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D501 Status report and analysis of global storage situation

ccsp
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Abstract

CCS is a climate change mitigation tool which captures the CO_2 emissions from power plants and industrial processes, transports them via pipeline or shipping, and then permanently stores the captured CO_2 in depleted oil and gas fields or deep, underground saline formations or other suitable underground layers. Geological storage (CGS) sites should have adequate capacity, injectivity and a sufficiently stable geological environment.

Geological formations in Finland do not appear to offer any storage opportunities but there is a large capacity for storage in some neighbouring regions to Finland. The offshore capacity in Scandinavia is particularly good compared to the rest of Europe and Russia also seems to have a large capacity for storage in depleted hydrocarbon fields.

A number of CCS projects have been in operation since the mid-1990s but the technology would still need to be developed and improved to make it more economical. Nearly all of the operating or committed capture projects are either CO_2 EOR related and/or based on gas processing. Recently, coal mining companies and electricity-generation companies have also started to investigate geological storage as a mitigation option. However, where the cost of capture is relatively high, such as power generation, developing a strong business case for CCS is still a big challenge. At the end of 2011, there were 74 large scale projects across the world (8 in operation, 6 under construction and 60 planned). The 14 committed projects have a total CO_2 storage capacity of 33 Mt CO_2 per year. North America and Europe have most of the large CCS projects followed by Canada, Australia and China. No projects are currently planned in developing countries.

The EU has supported research, development and demonstration of clean coal and CCS technologies for about 20 years and the current roadmap foresees an important role for CCS. The European Emission Trading Scheme is also designed to incentivise companies to invest in CCS but the cost of emissions is still too low. As carbon price is expected to rise in the future companies may in addition have to put up large security sums to cover possible future carbon leakages from their projects. Uncertainty about legislation, public support and project costs have furthermore hampered the CCS development in Europe.

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1 Introduction

It is becoming accepted that anthropogenic activities are disturbing the natural carbon cycle. During 10 000 years before the industrialisation the balance between the geosphere, the biosphere, the ocean and the atmosphere, resulted in small CO_2 concentrations around 280 ppm in the atmosphere (Indermühle et al. 1999). Over the last three centuries the consumption of fossil fuels and land use has increased this amount. About half of the human induced emissions has been absorbed by vegetation and dissolved in the oceans, the latter causing acidification and negative effects on marine life. The remainder has accumulated in the atmosphere where it contributes to the greenhouse effect. Today the concentration in the atmosphere is 387 ppm and experts believe that 450 ppm is a limit beyond which drastic environmental consequences are inevitable (IPCC 2007).

Especially the industrialized world has made great efforts to reduce emissions of carbon dioxide. Large point emissions of fossil CO_2 is internationally primarily from large-scale power generation, where coal, natural gas or oil is used as fuel. Also steel, cement, petroleum and paper industries have large emissions. The EU has stated, as an overall climate goal, the preventing of global warming from increasing with more than two degrees (compared to pre-industrial levels before year 1750) and the concentration of greenhouse gases to be stabilized at about 450 parts per million. The UN's climate panel (International Panel on Climate Change, IPCC) has also made similar statements.

Several strategic technologies are considered which together with the efficiency and savings measures could give the relevant contribution to the necessary reduction in CO_2 emissions. An announcement in 2007 from the European Commission marked that by 2050, global emissions should be reduced by 50% compared to 1990 levels, which requires 60-80% reduction by 2050 in developed countries. EU has also set a binding one-sided target to cut down greenhouse gas emissions 20 % by 2020. According to the burden sharing Finland is to cut down the emissions by 16 % by the year 2020 compared to year 2005, and in addition the share of renewable energy sources in primary energy consumption be raised from 28.5 % to 38 %. This means that extensive measures and vast variety of technologies in industry and especially in energy production are needed.

CCS is a climate change mitigation tool which captures the CO_2 emissions from power plants and industrial processes, transports them via pipeline or shipping, and then permanently stores the captured CO_2 in depleted oil and gas fields or deep, underground saline formations or other suitable underground layers. Recent research makes a strong case that CCS should play a key role in producing cost effective, low-carbon electricity and reducing greenhouse gas emissions from major point sources.

There is no known large-scale potential geological storage site for CO_2 in Finland's territory. Transportation of CO_2 would thus play an important role in application of

CCS in Finland due to the large distances from sources to areas with high potential for storage. The most potential facilities for CO_2 capture are situated in the coastal region of Finland, and ship transportation could therefore be the most viable option especially during early stages of CCS deployment. In Finnish conditions, fixation of CO_2 to mineral matter might offer an alternative for CO_2 storage.

This report is part of the Finnish Carbon Capture and Storage Programme (CCSP), managed by the Technical Research Centre of Finland (VTT). The CCSP covers the whole carbon capture and storage chain from carbon capture to geological storages including public acceptance issues, health and safety aspects and legislative framework of CCS. Timetable of the program is 2011 – 2015. The main objective of the CCSP is to develop technologies and concepts for CCS deployment in Finland, leading to industry pilots and demonstrations by the end of the programme and targeting further to commercial applications emerging from ca. 2020 onwards. This report aims at providing an updated overview of global status and capacity for geological CO_2 storage.

2 CCS – an introduction

The CCS process is usually described in three steps: capture of carbon dioxide from an industrial or combustion process, transport to the storage site and the actual geological storage.

Separation → Transport → Storage

Capture

Depending on the process, or the power plant carbon dioxide can be captured in three different ways. Pre-combustion capture can be achieved for natural gas power plants and gasification power plants. Post-combustion CO_2 capture from flue gases can in turn be implemented as well as in the above-mentioned natural gas and gasification power plants also from solid fuel combustion process. In oxygen (oxyfuel) combustion the combustion takes place in a pure oxygen environment, in which the flue gases mainly will consist of carbon dioxide. Oxyfuel combustion makes carbon dioxide separation easier, because the flue gas does not contain nitrogen.

The separation or capture of carbon dioxide is the most costly part of the system. According to some analysts, this part of the process stands for at least 75% of the total cost. All three options require a lot of energy and the choice of recovery method is evaluated separately in each case. It is estimated that due to carbon capture the fuel consumption would increase by 10-40% and the electricity production cost would increase by 20-90%, depending on the recovery process and the price of fuel (IPCC, 2005). It is currently estimated that future capture technologies will lower the energy consumption by more than half (Teir et al. 2011).

Transport

When carbon dioxide is separated, it shall be transported to a storage location. Transport of carbon dioxide by ship and by pipeline is the main solutions being discussed. Pipeline CO_2 transportation process is well understood as CO_2 pipelines have been used since the 1970s, transporting large volumes of CO_2 to oil fields for enhanced oil recovery (EOR). For example, US pipeline infrastructure has the capacity to carry 50 million tons of CO_2 a year. Technology systems and transport solutions will evolve over time, especially in view to the scale that will be required. Transport systems are likely to evolve from a single pipeline to complex systems interconnecting multiple separation and storage sites both on land and at sea. Before the large-scale pipeline systems develop, ship transport using existing and proven technology will also be an option. Vessels require more logistics of loading and unloading, including intermediate storages. The intermediate storage tank size is limited by the constraints set by the cold, pressurized CO_2 and the material properties. Excavated rock caverns could also be an option and holds promise of cost reductions with increasing storage size. Experience exists from storing propane in underground caverns but effect of stored CO_2 on groundwater/ice needs to be investigated.

Transportation usually takes place in liquid form for reduced transport volume. This means that transport systems must withstand high pressures (> 73.9 bar) or low temperatures (< -50°C). Transport of carbon dioxide places great demands on the strength of materials because it can form corrosive carbonic acid with water. The content of sulphur, oxygen, nitrogen and hydrocarbons must also be limited to prevent formation of corrosive compounds.

Storage

After the capture and transport the carbon dioxide is permanently stored, isolated from the atmosphere. The idea is to recreate a gas field as those found in nature by pumping down CO_2 into the rock. To store CO_2 a porous, permeable formation with a caprock usually at a depth below 800 m is needed. Porosity is required for the space to store, permeability for the ability to inject large quantities of CO_2, caprock to ensure that the CO_2 stays inside the formation and sufficient depth to maximise the quantities stored. Millions of tons need to be stored annually and therefore there are only a few possible storage options available. Storages may be geological formations of sedimentary rocks, as depleted oil and gas fields, saline deep aquifers or porous unmineable coal seams. See next section for more detailed description.

