Memo
March 2009

Is Sleipner Broken?

The Sleipner Project, operated by Statoil in the North Sea about 250 km off the coast of Norway, was the first commercial scale project dedicated to geological CO_2 storage in a saline formation called the "Utsira" formation. The source of the CO_2 is the Sleipner West gas field, where it is separated from natural gas, and then injected into a saline formation 800m below the seabed of the North Sea. From 1995, the IEA Greenhouse Gas R&D Programme has worked with Statoil to oversee and coordinate the monitoring and research activities. Approximately 1 $MtCO_2$ is injected underground annually in the field. The CO_2 injection operation started in October 1996. The fate and transport of the CO_2 plume in the storage formation has been monitored successfully by seismic time-lapse surveys, which also show that the caprock is an effective seal that prevents CO_2 migration out of the storage formation. Overall, the Sleipner experience to date has produced strong evidence in support of the safety and efficacy of permanent geologic CO_2 sequestration.

The Tordis Incident

An unrelated incident that took place in May 2008 at the Tordis oilfield, about 300km North of the Sleipner project, has led some to question the effectiveness of the Sleipner injection and CO_2 sequestration more generally. A closer look however reveals that Sleipner is still intact, and that the Tordis incident does not call sequestration into question – although it does highlight the need for good operational practices and adequate regulatory oversight.

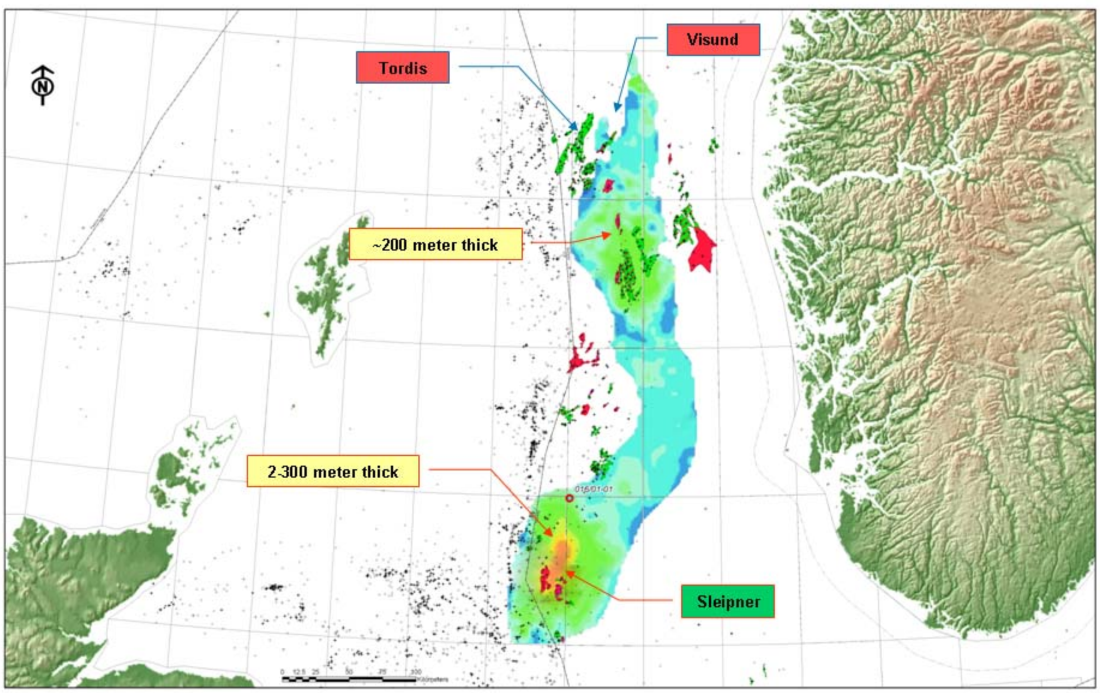
Tordis is not a CO_2 sequestration project, and no CO_2 was involved in the operations. Instead, it is an oil production project utilizing a technique known as "subsea processing" that aims to increase oil recovery, reduce water discharges and reduce energy consumption.[1] According to operator Statoil, produced water from the Tordis oilfield was being re-injected into the Utsira formation. The reinjection of produced water caused pressure build-up in the Utsira formation which eventually resulted in some fluid leakage to the sea bottom. Monitoring instruments detected unexpected injection pressure drops. Shortly thereafter, a sheen of oil was evident at the sea-surface and injection of produced water was stopped. An investigation was launched and an incident report issued.[2]

[1] See for example: http://www.statoilhydro.com/no/ouroperations/explorationprod/ncs/tordis/pages/default.aspx

[2] Available only in Norwegian to date.

The Tordis incident is unrelated to Sleipner for a number of reasons:

- Even though Tordis and Sleipner were injecting into the same geologic formation (the Utsira formation), the two fields are 300km apart. The maximum lateral extent of the CO_2 plume at Sleipner CO_2 storage project is around 3km, or 1/100th of the distance between Tordis and Sleipner. It is not possible that CO_2 from the storage project could move 300 km to the site of the Tordis incident.
- Lithologically, Tordis and Sleipner are very different. Tordis is on the very edge of the sedimentary basin, where the Utsira formation does not feature the sequence of thick sealing layers nor the thick and permeable injection zone that is present at Sleipner. The same holds true for the Visund and Ringhorne fields, where similar incidents have been reported. None of these fields would have ever passed the screening criteria for CO_2 sequestration. Based on the permeability of the rocks in the Utsira Fomation near the Tordis Oilfield, the injectivity[3] at Tordis is estimated to be at best 1/10th of that at Sleipner. Moreover, since water is greater than 10 times more viscous than CO_2, injection into the Utsira at the Tordis oilfield requires much higher injection pressures than the CO_2 storage project at Sleipner and consequently, injection is much more likely to fracture the reservoir and caprock at Tordis than at Sleipner. In fact, there is no evidence nor any reason to believe that the Sleipner injection has had any impact on the caprock whatsoever.



