank liquid CO_2 is kept at temperature between −35 and −28 °C, corresponding to a boiling point between 12 and 15 bar. The evaporator turns the liquid CO_2 into its gaseous phase by adding heat and thereby increasing the temperature of the CO_2 while the pressure is kept constant (isobaric process).

The CO_2 injection rate is regulated by a mass flow controller (MFC) and can be set with a resolution of 0.01 kg/h. The maximum rate set by the MFC is 18 kg/hour. The maximum rate used in past experiments is 12 kg/hour.

A data acquisition unit with real time display of both CO_2 and brine injections is located inside the CO_2 instrument cabinet.

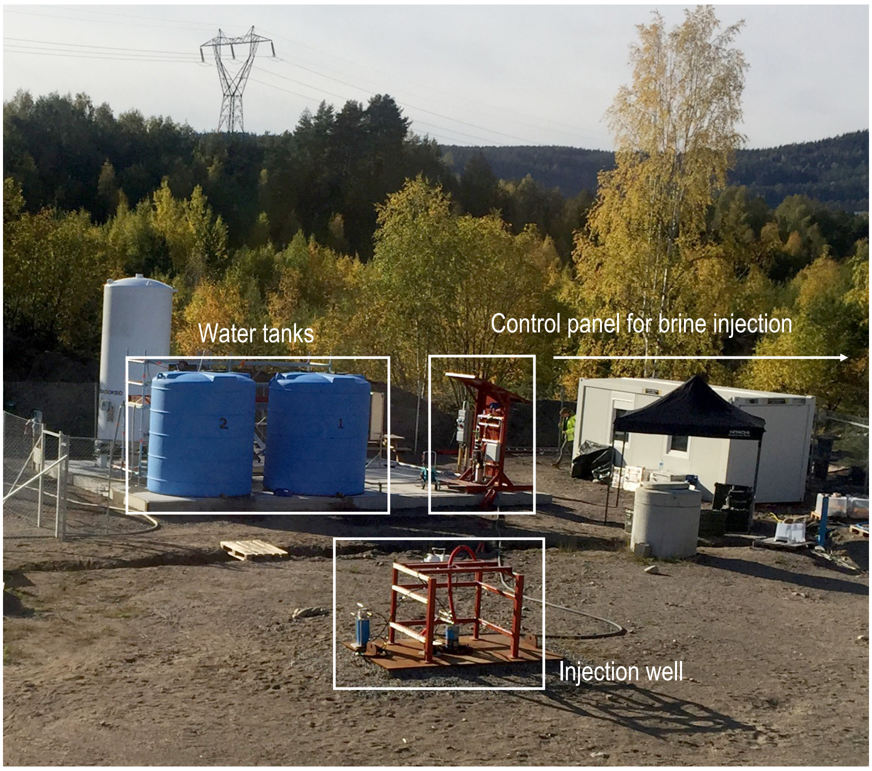


Filling the CO_2 tank with CO_2

INFRASTRUCTURE FOR BRINE INJECTION

The infrastructure for brine injection consists of two 10 m^3 water tanks and an instrument panel for fluid flow control. The dual tank setup allows for preparation of saline injection water without interrupting injection. This is necessary to avoid disrupting resistivity tomography measurements with injected water of a deviating conductivity. The salinity of the pore water in the injection layer is close to the salinity of sea water. This corresponds to 11 sacks of 25 kg NaCl added to fresh water in the water tanks. A custom designed mixing pump aids in rapid dissolution of the salt into the water.

The maximum injection rate, set by the capacity of the centrifugal water pump, is 2 m^3/h. Up to 1.5 m^3/h has been used in past experiments.