3 CO_2 Geological Storage (CGS)

3.1 Storage

Geological storage of CO_2 can be undertaken in a variety of geological settings in sedimentary basins. Sedimentary basins are depressions or areas of subsidence with infillings of sediments either offshore or onshore. Several types of rock formations are suitable for CO_2 storage (Fig. 3-1). These include depleted oil and gas reservoirs, use of CO_2 in enhanced oil recovery (EOR), deep saline aquifers, deep unmineable coal seam and use of CO_2 in enhanced coal bed methane recovery. Deep, porous rock formations with trapped natural fluids such as oil, natural gas or highly salty and unusable water are common throughout the world. Geologists have found that these formations have the capacity to securely hold vast amounts of CO_2, potentially equivalent to hundreds of years of man-made emissions. In general, geological storage sites should have: adequate capacity, injectivity and a sufficiently stable geological environment.

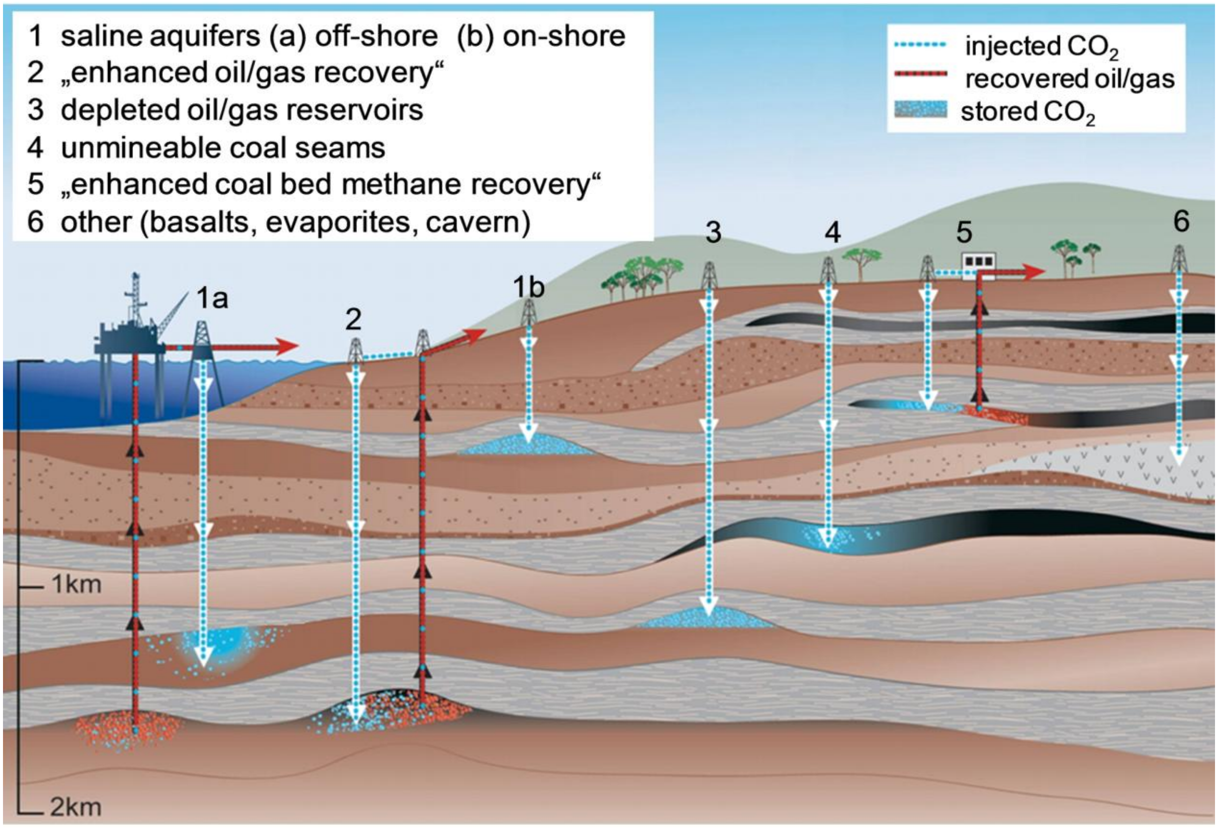

Figure 3-1. Options for storing CO_2 in deep underground geological formations (IPCC, 2005).

Storage potential should preferably be more than what the carbon source generates during its lifetime. Actual storage capacity is generally much smaller than the theoretical, due to a variety of factors. These may be the presence of faults, heterogeneous rock, chemical conditions, temperature, formation pressures, rock stresses, etc. Some of the requirements for geological storage are gathered in Table 3-1 (IPCC 2005).

Adequate porosity and thickness (for storage capacity) and permeability (for injectivity) are critical. The theoretical amount of carbon dioxide that can be stored in the bedrock depends on the total volume of the formation and on the amount of pores, i.e. porosity. Porosity values of at least 15-20% have been set as requirements by some including the CO2STORE project (Chadwick et al 2008), while others refer that the porosity shall exceed only 10%. Another important factor is determining how easy it is to inject the carbon dioxide into the bedrock. Permeability is a measurable parameter that gives an indication how easily fluids and gases can be transported through the rock. Requirements of at least 300 mD are stated (Chadwick et al 2008) but also significantly lower permeability criteria are mentioned. The storage formation should be capped by extensive confining units (such as shale, salt or anhydrite beds) to ensure that CO_2 does not escape into overlying, shallower rock units and ultimately to the surface.

Extensively faulted and fractured sedimentary basins, particularly in seismically active areas, require careful characterization to be good candidates for CO_2 storage. Injection in an aquifer causes pressure increase when the formation fluid in the rock pores is displaced. This pressure increase must not lead to cracking and leakage through the caprock. A certain amount of the pressure is taken up by the compressibility of the formation, but fluids can penetrate the aquifers open borders if the pressure rise is large enough. One advantage of storage in depleted oil and gas fields is that the production of hydrocarbons resulted in a drop in pressure in the formation, which reduces the risk of pressure influence of injection. Storage in large open aquifers is advantageous because of the regional distribution of the pressure while closed aquifers have limited potential for storage, because the formation water can not be pushed aside more than the compressibility and formation integrity allows (IPCC 2005).

Geological storage of CO_2 requires compression of CO_2 to allow injection. This is done by compressing the CO_2 to a dense fluid state known as ‘supercritical’. This supercritical state is achieved by exposing the CO_2 to temperatures higher than 31.1° C and pressure greater than 73.9 bars. The density of CO_2 will increase with depth, until about 800 metres or greater, where the injected CO_2 will be in a dense supercritical state. The injected CO_2 will be in same temperature and pressure as the prevailing conditions in the storage formation. Conditions can be approximated by evaluating the hydrostatic pressure at a similar depth (Fig. 3-2) and at the same time, taking into account the temperature gradient.

The supercritical CO_2 has density that provides the potential for underground storage in the pore spaces of sedimentary rocks. CO_2 can be trapped underground by various storage mechanisms, such as:

1) Trapping below an impermeable, confining layer or caprock (structural and stratigraphic trapping).

2) The CO_2 is retained or adhered on the surfaces of the pore spaces of the storage formation so that it becomes contained as immobile phase (residual CO_2 trapping).

3) Dissolved in the fluids contained in the pore spaces of the formation (solubility trapping).

4) Trapped by reacting with the minerals in the storage formation and caprock to produce carbonate minerals (mineral trapping).

CO_2 becomes less mobile over time as a result of multiple trapping mechanisms, further lowering the prospect of leakage (Fig. 3-3).

Table 3-1. Requirements on CO_2 geological storage (based on Chadwick et al. 2008)

Parameter	Requirement	Comments
Capacity	**> 100 Mt CO_2**	Equivalent production of about 2 Mt of carbon dioxide per year from a source under 50 years. Storage capacity should generally be much larger than what the nearby source produces during its lifetime.
Depth	**800-2500 m**	At around 800 m depth CO_2 enters supercritical state. Below 2500 m depth the rock (aquifer) is generally too dense. Shallower aquifers may be interesting if the carbon dioxide can be injected under positive pressure and still be in supercritical state (Ketzin).
Thickness of formation	**20-50 m**	Net thickness. Can thus be divided into one or more sandstone levels separated by dense rocks.
Porosity	**>10%**	Preferably above 15%.
Temperature	**>31.1°C**	For the CO_2 to enter supercritical state.
Salinity	**>30g/l**	Preferably above 100g/l
Pressure	**>73.9 bars**	For the CO_2 to enter supercritical state.
Permeability	**>200 mD**	Different numbers reported.
Caprock	**Site specific**	Layers of low permeability rock that overlay the storage formation, ensuring that buoyant dense or vapour-phase CO_2 does not leak into overlying strata.

