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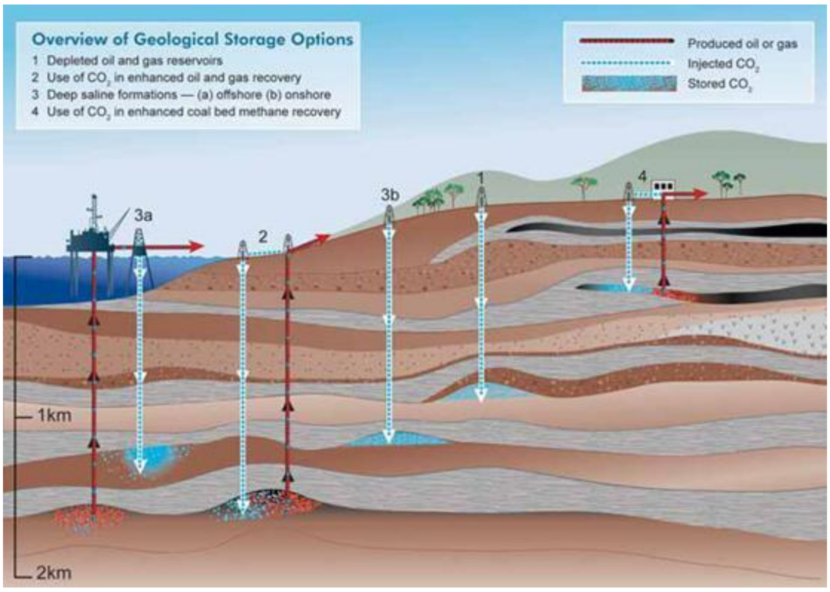
Note

CO_2 Storage

An overview



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Abstract

This note is a brief introduction to why, where and how to store CO_2.

Figure on front page is taken from CARBON DIOXIDE CAPTURE AND STORAGE, Intergovernmental Panel on Climate Change (IPCC) Special Report (2005).

Keywords	
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Availability	Open
Project number	
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Contents

1 Introduction

Geological storage of CO_2 is a technology for reducing the rate with which anthropogenic CO_2 is emitted into the atmosphere, and thereby mitigate the amount of greenhouse gases and limit the rise in global temperatures. Geological storage aims at being a bridging technology on the road towards widespread use of renewable energy resources and other sustainable technologies. It should not serve as a means to continue the high use of fossil fuels [1].

The idea is to inject CO_2 into underground storage sites and make sure it stays there for the unforeseeable future. This raises concerns and challenges on many different levels, such as what are appropriate storage sites, how to capture, transport, and inject the CO_2, how to ensure it stays underground, how to ensure the storage does not have unwanted consequences.

This note provides a limited overview of some aspects related to CO_2 storage. For selected topics, such as monitoring, we provide more in-depth information for specific cases. The note does not discuss CO_2 capture and transport. Our main concerns are related to the petroleum industry, and not with for instance coal beds.

2 Basics on CO_2 emission

Anthropogenic CO_2 is presently emitted at an annual rate of around 10 gigatons [2]. Important sources are combustion of coal, oil, and natural gas; and also cement manufacturing, fertilizer plants, petrochemical industry, and industry gas contribute significantly.

The annual Norwegian emittance of greenhouse gases for the years 1990 through 2008 is shown in Figure 1, taken from [3]. In 2008 CO_2 contributed with close to 45 million tons.