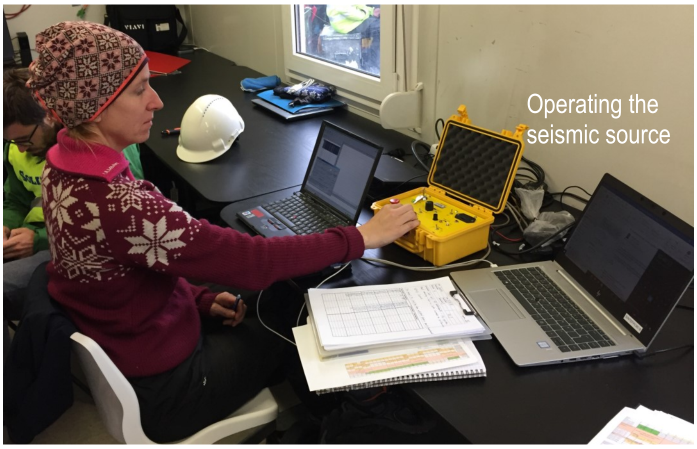
Control panel for brine injection

CONTROL- AND INSTRUMENT CABIN

Brine and CO_2 injection data including topside pressures, temperatures and flow rates, and downhole pressure and temperature are displayed real time on the outdoor control panel and on the injection control system in the control- and instrument cabin. CO_2 injection is controlled manually from the outdoor control cabinet. The brine injection may also be controlled manually from the outdoor control panel or remotely with a Bluetooth-connected iPad.

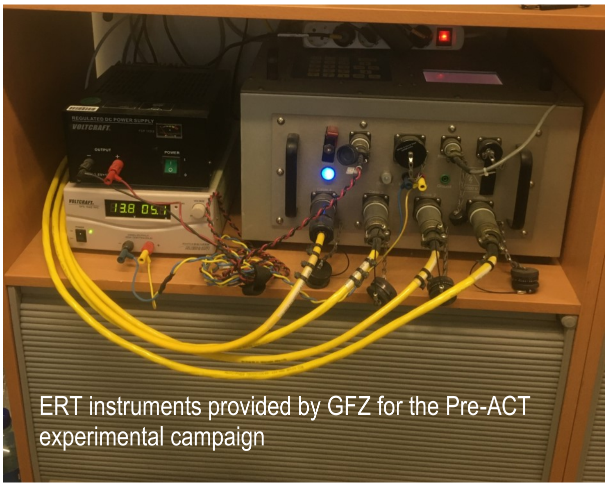
In addition to the injection control system, instruments and data storage systems for downhole sensors are located in the cabin. The seismic source may either be operated outdoor or from inside the cabin, depending on the weather conditions.

Seismic data can be inspected during recording using the acquisition software. Images can also be saved for later retrieval on the computer screens in the cabin.