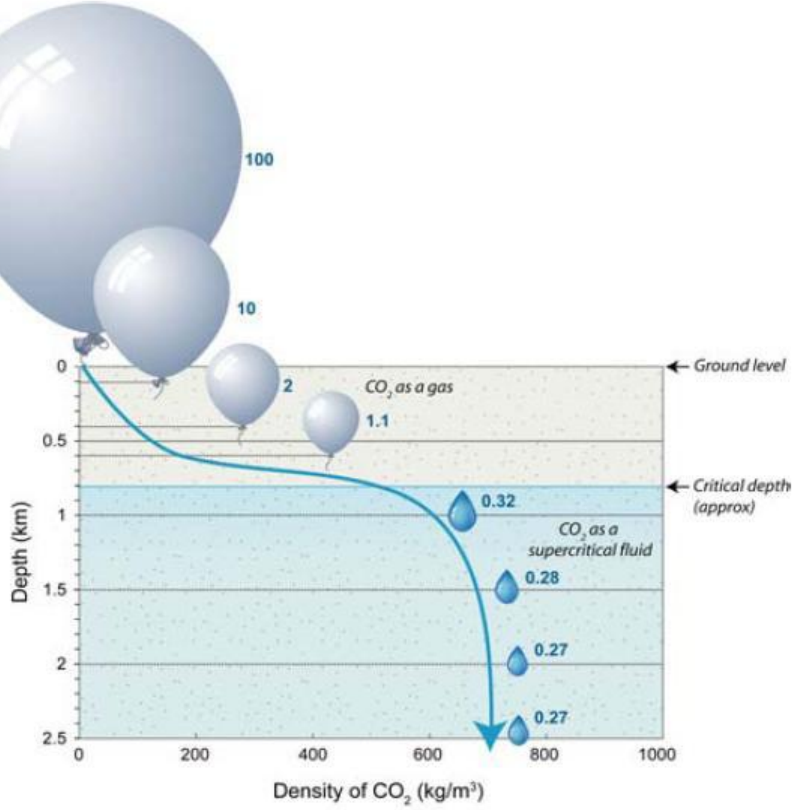

Figure 3-2. CO_2 density by depth approximated by hydrostatic pressure, the geothermal gradient of 25° C/km and ground temperature of 15° C (IPCC, 2005).

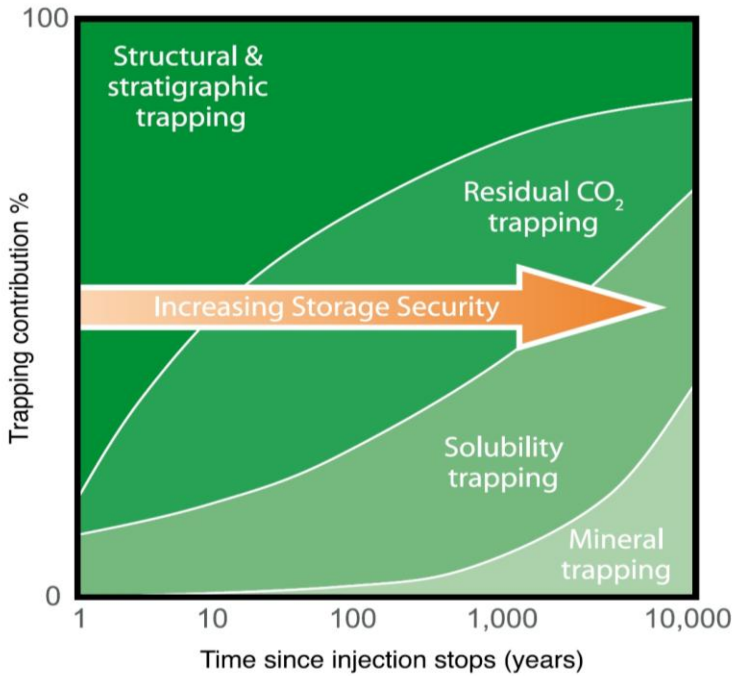

Figure 3-3. The process of residual trapping and geochemical processes of solubility trapping and mineral trapping increase with time (IPCC, 2005).

3.2 Monitoring

Monitoring is an essential activity required to ensure the safety and public acceptability of geological storage. The main monitoring requirements are described in the European Commissions guidance documents on CO_2 storage (EC, 2009). The operator has to carry out monitoring of the injection facilities, the storage complex (including the CO_2 plume) and the surrounding environment. Comparison between the actual and modelled behaviour of CO_2 and formation water is also required to detect, significant irregularities, migration of CO_2, leakage of CO_2, significant adverse effects for the surrounding environment and assessment of the safety and integrity of the storage complex in the short- and long-term.

The EC Directive requires a monitoring plan prepared which shall be prepared in accordance with a risk assessment previously made in connection to the modelling and characterisation of the storage complex and surrounding areas. The monitoring plan shall be updated at least every five year to take account of changes that affect the estimated leakage risks, risks to the environment and health, new scientific knowledge and improvements of existing technology. Through the gradual trapping, solution of CO_2 in formation water and mineralization of CO_2, the risk of leakage reduces over time. Therefore the need for monitoring will also gradually become less significant over time.

A monitoring plan has as its principal target to monitor and control the storage complex and CO_2 prevalence and characteristics over time. In injection wells the injection is checked with respect to pressure in the well and the well head. Furthermore, any leaks in or around the well shall be detected. In case of a leakage, the monitoring has to demonstrate the scale, location and type of leak from the primary aquifer to the surface and atmosphere. It is therefore necessary to have the ability to monitor the CO_2 plume both in supercritical state and in a gas phase.

The parameters that must be included in the monitoring plan are:

1) Leakage of carbon dioxide at injection.
2) The flow, temperature and pressure of carbon dioxide in injection wells (to determine the mass flow volume per time).
3) Chemical analysis of the injected material.
4) The aquifer temperature and pressure (to determine CO_2 state and properties).

Other parameters that can be monitored are:

1) The proportion of dissolved CO_2 and the percentage of mineralisation in the aquifer.
2) Fracture zones or faults forming after the first modelling and characterisation of the storage complex.
3) Groundwater quality with respect to chemical composition.
4) CO_2 concentrations in shallow soil layers.
5) Impacts on surrounding ecosystems.
6) Micro seismic measurements in boreholes, linked to CO_2 injection.

According to the EU directive on geological storage of carbon dioxide, the choice of monitoring technology is based on the best available methods. Many methods for measuring are already proven and primarily being used in the oil and gas industry, but also in other industrial activities. Available methods include: reflection seismic, borehole seismic, electric & electromagnetic, satellite, gravitational, pressure, sampling, IR, temperature and flow measurements.

For most of the carbon storage projects demonstration and verification of monitoring is included as a priority task. The projects have shown that the tested monitoring methods can verify safe and efficient storage. The Sleipner and Weyburn projects have a good follow-up of the CO_2 plumes propagation, and estimation of the aquifer volume (Arts et al. 2004).

3.3 Natural analogues

The timescales needed for the geological storage of carbon dioxide are thousands of years and the industrial demonstration projects allow only injection, reservoir evaluation and for short term monitoring technologies to be tested. Industrial sites are also very unlikely to leak and therefore natural sites give opportunities to study processes controlling leaks and their potential impact on the environment (Lombardi et al. 2006). Before large-scale underground CO_2 storage can take place, it will also be necessary to demonstrate that the processes are well understood. One way of demonstrating that CO_2 can remain trapped for geologically significant times is to provide evidence from existing naturally occurring accumulations. Natural accumulations exist in a variety of geological environments and many have retained CO_2 for periods longer than those being considered for CO_2 storage. Although natural CO_2 accumulations provide greater confidence in the potential to store CO_2, not all natural accumulations should be considered as analogue to a storage situation. Many CO_2-rich seeps and springs occur in volcanic and tectonically active areas which may not be comparable to storage in a sedimentary basin.

Natural accumulations can also be used to test methodologies for geochemical and geomechanical modelling and monitoring of CO_2 leakage. Techniques for monitoring CO_2 in the shallow subsurface are used above repositories to establish baseline conditions and to monitor sites after storage. These can also be tested at naturally leaking sites. Techniques for determining the sealing capacity of caprocks have been tested on natural seals known to retain CO_2 and caprocks from future potential storage sites can be compared with these datasets.

Natural occurrences are common across Europe (Pearce et al. 2004) and occur in a wide variety of settings. Their occurrence is however primarily controlled by the Cenozoic rift sytem and associated Tertiary volcanism. Sources of CO_2 also include mantle degassing and metamorphism of limestones. There are three main types of natural occurrences: CO_2-rich waters at depth and in springs, dry CO_2 gas vents (moffettes) and CO_2 gas accumulations. The CO_2 rich waters are often exploited for mineral waters. The natural CO_2 accumulations in the Pannonian Basin and the small gas pools in the Southeast Basin may be considered the closest analogues to a storage site in the Western Europe, since CO_2 has been trapped here for geological timescales (Lombardi et al. 2006).