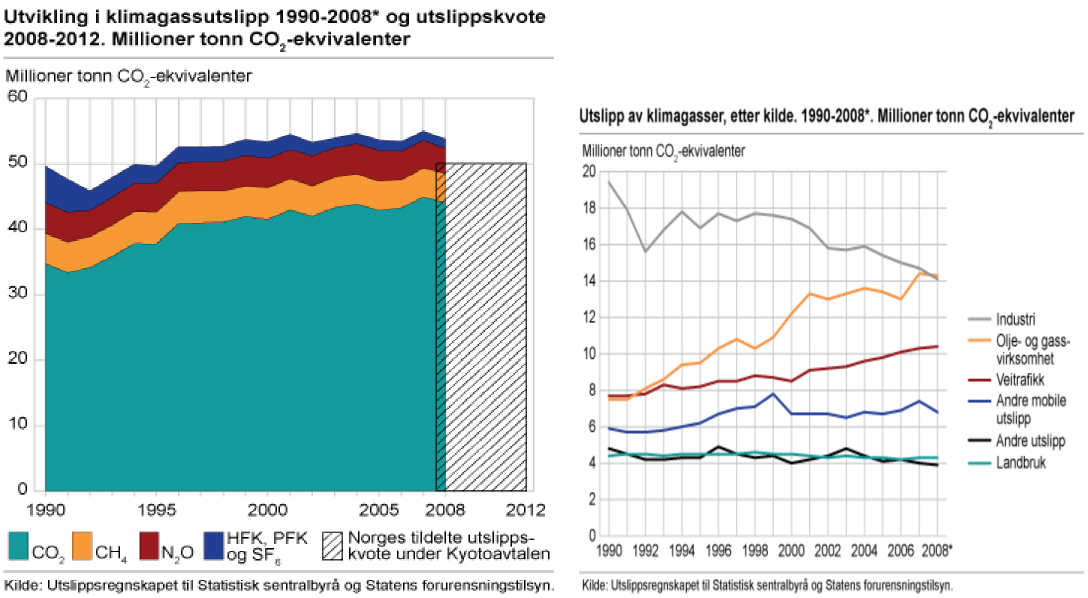

Figure 1: Norwegian annual emittance of greenhouse gases.

To put numbers into even finer perspective:

- Statistics Norway (Statistisk Sentralbyrå) reports that the annual Norwegian CO_2 emittance from private cars and other light vehicles in 2007 was roughly 7.3 million tons [3].

- According to http://www.carpages.co.uk/co2/ the average CO_2 emission from a car in the UK is 173 g/km. Hence a car that drives 10,000 km a year has an annual emittance rate of 1.73 tons CO_2.

2.1 CO_2 monitoring

CO_2 is normally not toxic to living organisms. The amount of CO_2 in the atmosphere is slightly lower than 0.04%, and a small leakage from a geological storage would normally not be hazardous. Large CO_2 concentrations do however imply real danger; in a meeting room a fraction of 1% makes us feel drowsy and uncomfortable, while a concentration of 8% is life threatening. Life threatening concentrations can be reached if CO_2 is trapped in for instance deep, not-aired valleys. Hence it is imperative to ensure that leakage from geological storage will never give high concentrations in air, not even locally. There are two main reasons for also wanting to prevent smaller, non-hazardous leaks through the earth's crust:

- The public opinion and general feel of safety demands operators to ensure leakage does not happen;

- From an environmental perspective the whole point about geological storage is to prevent CO_2 from entering the atmosphere.

Furthermore, for onshore storage it is also important to ensure that injected CO_2 does not affect the ground water resources. If CO_2 leaks into drinking water reservoirs it may cause leaching, release, and mobilization of contaminants such as arsenic, lead, and organic compounds, or degrade water quality by forcing saltier formation fluid into the reservoir [4].

It is obvious that proper control, such as site characterization and monitoring, of geologically stored CO_2 is a strongly advisable ingredient of any storage project. Two more aspects make sound control paramount as CO_2 capture and storage increasingly gain interest from the society:

- Legal regulations for CO_2 storage already exist, for instance in the European Union [1], and there is no reason to believe regulation requirements will be lessened in the future;

- Commercial interests, for instance trade of emission quotas, will increasingly demand reliable monitoring programs.

2.2 CO_2 physical properties

The melting point of CO_2 is -78°C (sublimation), and the boiling point is -57°C, both for a pressure of 1 bar. Source: http://en.wikipedia.org/wiki/Carbon_dioxide. The phase diagram of CO_2 (Figure 2) shows that the critical point is at 73.8 bar[i] and 31.1 °C. These temperature and pressure values often correspond to physical conditions at injection point. Near the critical point a small change in temperature has a huge impact on density. For this reason the density is

[i] 1 bar = 10^5 Pa = 10^5 N/m^2. 1 bar is roughly equal to the atmospheric pressure on Earth at sea level.

hard to monitor, and thus it is difficult to be very precise on mass monitoring. CO_2 is highly compressive [5], and hence a large change in seismic velocity will often be expected.