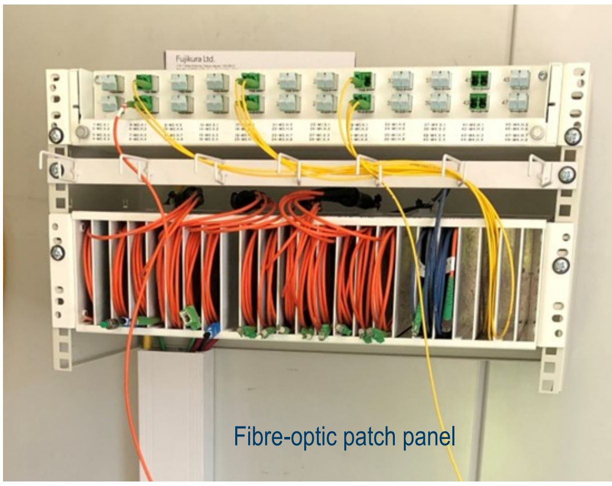


Operating the seismic source

Injection control system



ERT instruments provided by GFZ for the Pre-ACT experimental campaign



Fibre-optic patch panel

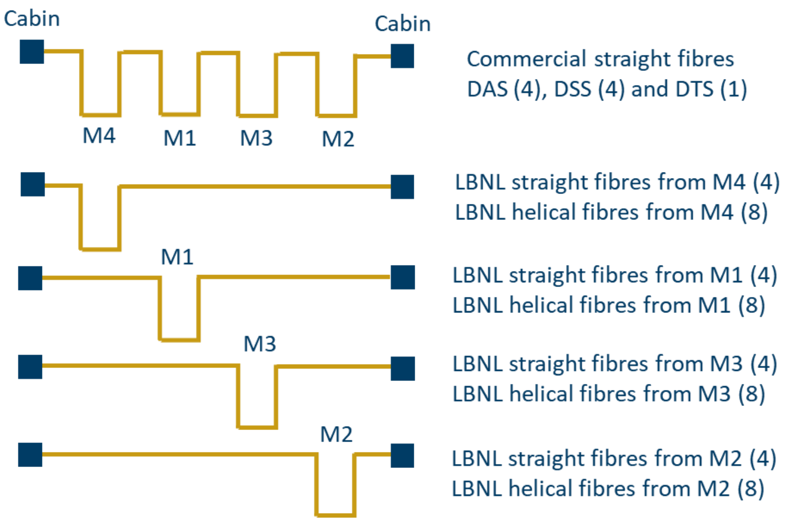
FIBRE-OPTIC DATA COLLECTION

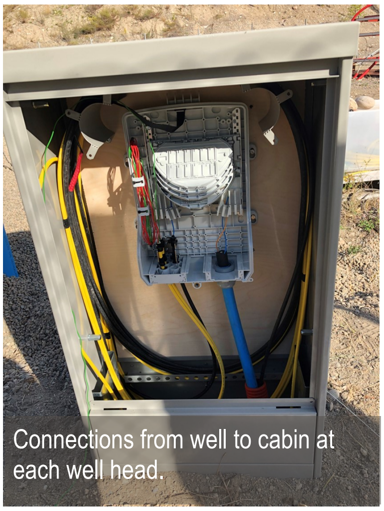
The four monitoring wells M1–M4 are equipped with a range of different fibre-optic cables.

- Commercial straight DAS cables (Distributed Acoustic Sensing) in a loop
- Commercial straight DTS cables (Distributed Temperature Sensing) in a loop
- Commercial straight DTS cables (Distributed Strain Sensing) in loop
- Cable from LBNL with straight DAS and DSS fibres
- Cable from LBNL with helical DAS and DSS fibres

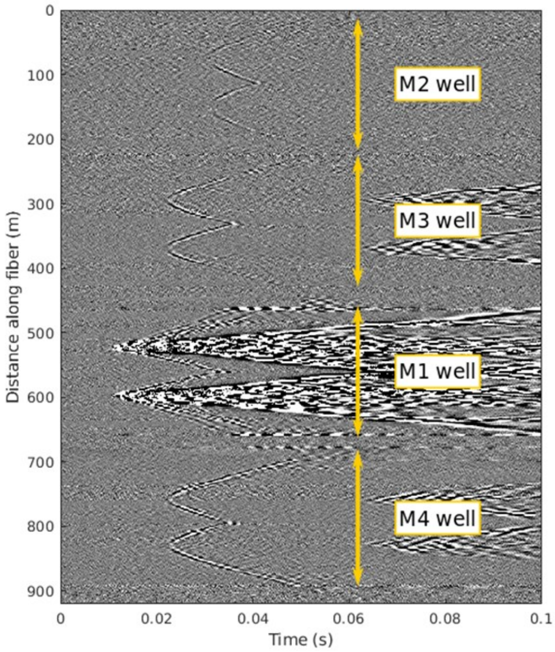
The injection well is equipped with a G4-9/OS2 AICI-I/O/RM cable.

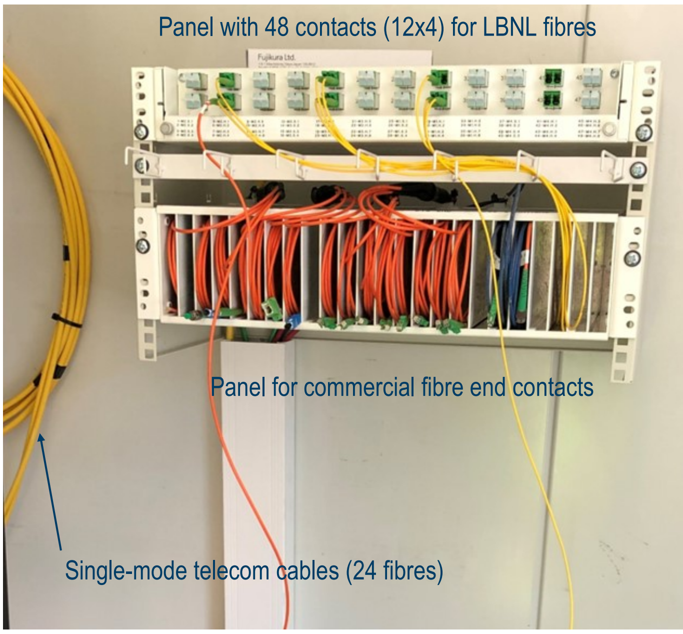
Using the patch panel in the control cabin these cables can be added as desired in to the final logging loop.