3.4 Alternative storage methods

Many alternative storage technologies are also currently being investigated. The possibility of using permafrost as a capping layer has been discussed but future climate scenarios will probably limit this possibility. Mineralisation of CO_2 with calcium- and magnesium-based silicates that react with CO_2 to form environmentally harmless carbonates is promising and has a huge potential worldwide. Analogues are known from natural weathering processes of Ca- and Mg-rich silicates. The major hold-up for this technology is the large amounts of material involved and the carbonation reaction kinetics. Many other carbonation routes and processes with other minerals have also been proposed but suffer from similar problems. Injection of CO_2 into basalt could also be an option. In Iceland a project will start in 2012 where a CO_2-water mixture will be pumped to 500 m into highly reactive fresh basalt. As the CO_2 charged water percolate through the rock the basalt will start dissolving and alteration minerals will form resulting in mineral fixation of carbon.

4 CCS from a Finnish perspective

4.1 Introduction

Finland is aiming at reducing its CO_2 emissions through more efficient energy use, more nuclear power, more use of renewable fuels and through CCS. This will be challenging, since the production and utilization of power and heat is already efficient and the base industry in Finland is very energy-demanding. Developments in CCS, EU's climate and energy policy as well as the directive of geological storage of CO_2, have in recent years, further increased interests for CCS in Finland. CCS does not however, provide an easy answer because there do not seem to be any suitable geological formations for long-term storage of CO_2 in the predominantly crystalline bedrock of Finland (Fig. 4-1).

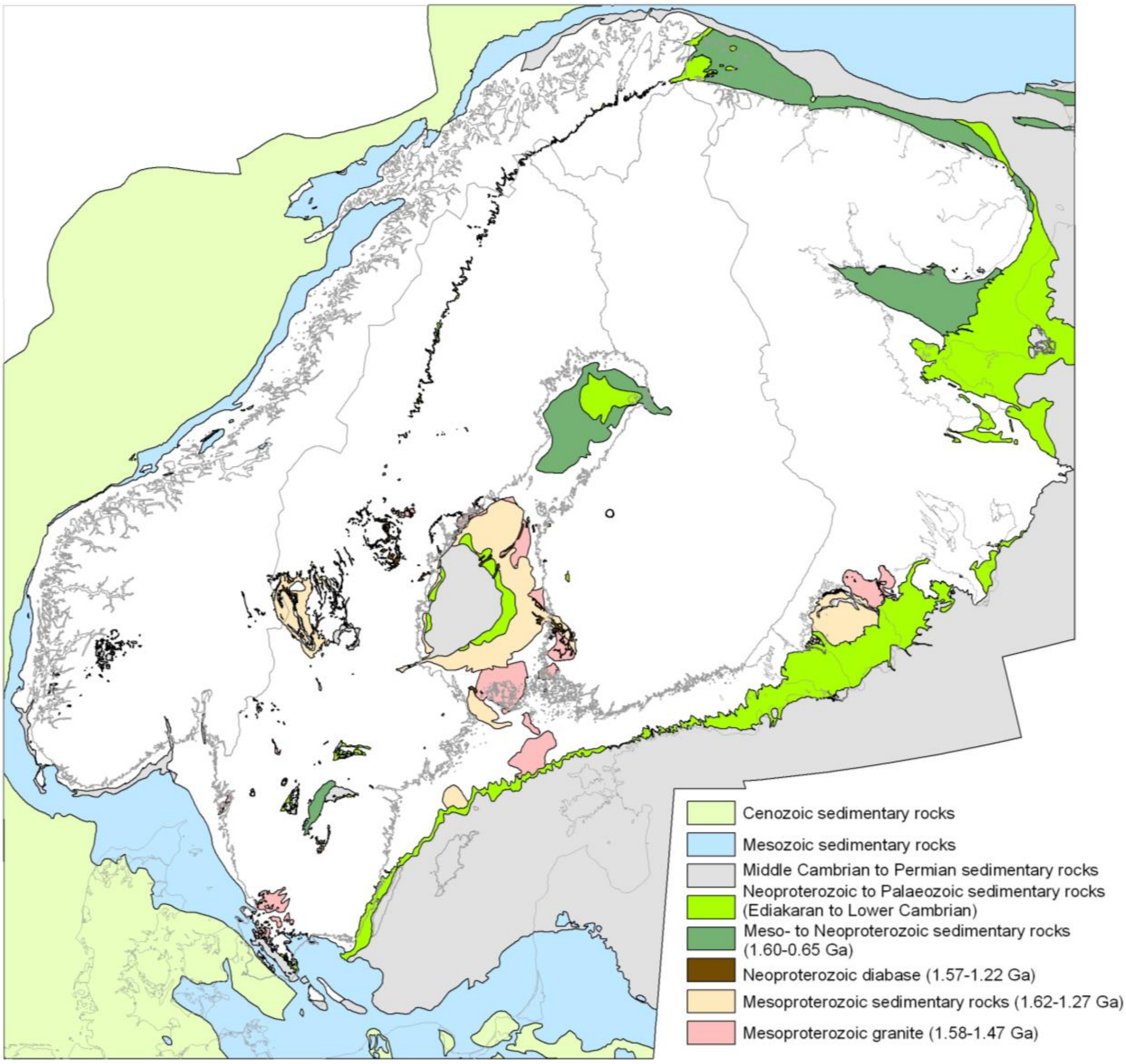

Figure 4-1. Sedimentary rocks on Fennoscandian shield and surrounding areas (Koistinen et al., 2001).

4.2 Geology and storage potential of Finland

The crystalline bedrock of Finland is a part of the Precambrian Fennoscandian Shield (Fig. 4-2). The Archaean area (3500 – 2500 Ma) in northeastern Finland, consisting mainly of tonalitic to granodioritic gneisses and migmatites, forms the oldest part of the Finnish bedrock (Gaál & Gorbatschev 1987, Vaasjoki et al. 2005). Narrow Archaean greenstone belts c. 2800 Ma in age occur within the basement complex. About 2440 Ma ago layered gabbro intrusions were emplaced in northern and NW Finland (Alapieti 1982), together with corresponding mafic dyke swarms (Vuollo 1994). The Archaean craton is discordantly overlain by 2500 - 2000 Ma old metasedimentary and metavolcanic rocks that are cut by 2200 - 1970 Ma diabase dykes (Laajoki 1991). The central and southern parts of the Finnish bedrock comprise Palaeoproterozoic metamorphic and igneous rocks (Gaál & Gorbatschev 1987, Koistinen 1996, Vaasjoki et al. 2005). These rocks developed between 1930 Ma and 1800 Ma, either during one long Svecofennian orogeny (Korsman et al. 1999), or during several separate orogenies (Korja & Heikkinen 2005). Later the crust was intruded by Mesoproterozoic anorogenic rapakivi granites, 1650 – 1540 Ma in age. The youngest basement rocks are the so-called Jotnian sandstones, c. 1400 – 1300 Ma in age, 1270 – 1250 Ma old olivine diabase dykes in south-western Finland, and the 1100 and 1000 Ma old dykes in Salla and Laanila, respectively, in northern Finland.

The bedrock was eroded almost to its present level prior to the beginning of the Cambrian (about 600 million years ago). Due to erosion and continental conditions, it is almost totally lacking in sedimentary rocks younger than the Precambrian (Fig. 4-3). In eastern Finland, kimberlites were emplaced at c. 600 Ma, and in northeastern Finland there is one alkaline and one carbonatite intrusion with an age of 370-360 Ma.

As sedimentary age increases, so does the likelihood that the porosity and permeability is reduced. Due to density and other geological characteristics the few and small existing Finnish sedimentary formations are unsuitable for CCS. Storage potential in a sufficiently deep (> 800 m) and porous sedimentary rock does not occur in Finland. Known sedimentary rocks are generally too shallow and the porosity is poor. The porosity is regularly higher (5-10 %) in the upper and younger layers of the Finnish sedimentary formations and gradually decreases towards the deeper and older layers. Pososity is generally < 5 % in sufficiently deep layers. Formations also usually lack possible caprocks. Due to lack of geological data, the possibility to store in geological formations in Finland can not be totally excluded but it can be regarded very unlikely and theoretical volumes would probably be negligible (Solismaa 2009). Finnish basaltic volcanic rocks are also old and metamorphosed, thus lacking in porosity. The potential for storage increases in the Baltic Sea, southward from Åland Islands.