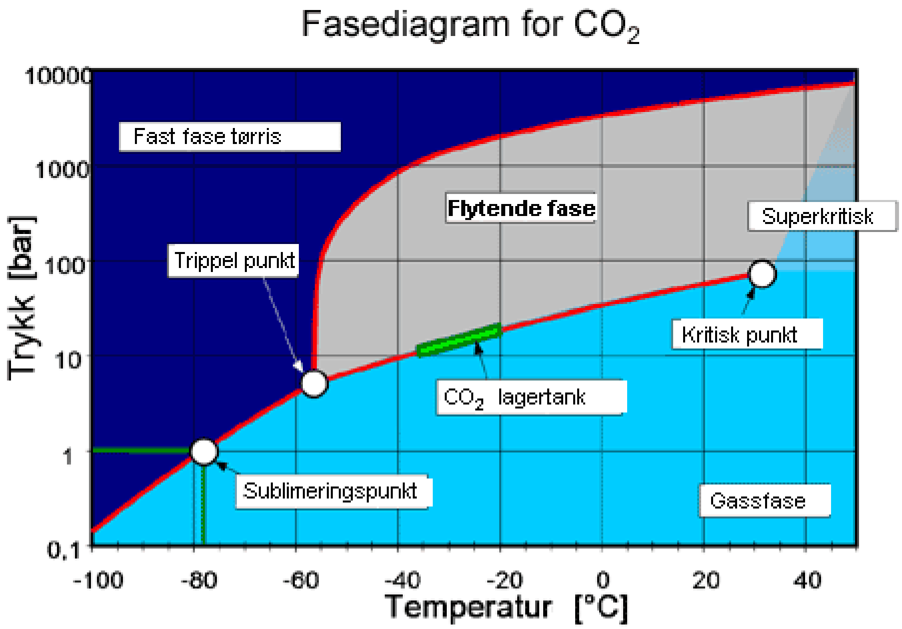

Figure 2: CO_2 phase diagram.

3 Existing storage programs around the world

There are several modes of geological storage of CO_2:

- Depleted gas and oil reservoirs
- Deep saline aquifer formations
- Enhanced Oil Recovery
- Coalbed formations

There are two purposes for geological storage of CO_2. One is for enhanced oil recovery, where CO_2 is pumped into the reservoir to be able to get more oil out. The other purpose is storage for environmental reasons, to reduce CO_2 emitted to the atmosphere. The Sleipner field was the first place with CO_2 storage for environmental reasons. The Utsira formation, used for CO_2 storage at the Sleipner field, is a deep saline aquifer formation.

Depleted reservoirs are readily available storage sites because they are thoroughly characterized, with large amounts of data being available. They often offer suitable pressure regimes for CO_2 injection and storage, and there are already existing wells.

Deep saline formations are promising for storage because they are larger than depleted reservoirs, and they are often located above or below known oil or gas reservoirs. The site characterization methods are similar to those for oil and gas reservoirs.

In Figure 3, planned and current locations for CO_2 storage are shown in a map. For some selected sites, Table 1 provides more information.

There are also projects on so-called Enhanced Coal Bed Methane recovery (ECMR), the use of CO_2 to enhance the recovery of the methane present in unminable coal beds through the preferential adsorption of CO_2 on coal. Examples of such projects are Frio (USA), Fenn Big Valley (Canada), Quinshui Basin (China), Yubari (Japan), and Recopol (Poland).

