

# The CCS greensand project: CO<sub>2</sub> pilot injection and monitoring

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**Abstract.** Carbon capture and storage (CCS) is a proven, safe, reliable and affordable technology. CCS entails the capture of CO<sub>2</sub> (e.g. from power plants or industrial facilities) as well as its long-term storage in subsurface geological structures, such as depleted gas and oil reservoirs or deep-lying rock strata known as saline aquifers. This technology enables the reliable and cost-effective decarbonisation of industrial sectors with CO<sub>2</sub> emissions that are difficult or impossible to avoid. The International Energy Agency (IEA) and other leading organisations believe that CCS will play a key role in climate protection efforts and emphasising that ambitious climate targets cannot be achieved without CCS.

In February 2023 INEOS Energy Denmark (Op.), Wintershall Dea and Nordseafonden (Danish State Participation) have been awarded the first Carbon Storage Exploration License (Iris) that covers the Siri oil fairway, a depleting oil production infrastructure hub, offshore Denmark. As part of the License work program it is planned to submit a Storage License Application by February 2024 to commission the first CO<sub>2</sub> permanent storage facility in Denmark by 2025.

Initial research studies to convert the depleted oil field Nini West, one of many oil segments in the Siri Fairway, into a permanent CO<sub>2</sub> storage site started already in 2020 and is called Project Greensand Phase 1 and Phase 2, co-funded by the Danish Energy Development and Demonstration Programme (EUDP).

Project Greensand Phase 2 is a large and comprehensive research and pilot project, consisting of 13 work packages and 120 individual tasks that are worked through by a consortium of 23 research partners, led by INEOS Energy Denmark, with altogether some hundreds of researchers and contributors involved. The project scopes are aiming to de-risk and specify all aspects related to carbon storage in the Nini West segment and to provide key documents ready for submission to the Danish mining authorities. Wintershall Dea is key partner in the research consortium, contributing to all work packages and is leading the monitoring related research scopes.

The Greensand project has cleared a first major hurdle in fall 2020 with the independent 3rd Party certification of the Nini West reservoir as a feasible CO<sub>2</sub> storage. This certification confirms that the reservoir is conceptually suitable for injecting 0.45 million tonnes CO<sub>2</sub> per year per well for a period up to 10-years and that it can safely contain the CO<sub>2</sub> injected.

In August 2021, the consortium moved ahead to the pilot phase. The pilot's first offshore injection was successfully conducted in winter 2022/2023 by injecting 4.000 tons of CO<sub>2</sub> into the depleted Nini West oil field and demonstrating the full value chain across international borders. This operation lasted 90 days and included 7 shipments of CO<sub>2</sub> to the Nini site.

The CO<sub>2</sub> was captured and liquified in a chemical plant in Antwerp and loaded into 40 ISO-tanks that were mounted and piped together to an installed rack on a conventional coastal carrier. This low cost custom made transport concept successfully demonstrated temporary carrier solutions for CO<sub>2</sub> shipments until dedicated low-emission CO<sub>2</sub> cargo ships have been designed and constructed.

The pilot injection was accompanied by a focused seismic monitoring program. Despite unfavorable weather conditions one baseline and two monitor seismic acquisitions have been successfully completed as part of Project Greensand to monitor the CO<sub>2</sub> plume migration more frequently and with less impact on the environment [1, 2, 3].

The seismic data has been retrieved, processed and analyzed. Based on the results it is possible to detect the CO<sub>2</sub> presence inside the reservoir [4, 5]. Prior to injection a dynamic simulation provided results on the expected areal coverage of the CO<sub>2</sub> plume. A pattern of 7 spots was planned to detect the presence of the CO<sub>2</sub> with our novel focused seismic concept. Some locations were expected to show an effect caused by the CO<sub>2</sub> plume, some spots should confirm the absence of CO<sub>2</sub>. After processing of the monitoring spot gathers and evaluation of the difference traces, a qualitative result was provided for the individual spots. All spots were targeted more than once by different source and receiver locations to get a confirmation from measurements at different offsets and/or azimuths. A strong positive response can be seen directly at the injection location, a medium amplitude response for an up-dip spot towards north-east. All other spots do not show presence of CO<sub>2</sub> in their spot seismic monitoring results as predicted by dynamic simulation.

This spot seismic method has the potential to replace 4D seismic for CO<sub>2</sub> plume monitoring and verification during the full field injection and post injection phases and could thus significantly reduce cost and environmental impact.

Further, the partners in the Greensand research consortium of monitoring scopes are developing sea floor sensors [6] that are able to detect and record CO<sub>2</sub> leakage and seismicity. These sensors will be connected to a power and data hub offshore to ensure data communication in real time.

For INEOS Energy and Wintershall Dea, Greensand is a pioneering CCS project as it ranks among the most advanced CCS projects in EU. Beyond the Nini West storage complex, work is ongoing to mature the remaining depleted oil field and aquifer potential in the Siri Fairway with the view to expand the capacity to up to 8 MTA until 2030. The entire CCS value chain (capture, transport, and storage) will be implemented across borders.

**Keywords:** CCS, greensand, monitoring, focused seismic, water column sensors.

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