Connections from well to cabin at each well head.

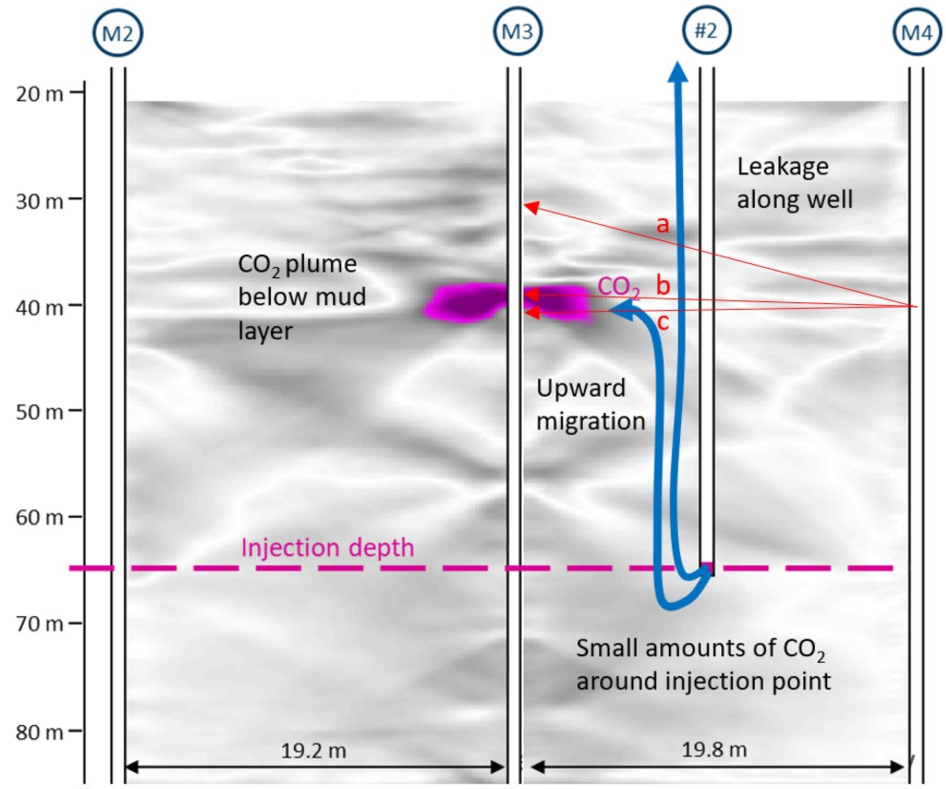
DAS response to seismic shot in M1 well



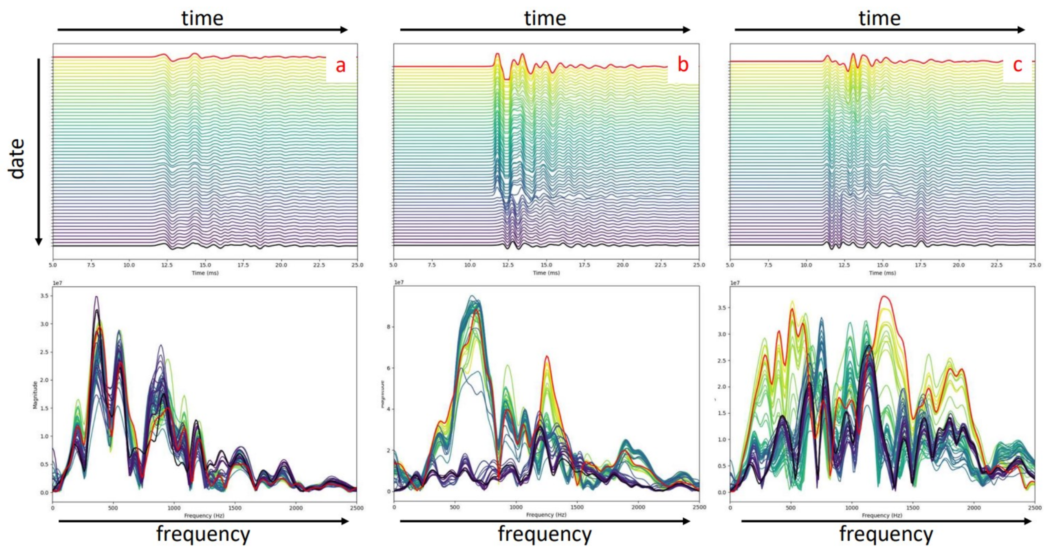


EXAMPLE OF DATA FROM SITE

The purpose of the Svelvik CO_2 Field Lab is to support the development and testing of new technology for CO_2 monitoring, in particular for discrimination and quantification of pressure and saturation during CO_2 injection. Several injection campaigns have been conducted successfully at the field lab, showing high quality and repeatability of acquired data. The campaigns also revealed the behaviour of the injected CO_2 in the subsurface. Both water (brine) and CO_2 can be injected at the site, resulting in subsurface changes in pressure, CO_2 saturation, or both.



Several injection campaigns, conducted since 2019, show the same site behaviour and CO_2 migration when CO_2 is injected: The CO_2 migrates upwards from the injection point and accumulates as a CO_2 plume around well M3 below a mud layer at ~37 m depth. In addition some leakage (~10% of the injected amount) is observed along the outside of the injection well casing. The acquired seismic data shows exceptional data quality and repeatability.