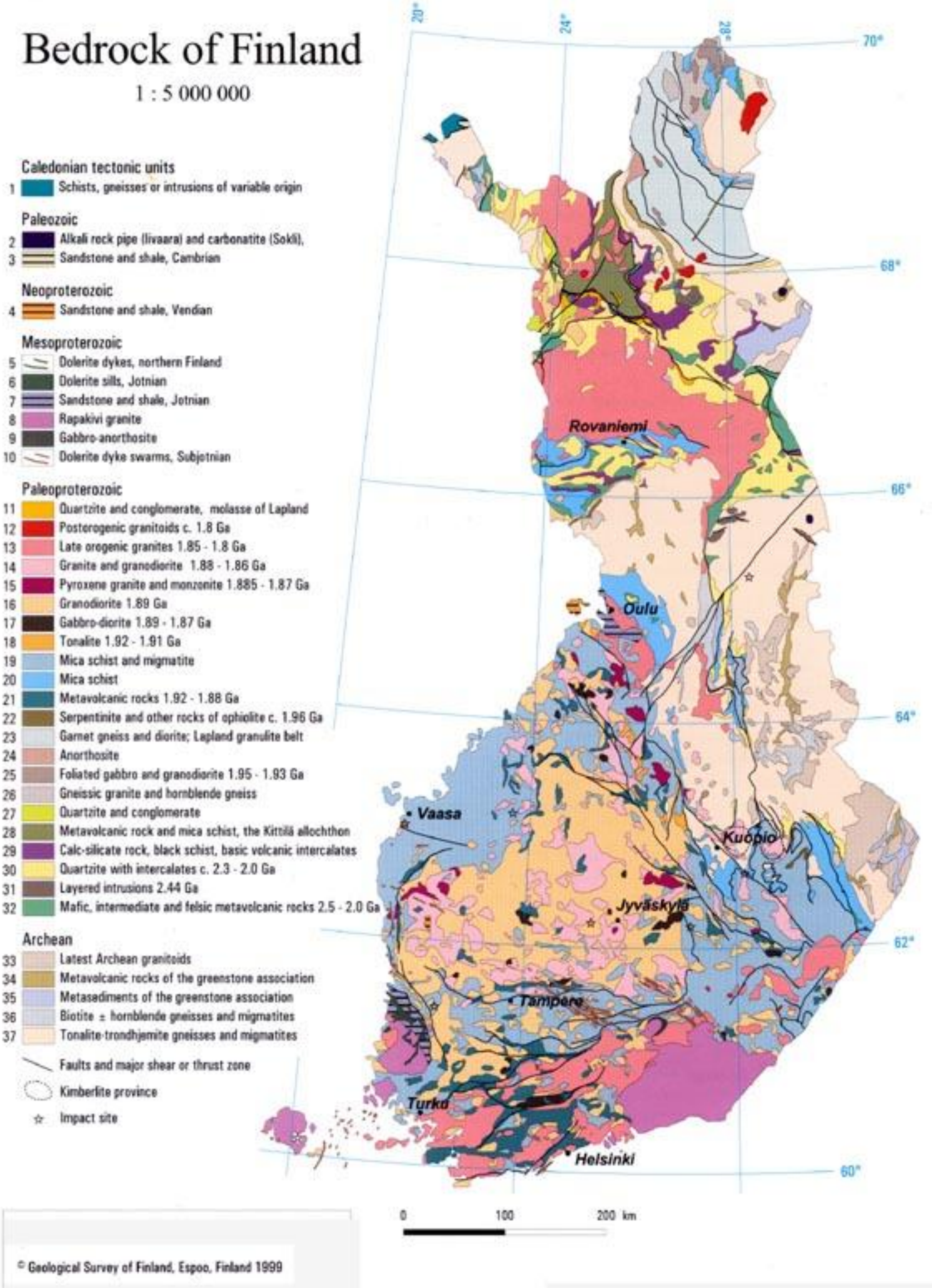

Figure 4-2. Bedrock geology of Finland. ©Geological Survey of Finland, Espoo 1999.

In addition to geological storage, other storage technologies have also been developed. In Finnish conditions fixation of CO_2 to mineral matter might offer an alternative for CO_2 storage. Carbonation of silicate minerals has already been studied several years in Finland, in laboratory scale, and results have encouraged continuing development work towards piloting and demonstration. Large potential in Finland is offered by magnesium silicate mineral resources and a lot of expertise and industrial activity in the field of geology and large-scale mineral and ore processing is already available. Lately also a process involving dissolving of carbon dioxide and neutralisation with feldspar minerals has been proposed in Finland. The development work in mineralization is further supported by international project cooperation, as Finland's expertise in the field attracts interest from abroad. A feature that drives the interest of international R&D consortia is the option to apply mineralization directly to CO_2-containing gases, avoiding a costly and problematic CO_2 separation step. The major hold-up for this technology is the large amounts of material involved and the carbonation reaction kinetics.

5 Storage potential

5.1 Global

Estimates of global storage capacity indicate that 675 – 900 $GtCO_2$ can be stored in oil and gas fields, 3 – 200 $GtCO_2$ in unminable coal seams and 1000 – 10000 $GtCO_2$ in deep saline formations (IPCC 2005). This means that the storage capacity for CO_2 in geological formations is significantly higher than the global annual CO_2 emissions, which were 30.6 Gt CO_2 in 2010 (IEA 2010). Sedimentary basins and potential storage sites are quite unevenly distributed worldwide (Fig. 5-1).

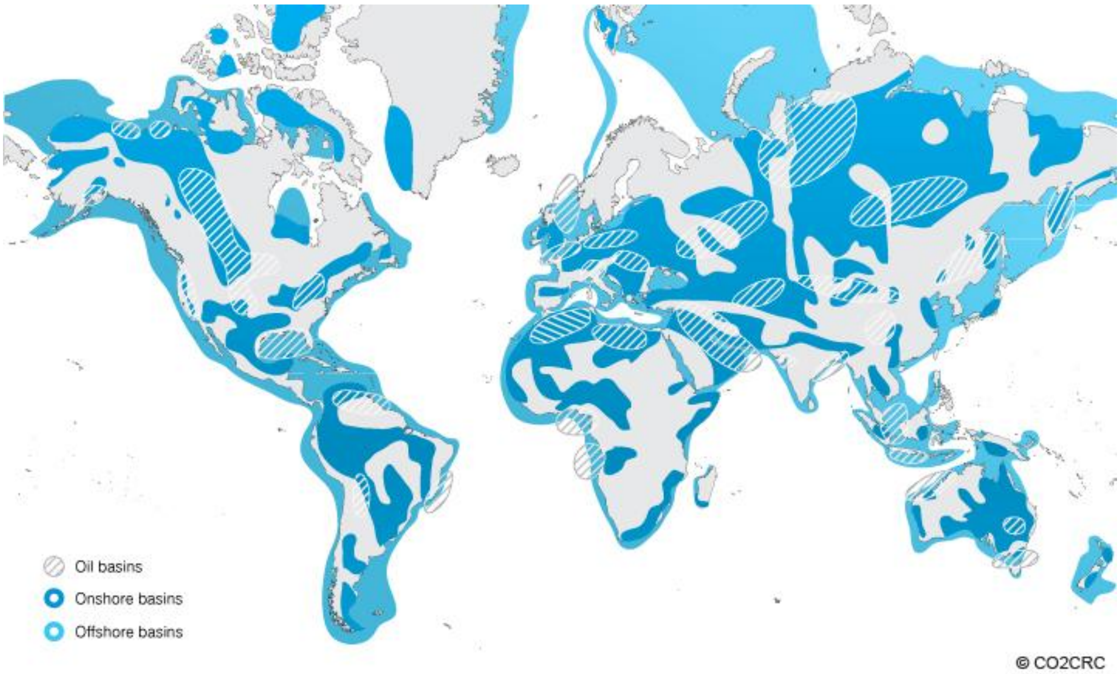

Figure 5-1. Map displaying the sedimentary basins of the world (© CO2CRC).

5.2 Europe

A few studies have been done on the European storage capacity. EU Joule project reported in 1996 the first numbers on possible capacity, followed by the EU FP5 project GESTCO covering Norway, Denmark, UK, Belgium, Netherlands, Germany, France and Greece. In the EU FP6 project CASTOR collaborative activities were initiated with Czech Republic, Hungary, Poland, Slovakia, Slovenia, Bulgaria, Romania, and Croatia using the research network ENeRG as a facilitator. The EU GeoCapacity project 2006-2008 focussed on countries in eastern, southern and central Europe not covered in detail before and combined results of the previous projects, thus providing coverage of the majority of the EU member states and neighbours.