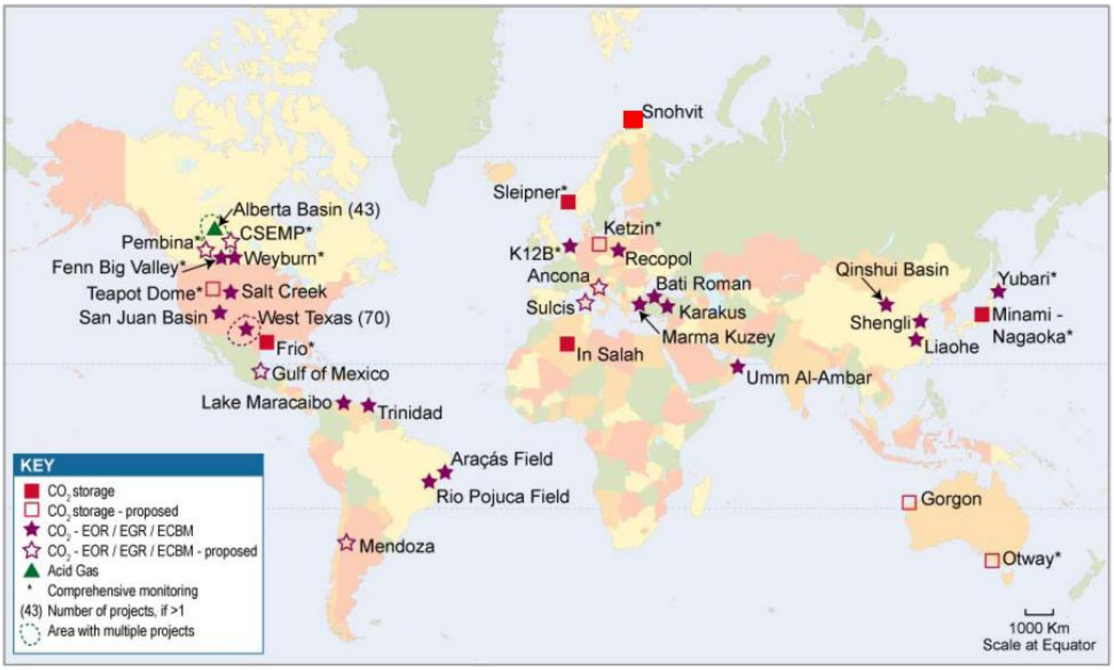

Figure 3: Planned and current locations for geological storage. From [6].

Table 1 Detailed information for some selected CO_2 storage locations.

	Purpose	Start year	Annual storage / Total capacity (million tons)	Geological features	Monitoring techniques
Sleipner, Norway	Gas production from Ty formation, CO_2 separated out and injected into	Gas production from 1993, CO_2 injection	1 / 600,000 in all of Utsira[ii]. Planned storage is 20	Saline aquifer. The Utsira formation is a long, narrow sand stone, 800-1100 m bsl, capped by 200-300 m shale, and water	Seismic (1994, 1999, 2001, 2002, 2004, 2006, 2009?); gravity (2002,

[ii] This corresponds to 600 years of the current CO_2 emission rate from all of Europe's gasworks; 1000 MT per year.

	the higher lying Utsira formation. (Statoil)	from 1996	million tons.	depth around 80 m. Unconsolidated sand with porosity 35-40%. Thin intra- reservoir shales, 1 m thick, 30 m vertical separation. Injection point 1012 m bsl.	2005); EM (?);
In Salah [7], Algeria	Gas production, separating out and reinjecting CO_2 for storage. (BP, Sonatrach, Statoil)	2004	1 / 17	Deep saline downdip of gas producing horizon: 20 meters sand stone interval, 1850 m below ground; porosity 13-20 %; permeability 10 mD. Overburden: 950 m mudstone + 900 m sandstone/mudstone.	Seismic (1997, 2009); InSAR (since 2004); Also tracers; well head preassure; well head fluid samples
Snøhvit, Norway	CO_2 extracted from produced gas and injected into a formation deeper than the gas reservoir. (Statoil)	2008	0.7 / unknown	Storage in saline aquifer in the sand formation Tubåen, at 2600 m bsl. A shale cap rock prevents the CO2 from moving to the surface.	
Weyburn, Canada	CO_2 is transported from North Dakota, USA, to Saschatchewan, Canada and used for Enhances Oil Recovery combined with storage.	2000	1.8 / 20		Oil reservoir (EOR)
Gorgon, Australia		2009 (started?)	3.5 / unknown	Saline aquifer	
Longyearbyen, Svalbard	Pilot project aiming at making Longyearbyen CO_2 neutral (coal mines and energy plant).				
Stogit's Cortemaggiore field, Italy	Current Eni-Stogit system is underground storage of natural gas, but the Cortemaggiore is planned to be a CO_2 injection	Monitoring since 2002		Eni-Stogit consists of eight fields, 1000-1500 m, sealed by shale. High operating pressures desired for the natural gas storage, mentioned numbers are 159-180 bar,	Pressure data, microgravity, seismic, ++

	pilot project (CO_2 as cushion gas during storage of natural gas)			but not clear of these are the pressures the CO_2 will be exposed to.	
Vacuum field, New Mexico [7]	Classic HC production area, with CO_2 injection for tertiary recovery	Discovered 1929. CO_2 injection from 1990		Carbonate formation at 1500 m. Many faults, poor lateral and vertical connectivity. Porosity 5-20 %, permeability 5-100 mD	Multi-component seismic
Prudhoe Bay, Alaska [7]	Enormous oil field, with water injection into gas cap. Valuable analog for CO_2 injection into saline water.	1977. Water injection from 2002		Sandstone at 2750 m, overlain by shale/mudstone. Porosity 18-28 %, permeability 450 mD.	Gravity (baseline in 2002 and 2003; yearly monitoring from 2005)

4 Storage life cycle

CO_2 capture and storage projects are divided in four phases [7]:

- Site selection and development (3 – 10 years).
- Operation (over decades). This period includes the entire period of gas injection, plus some years of additional monitoring.
- Closure (over years). Begins when monitoring indicates that injected CO_2 is well-managed. Most wells are plugged and infrastructure is removed.
- Post-closure. The operator is no longer involved.