Top: Recorded seismic traces over several days. The red trace serves as the baseline.

Bottom: The frequency content of the recorded seismic traces, colour coded in the same manner as the traces in the top panels.

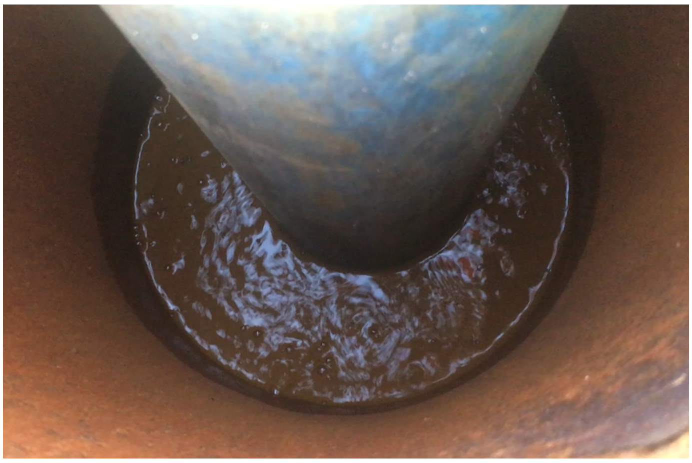
Effect of CO_2 saturation over time along three ray paths in the seal and through the CO_2 plume, at depths **a**, **b**, **c** indicated in the illustration above. Note the change in first arrival time in **b**. Note also the change in frequency content in **c** even without change in first arrival time. This shows the possibility of detecting the signature of small amounts of CO_2.

WELL INTEGRITY MONITORING

Repeated CO_2 injection campaigns since 2019 has demonstrated a repeatable behaviour where some of the injected CO_2 migrates rapidly from the injection interval at 64 m depth to the annulus between the ground casing and the PVC casing of the injection well at the surface. This migration, which must happen at least part of the vertical distance in near proximity to the PVC casing, represents an opportunity to study the acoustic and geophysical signature of CO_2 leaking along an injection well. Observed leakage rates correspond to about 10 % of the injection rate.