The database of GeoCapacity includes a total storage capacity of 360 Gt with 326 Gt in deep saline aquifers, 32 Gt in depleted hydrocarbon fields and 2 Gt in unmineable coal beds. The onshore storage capacity is up to 116 Gt and offshore up to 244 Gt. Some of the estimated capacity is in geological trapping structures but a large part is from whole aquifer estimates in regional deep saline aquifers without trapping structures. Not all of the capacity can be exploited and therefore also conservative estimates have been done. According to the conservative storage capacity estimates 96 Gt can be stored in deep saline aquifers, 20 Gt in depleted hydrocarbon fields and 1 Gt in unmineable coal beds. This totals 117 Gt CO_2 of conservative European storage capacity of which approximately 25 % is offshore Norway, mainly in deep aquifers (Vangkilde-Pedersen et al. 2009). A summary of European conservative storage capacities is given in Table 5.1.

Table 5-1. European conservative storage capacity estimates (after Vankilde-Pedersen et al. 2009).

Country	CO_2 storage capacity in deep saline aquifers (Mt)	CO_2 storage capacity in hydrocarbon fields (Mt)	CO_2 storage capacity in coal fields (Mt)	Total CO_2 storage capacity (Mt)
Slovakia	1716	-	-	1716
Estonia	-	-	-	0
Latvia	404	-	-	404
Lithuania	30	7	-	37
Poland	1761	764	415	2940
Czech Republic	766	33	54	853
Hungary	140	389	87	616
Romania	7500	1500	-	9000
Bulgaria	2100	3	17	2120
Albania	20	111	-	131
FYROM	390	-	-	390
Croatia	2710	189	-	2899
Spain	14000	34	145	14179
Italy	4669	1810	71	6550
Slovenia	92	2	-	94
Bosnia-Herzegovina	197	-	-	197
Germany	14900	2180	-	17080
Luxemburg	-	-	-	0
The Netherlands	340	1700	300	2340
France	7922	770	-	8692
Greece	184	70	-	254
United Kingdom	7100	7300	-	14400
Denmark	2553	203	-	2756
Norway	26031	3157	-	29188
Belgium	199	-	-	199
Total	95724	20222	1089	117035

5.3 Neighbouring regions to Finland

5.3.1 Norway

According to conservative estimates in the GeoCapacity database there should be a storage capacity of about 29 $GtCO_2$ in Norway, 26 $GtCO_2$ in deep saline aquifers and 3 $GtCO_2$ in hydrocarbon fields. Norway has over 40 years of experience of petroleum activity on the Norwegian continental shelf (Fig. 5-2) and the Norwegian Petroleum Directorate (NPD) has access to a huge amount of data collected by the petroleum industry. The NPD published in December 2011 a CO_2 Storage Atlas over the Norwegian part of the North Sea (NPD, 2011). According to this Atlas there is a storage capacity of 67 $GtCO_2$ in Norway, 43 $GtCO_2$ in aquifers and 24 $GtCO_2$ in hydrocarbon fields. According to the analyses by NPD the storage efficiency of the Norwegian aquifers seems to be much higher than the GeoCapacity conservative estimates.

Potential storage sites should have no influence on Norwegian petroleum activity and consequently aquifers in oil prospective areas have not been evaluated in the Atlas, except for EOR. Old oil wells are an issue that requires extra caution in the depleted hydrocarbon fields. While suitable aquifers should preferably be located in areas without hydrocarbon potential, the amount of pre-existing data is however limited in such areas which makes it challenging to identify storage and sealing formations. The NPD has established a maturity pyramid for storage sites with 4 levels (Fig. 5-3). Each step represents different degree of knowledge and safety level. The bottom level gives a theoretical volume of storage while the uppermost level will be reached when the injection project of a specific site is feasible. According to the Atlas a 1.1$GtCO_2$ capacity is presently available for injection (yellow level).

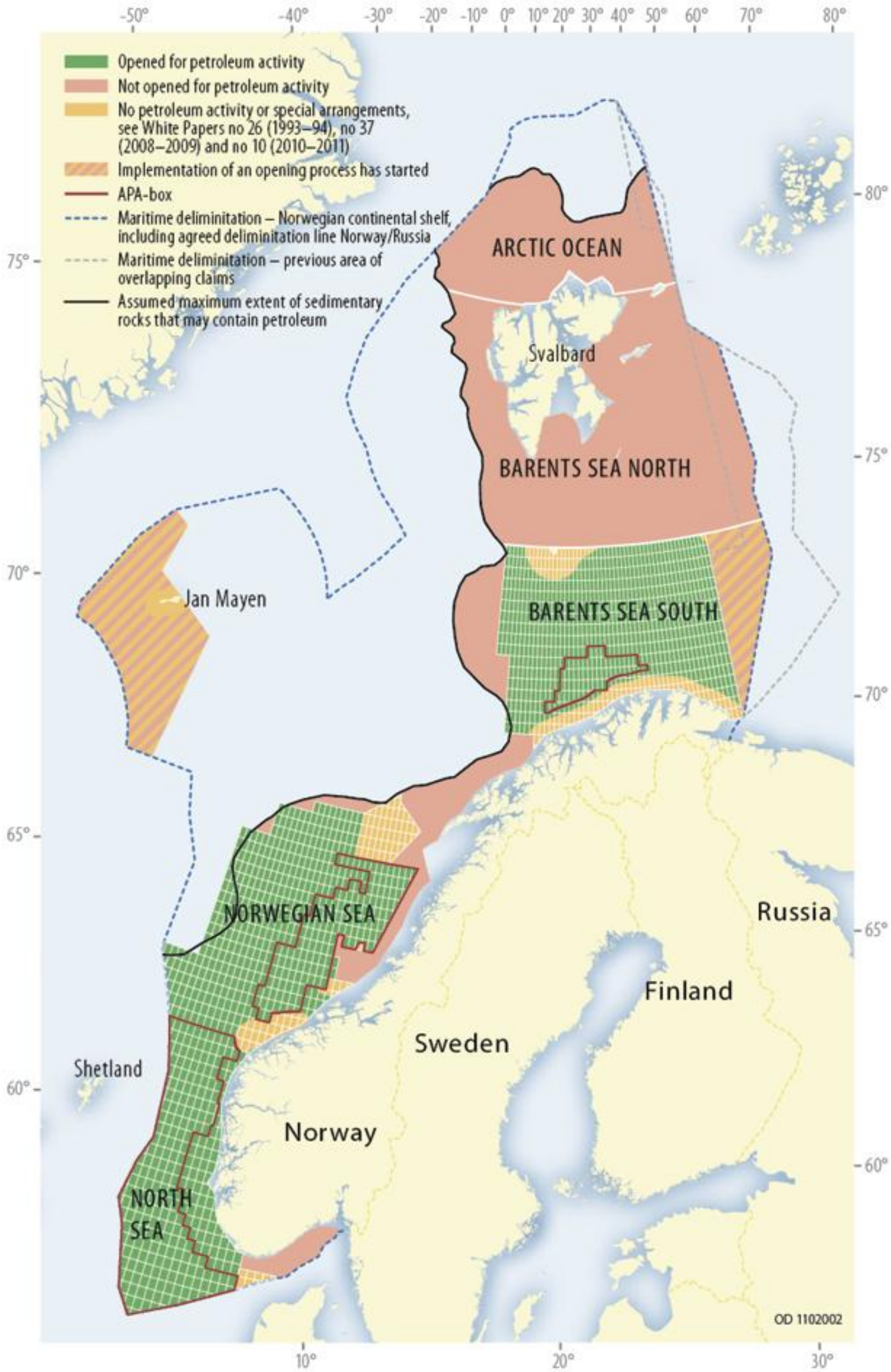

Figure 5-2. Map displaying petroleum activity on the continental shelf of Norway (Norwegian Petroleum Directorate).