Source: Statoil

The relation and analogues between Tordis and Sleipner are therefore limited. A carefully selected and operated site like Sleipner for the specific purpose permanently storing CO_2,

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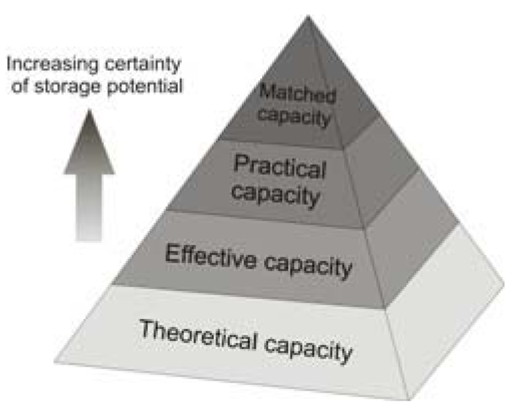
3 "Injectivity" is a measure of the rate at which a quantity of fluid can be injected into a well.

located in a prime spot in the target formation is very different to an oilfield operation at the edge of the formation that has not undergone the same screening and where the primary purpose of the injection is to improve project economics and minimize discharges by re-injecting a fluid that could have been released intentionally instead.

There are lessons to be learned from experiences like Tordis, however. According to Statoil[4] "high pressure reinjection of water should not have taken place in this particular area due to the injectivity properties of the Utsira formation in the Tordis region". The experience highlights the need for sound operating practices and adequate regulation of CO_2 injection. Adequate siting criteria should ensure that sites with the necessary sealing stratigraphy are selected. Operating conditions should not be allowed to stress the formation beyond safe limits that could compromise its integrity. Management of sequestration sites should be performed by competent operators and regulators. All of today's sequestration projects, including Sleipner, have been successful in that respect so far.

The Storage Capacity of the Utsira Formation

Initial estimates placed the theoretical storage capacity of the Utsira formation at several hundred billion tonnes of CO_2, a capacity that could sequester many centuries' worth of European CO_2 emissions. Recent estimates are lower, with the latest studies indicating that cost effective utilization of the reservoir could sequester 20 to 60 billion tonnes of CO_2. This is still a very large capacity capable of accommodating decades' worth of European emissions. More importantly though, the downwards revision in capacity is to be expected, and does not cast doubts on the safety or efficacy of sequestration in the Utsira or elsewhere. Initial capacity estimates are conducted on a theoretical basis based purely on the estimated pore volume. Later estimates also incorporate geologic and risk constraints (leading to an "effective" capacity estimate), regulatory, economic and legal factors (leading to a "matched" capacity estimate) and finally produce a "matched" capacity estimate when a storage site is matched to a single point source.



Source: Geological Society[5]

[4] "Tordis and CCS Memo", Statoil, available by request.
[5] http://www.geolsoc.org.uk/page4689_en.html

Sleipner Today

Sleipner today remains a very valuable and successful sequestration project. The footprint of the CO_2 plume extends over an area of approximately $5km^2$. Reservoir studies and simulations covering hundreds to thousands of years have shown that CO_2 will eventually dissolve in the pore water, which will become heavier and sink, thus further reducing the potential for long-term leakage.[6] The ongoing CO_2 injection at Sleipner has demonstrated that 2/3 of the injected CO_2 has not reached the top of the Utsira formation where the main sealing layer is located, but has instead migrated laterally below additional imperfect intra-reservoir seals that further limit the movement of the CO_2. This additional trapping below the structural spill point in the Utsira formation is due to local mini-traps, capillary flow resistance, and the hydrodynamic drive of the injection. About 40 % of the CO_2 that has entered the pore systems will remain as "residually trapped" CO_2 (i.e. immobilized by capillary forces and not by the caprock – which adds redundancy to the trapping).[7] The rest will remain safely trapped below the caprock and eventually, over thousands of years, dissolve into the salty water in the Utsira formation. The latest set of seismic monitoring results from Sleipner released in 2009 yet again confirmed the trapped nature of the CO_2 and the effectiveness of the storage.[8]

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Note: The information in this memo is based on data available in February 2009 and on the Norwegian version of the Tordis incident report. The memo will be updated if any new data becomes available and/or when the report is translated into English.

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[6] IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [Metz, B., O. Davidson, H. C. de Coninck, M. Loos, and L. A. Meyer (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA (2005), Box 5.1, p. 202.
[7] "Storage of CO_2 in saline aquifers – lessons learned from 10 years of injection into the Utsira Formation in the Sleipner area", Christian Hermanrud et. al., proceedings of GHGT9 conference, December 2009.
[8] See for example "StatoilHydro says subsea carbon store does not leak", Reuters, 03/05/2009, http://www.reuters.com/article/environmentNews/idUSTRE5245YT20090305?feedType=RSS&feedName=environmentNews