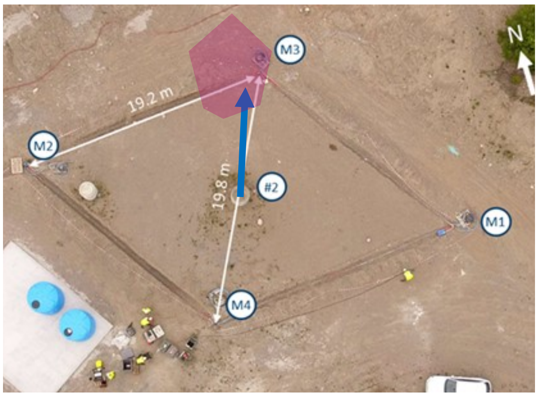
For the purpose of such studies, the injection well was recently instrumented with a loop of fibre-optic cable. The acoustic profile of data recorded during injection and during stops in the injection can now be recorded. The leakage rate and total volume is measured using a gas meter and can serve as reference for leakage detection and quantification experiments.

In addition, as the injected CO_2 migrates from the injection point and accumulates as a plume around well M3 this can be also utilized for testing of well integrity and detection of CO_2 behind casing, e.g., using tube waves.

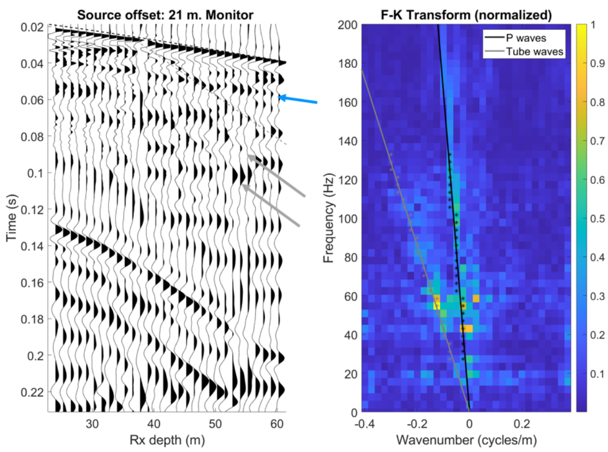


Leakage (CO_2 bubbles) observed along the outside of the injection well PVC casing (blue).

Leakage measurement using a gas meter.



Approximate surface location of the CO_2 plume around well M3 during injection experiments.



Example data showing tube waves that can be used for detection of CO_2 on the outside of the casing of well M3.