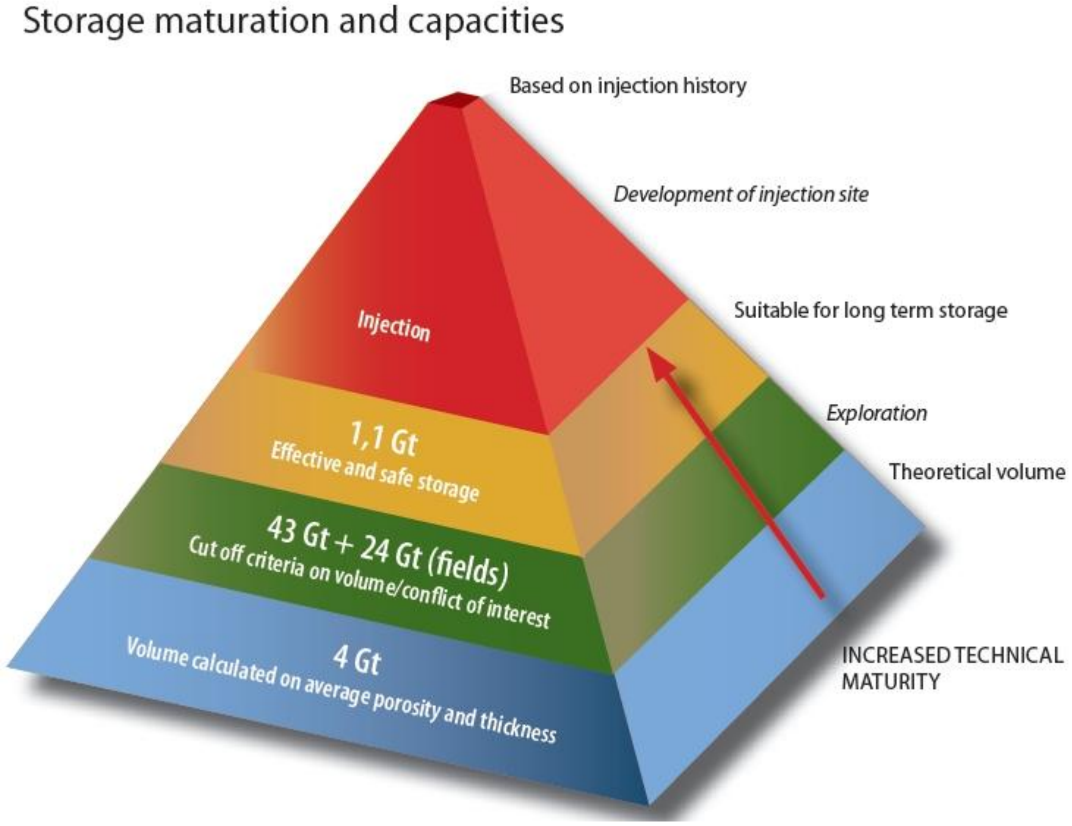

Figure 5-3. Maturity pyramid with 4 levels, established by NPD (2011).

The NPD has grouped sedimentary formations into aquifers if there is a connection between different formations. When not taking into account aquifers in the petroleum systems, two aquifers with significantly greater theoretical storage potential than the others have been identified. These are the Utsira – Skade Formation aquifer (15.8 $GtCO_2$) and the Bryne – Sandnes Formation aquifer (13.6 $GTCO_2$). CO_2 has already been injected into the Utsira formation and analogous structures to the Sleipner site has been identified and classified in the third level of the maturation pyramid (1 $GtCO_2$). The Bryne – Sandnes formation has formations formed by salt tectonics that may be attractive for storage but needs to be studied in more detail. The Johansen – Cook Formation aquifer is smaller (1.8 $GtCO_2$) but it has good properties. A potential storage site in the Johansen Formation has recently been investigated by Gassnova and it is included in the 3rd step of the pyramid (0.1 $GtCO_2$).

5.3.2 Sweden

Screenings for CO_2 storage capacity in the Swedish territory indicates three potential areas for CO_2 storage in southern Sweden. Suitable aquifers are present in the southern Baltic Sea (adjacent to Polish, Russian, Lithuanian and Latvian waters), SW Skåne and SW Kattegatt (adjacent to Danish waters) (Erlström et al. 2011) (Fig. 5-4). Sweden was not included in the GeoCapacity project but calculations by Shogenova et al. 2011 indicate a total conservative storage capacity of 1.5-3 $GtCO_2$ in Swedish aquifers.

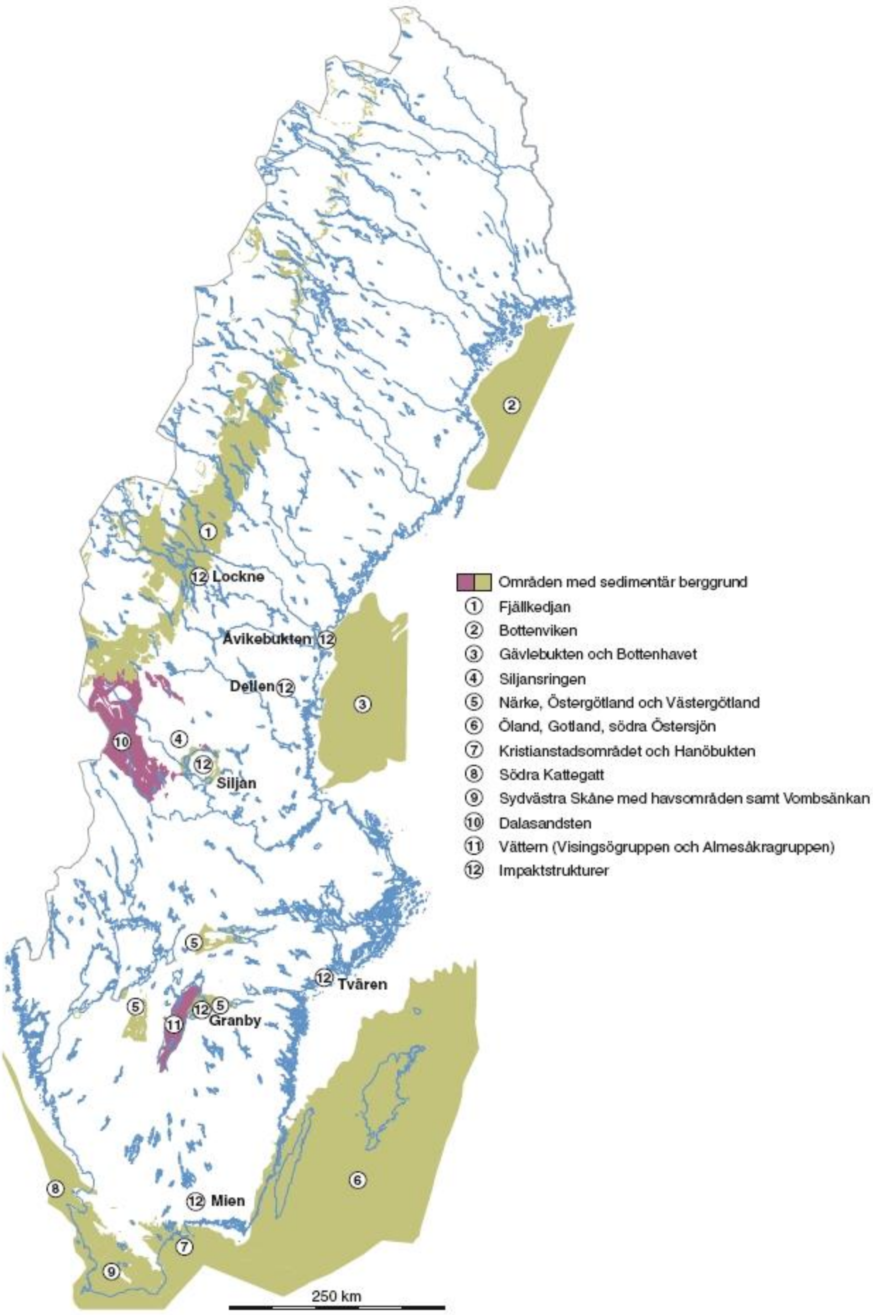

Figure 5-4. Sedimentary bedrock of Sweden (Erlström et al. 2011).

The Cambrian sandstone of the Baltic Sea could be suitable for storage. The Cambrian sandstone appears near the surface on Gotland and is dipping towards the southeast. Therefore the depth of the Cambrian sandstone increases towards the Baltic's and highest potentials are close to the border between Swedish, Polish, Russian, Lithuanian and Latvian waters. Due to oil prospecting these areas are quite well studied. The prospective parts of the Cambrian sandstone formation in the Baltic Sea has a average porosity of 15.7%, permeability of 220mD, 0-50 m thickness and a depth of 0.45-1.2km (Erlström et al. 2011).

In SW Skåne the sandstones from older Cretaceous, older Jurassic and older Triassic, present at a 1200-2500 m depth, seem to be very suitable for CO_2 storage but more detailed investigations are needed (Erlström et al. 2011).

In the southern Kattegat there are sandstone layers in the Skagerrak and Gassum formations (younger Triassic – older Jurassic) which could be possible storage options. The Gassum formation is over 350 m thick and consists of a varied sequence with sandstone, shale and siltstone. Physical testing has not been performed, but data from geophysical logs indicates porosity around 25% for sandstone sections. In the Swedish regions the formation is likely to be too shallow for CO_2 storage. The top of the formation is at about 500 m depth and bottom of about 1000 m depth. The underlying Skagerrak formation is approximately 1000 m thick and lies at depths between 1000 and 2000 m, making it more interesting for storage. Layers are highly variable but there are coarse, feldspar-rich sandstone layers with potentially good aquifer properties which however have not been investigated in detail. What makes the bedrock in the Swedish part of the southern Kattegat interesting is the presence of a anticline structure that may be suitable for storage if it is closed, extensive investigations would however be needed (Erlström et al. 2011).