The risk associated with injected CO_2 is not constant with time. The probability of leakage increases as volumes and subsurface pressure increase and this requires close monitoring during the operation phase. The most effective way to minimize risk is to start with wisely chosen storage sites.

4.1 Storage site characteristics

Three elements are essential to consider CO_2 storage in a location:

- Sufficient pore volume to store all the gas.
- An overlying sealing to ensure containment.

- Injection from the wellbore must be possible.

The depth should be below 800-1000m, where CO_2 is compressed to a dense phase. This enhances both capacity and containment ability. The pore volume available for containment depends on formation thickness, porosity, density of CO_2 and storage efficiency (fraction of pore volume actually saturated with CO_2). Containment depends on geometry and distribution of rocks and pressure systems that avoid fluid to flow in the subsurface. Injectivity depends on permeability.

4.2 CO_2 trapping mechanisms

When CO_2 is injected in a reservoir, the pores are being filled. In most cases the pores were already filled with water, which is then replaced by CO_2.

A number of different trapping mechanisms exist:

- Structural trapping – accumulation under cap rock. This is the most important mechanism.

- CO_2 residual gas trapping. Pores are so small that CO_2 can not move upwards.

- Geochemical trapping mechanisms – CO_2 reacts with natural fluids and minerals and leads to permanent storage of CO_2 in the subsurface.

At Utsira it is expected that geochemical reaction between CO_2 and the sand stone will be rather limited, but it may react stronger with the intra-reservoir mudstones layers [8].

5 Monitoring methods

Monitoring is done to verify that storage is working as expected. Successful monitoring depends on selecting the right tool for the job.

Table 2 and Table 3 give an overview of important monitoring techniques for detecting seal integrity, fault integrity, well integrity, ground movement and/or leakage of saline fluids. The two tables refer to the use of (near) surface methods and monitoring wells, respectively, and are taken from [9]. In addition, well integrity can be monitored by various injection well monitoring techniques, while pressure and chemical sniffers can be buried above top-seal and used to detect pressure increase and CO_2 concentrations above some threshold.

Table 2 Monitoring techniques, (near) surface methods.

	Seal integrity	**Fault integrity**	**Well integrity**	**Ground movement**	**Leakage of saline fluids**
Time-lapse seismic	Gas pocket detection	Gas chimney	Only accumulations at	Not likely	Not likely
Time-lapse	Anomalies in overburden	Possibly gas		Possible	

gravity	(low resolution)	chimneys	intermediate levels		
Time-lapse EM	Anomalies in shallow overburden (low resolution)	Not likely	—	—	Possibly very shallow
Concentration measurements (sniffers)				—	—
Flux measurements	Only when seafloor is reached at measured location			—	—
Isotop contents				—	—
Groundwater samples	Only when aquifer below seafloor is reached			—	
InSar (onshore only)	—	—	—	Only onshore	—

Table 3 Monitoring techniques, monitoring wells.

	Seal integrity	Fault integrity	Well integrity	Ground movement	Leakage of saline fluids
Offset VSP	Gas pocket detection	Gas chimney	Only accumulations at intermediate levels	—	—
Cross-well seismics	Gas pocket detection	Gas chimney	Anomalies in first arrivals	—	—
Cross-well EM	Gas pocket detection (low resolution)	Possibly gas chiemney detection as anomaly	—	—	Possibly changes in signal (not very likely)
Microseismic	In case the seal is fractured by the CO_2	In case of fault (re-)activation	—	Yes (if detectable)	—

	pressure				
Pressure (BHP)	Anomaly in behaviour indicates leakage			—	Anomaly in behaviour indicates leakage
DTS or repeated Temp-logging				—	—
Fluid Ph (BH)	Only when measured above the seal		—	—	—
CO_2 detection (neutron, resistivity, gravity, accoustic,…)	In the near-well region measured above the seal	—	In the near-well region measured above the seal	—	—
Fluid sampling	Only when measured above the seal		—	—	Only when measured above the seal

6 Open issues

The lack of uncertainty modeling reported in [10] is a key problem that has not yet been resolved. From [10] "…This demonstrates the resolving power of this technique assuming there is uncertainty only in the gravity; however, there are unaccounted for uncertainties in the modeling, which arise from uncertainties in the seismic data, uncertainties in determining CO_2 saturation from seismic pushdown, and unknown flow geometry from 2002 to 2005."

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