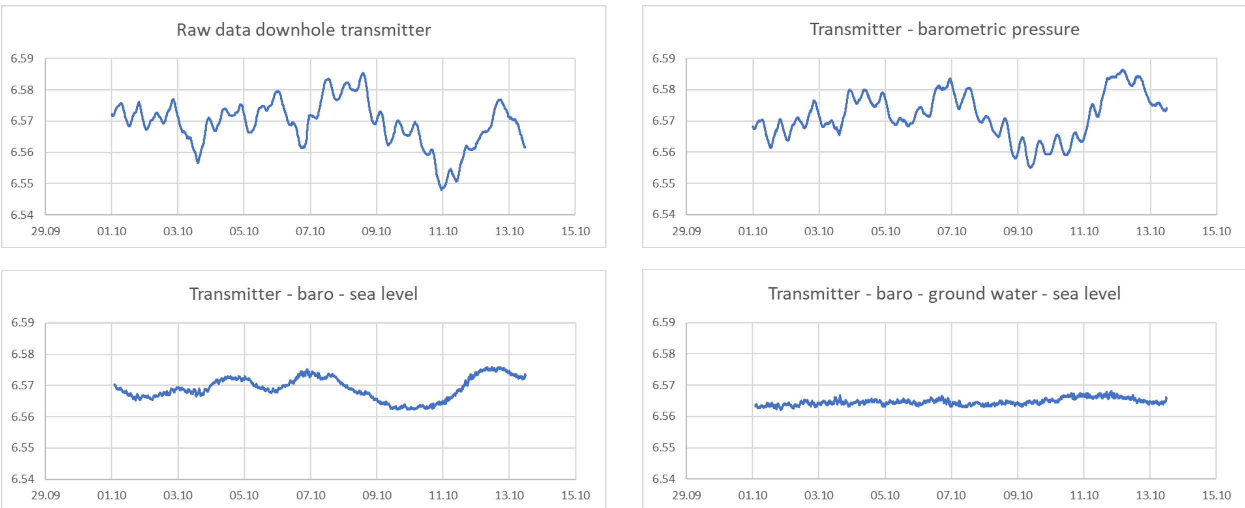
GROUND WATER MONITORING

The location of the Svelvik ridge means that both the deep and shallow aquifers are influenced by the tides. In addition, precipitation will affect the ground water level. The cumulative effect of these influences can be recorded in the signal from the pressure transducers installed in the monitoring wells and in the injection well. In addition, the ground water level in three shallow (~5 m) wells around the field lab site and the water level in the fjord south of the ridge is continuously recorded, along with the local atmospheric pressure is also recorded. This provides us with a rich data set for studies of aquifer systems in a tidally influenced environment.

The local measurement of groundwater level and tides is also useful in the analysis of pressure perturbation from water or CO_2 injection, since the pressure variation from the environmental factors is of the same order of magnitude and need to be removed for easier analysis.

Readout of data from water level monitoring probe in one of the shallow wells at the site.

Below: Gradually removing environmental factors from pressure transmitter data at 65 m depth. This data series is from a time period without activity at the site.



EXAMPLES OF PAST ACTIVITY

Major experimental campaigns through national and international research projects

Pre-ACT — SINTEF-coordinated project (2017–2020) with the aim to equip operators and regulators with recommendations and guidelines for pressure-driven decision-making that enable them to establish a safe and efficient monitoring system to assess qualitatively site conformance. The first experimental campaign with water and CO_2 injection at the field laboratory was conducted within this project, and the project also co-funded the upgrade in 2019.

Digimon — NORCE-coordinated project (2019–2022) with the aim to accelerate the implementation of CCS by developing and demonstrating an affordable, flexible, societally embedded and smart Digital Monitoring early-warning system. An experimental campaign was conducted in 2021 to test cross-well seismic monitoring with DAS data during CO_2 injection.

Muon detection for CO_2 monitoring — Geoptic-run project (2023) where the feasibility of combining seismic monitoring methods with muon detection was tested. The flux of cosmic ray muons into the subsurface will be affected by density contrasts such as when CO_2 displaces formation water.

LINCCS — Aker Solutions-coordinated project (2021–2024) with the aim to develop technologies to accelerate uptake of CCS. An experimental campaign at the field laboratory is underway to study geophysical data related to leakage of CO_2 along the outside of an injection well.

Student projects

A long range of student projects have been conducted associated with the field laboratory, ranging from summer-job assignments to PhD projects. Examples of the topics studied are:

- Simulation of CO_2 migration in shallow sediments
- Use of noble-gas tracers for detection of leakage from CO_2 storage
- Dynamics of shallow and deep aquifers in near-coastal environments
- Use of fibre-optic data in cross-well seismic monitoring
- Analysis of well logs

ACKNOWLEDGEMENTS

The upgrade of the field laboratory was financed by the Norwegian Research Council (RCN) through ECCSEL Infrastructure grants, and by SINTEF. Parts of the upgrade was supported by the ACT Pre-ACT project funded by RCN and Gassnova (Norway), BEIS (UK), RVO (Netherlands) and BMWi (Germany), by the European Commission under Horizon 2020 (ACT Grant Agreement No 691712), and by industry partners Total, Equinor, Shell, and TAQA.

The upgrade was organised and lead by SINTEF. GFZ (Germany) contributed with expertise related to design and installation of the ERT systems, and NORSAR to planning of the fibre-optic DAS installation. Fibre-optic research cables have kindly been provided by Lawrence Berkeley National Laboratory. Anja Sundal, at the time at the University of Oslo, is acknowledged for being the “local geologist” and responsible for updating the geological model of the test site.

The contributions from our sub-contractors are also highly appreciated: Brøndboringsfirmaet Brøker, RUDEN, Marine Tech, Ingeniør Pettersen, Arild’s rør og sveiseservice and Svelviksand.

The field laboratory would not have been possible without the support of Hurum municipality.

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