5.3.3 Denmark

According to GeoCapacity conservative estimates the storage potential in Denmark is 2.6 $GtCO_2$ in deep saline aquifers and 0.2 $GtCO_2$ in hydrocarbon fields. Denmark has through international cooperation purposefully studied the structures of the bedrock. The depth of the top of Early Jurassic–Lower Triassic reservoir sandstones of the Gassum, Bunter and Skagerrak formations structures is usually between 1000–1900 m, permeability 75–1000 mD, porosity 10–25% and the thickness of sandstones between 100–760 m (Shogenova et al. 2011). In Denmark salt domes has produced anticlines that would be very good reservoirs. A number of closed structures have been identified in close proximity to emission sources and the total estimated storage volume in the Danish structures could cope with a storage corresponding annual production from major point sources for several hundred years. In addition to carbon storage the identified aquifers are also interesting for geothermal energy production, hydrocarbon prospecting and energy storage. This means that in some cases there could be conflicts of interest (Erlström et al. 2011).

5.3.4 Baltic's

The Baltic countries are situated in the eastern part of the Baltic sedimentary basin that overlies the western periphery of the East European Craton. The basin contains the Ediacaran (Upper Vendian) and all of the Phanerozoic systems. The thickness of the sediments is less than 100 m in northern Estonia, increasing to 1900 m in south-western Latvia and 2300 m in western Lithuania. Cambrian sandstones are the most prospective reservoir rocks for CO_2 storage in the Baltic region (Shogenova et al. 2011).

The storage potential of the Baltic countries has been reported by Sliaupa et al. in 2009. According to this report the storage possibilities in Estonia are virtually nonexistent since the potential aquifers are too shallow. In Latvia the Cambrian sandstone aquifers contain 15 structural traps suitable for CO_2 storage. The assessed total storage capacity in Latvia is 0.4 $GtCO_2$, 0.3 $GtCO2_2$ onshore and 0.1 $GtCO_2$ offshore. In Lithuania, a comprehensive survey of potential aquifers and their suitability for carbon storage has been carried out. Two aquifers in Cambrian and Devonian formations were identified as suitable. The theoretically possible regional storage capacity of the two aquifers is very large (1-2 $GtCO_2$), but assessments are focused on closed structures (Sliaupa et al 2009). A number of structural traps, which theoretically can store up to 200 $MtCO_2$ have been identified and a practical capacity of 37$MtCO_2$ has been calculated.

5.3.5 Poland

Poland's is dominated by sedimentary bedrock with aquifers at different depths. The best aquifers occur in the Lower Cretaceous Lower Jurassic and Lower Triassic formations in the central and northern parts of the country. Numerous tectonic structures, anticlines (mainly salt tectonics) and grabens, occur within the Mesozoic aquifers of the Polish lowlands. Among structures suitable for CO_2 storage 18 prospective local uplifts were estimated: 7 structures in the Lower Cretaceous, 7 in the Lower Jurassic and 4 in the Triassic (Tarkowski et al. 2009). In addition to aquifers there is in Poland an opportunity to exploit the oil and gas fields for storage. These are primarily in the south-eastern and central western parts of Poland. In the southern Baltic Sea there is some hydrocarbon prospecting and production in the Cambrian sandstone and in the future it is considered possible to use these structures for storage. The capacity is expected to be small relative to other opportunities in Poland. Conservative figures by the GeoCapacity project indicate a 2.9 $GtCO_2$ capacity in Poland.

5.3.6 Baltic Sea

The Cambrian sandstone of the Baltic Sea could be suitable for storage (Fig. 5-5). The knowledge of the Cambrian layer sequence in the southern Baltic Sea and on Oland and Gotland are based largely on information from the hydrocarbon prospecting in the 1970s by OPAB (Oljeprospektering AB), partly in collaboration with other stakeholders.

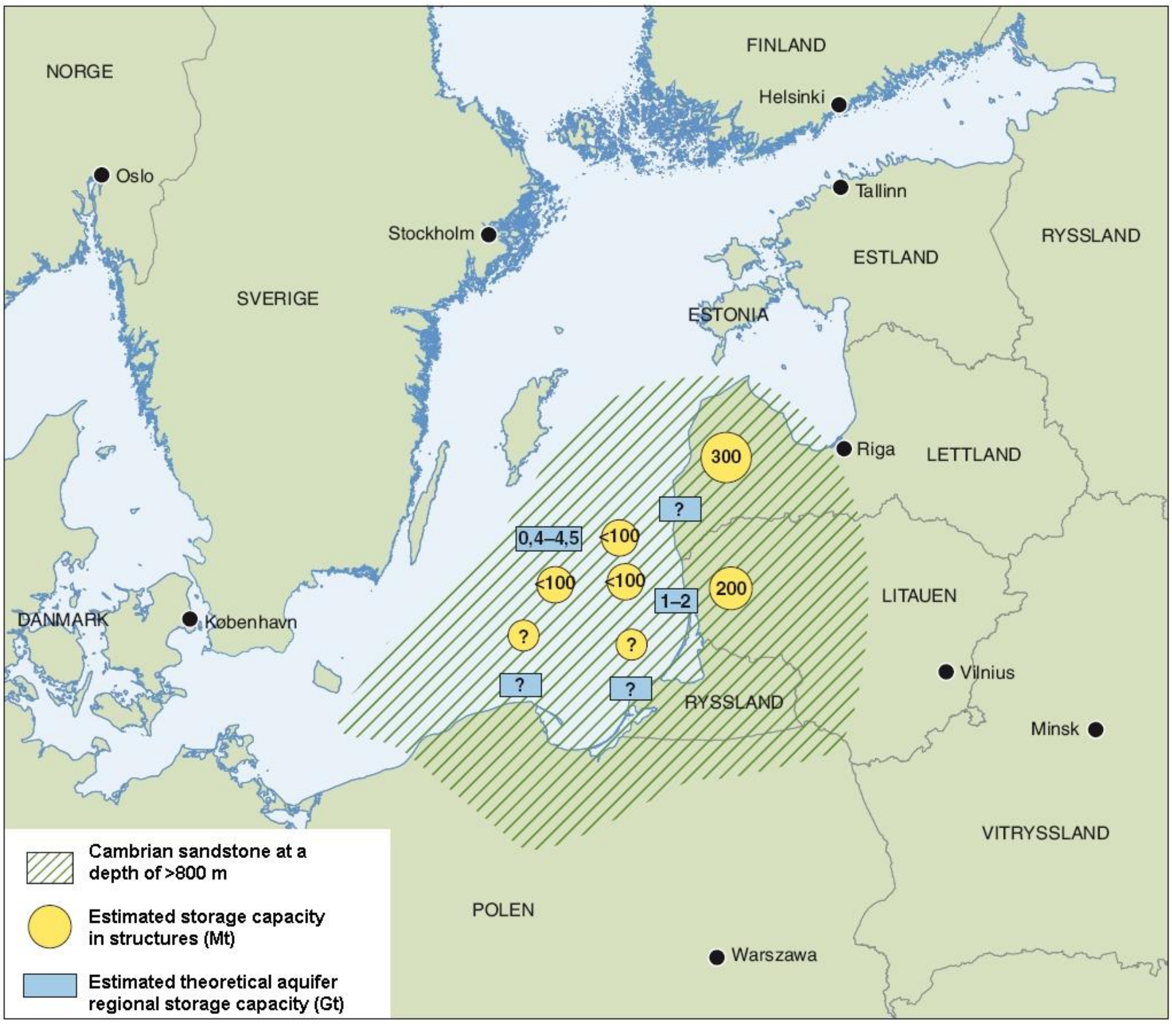

Figure 5-5. Estimated storage capacities in the Cambrian deep saline aquifers in the southern Baltic after Erlström et al. 2011.

The Under Cambrian to the Lower Ordovician sequence in the southern Baltic was deposed in a stable tectonic conditions, which among other things, has resulted in a relatively slow and uniform sedimentation. This means that most bedrock units can be followed over much of the area. Variations in the lithological building has its origins in changes in deposition environment, such as distance to coast, the appearance of estuaries and deltas, water depth, water currents and waves. The bedrock is tilted slightly (<1 °) to east-southeast which means that successively younger rocks forming the bedrock surface towards the Baltic part of the Baltic Sea. In the same direction, one finds also the Cambrian sandstone at greater depths (Fig. 5-6). The geological map shows that the Cambrian rocks are at the surface in the westernmost part of the Baltic (Öland), while rocks formed during the Devonian are exposed at the surface in the southeast of the southern Baltic (Erlström et al. 2011).

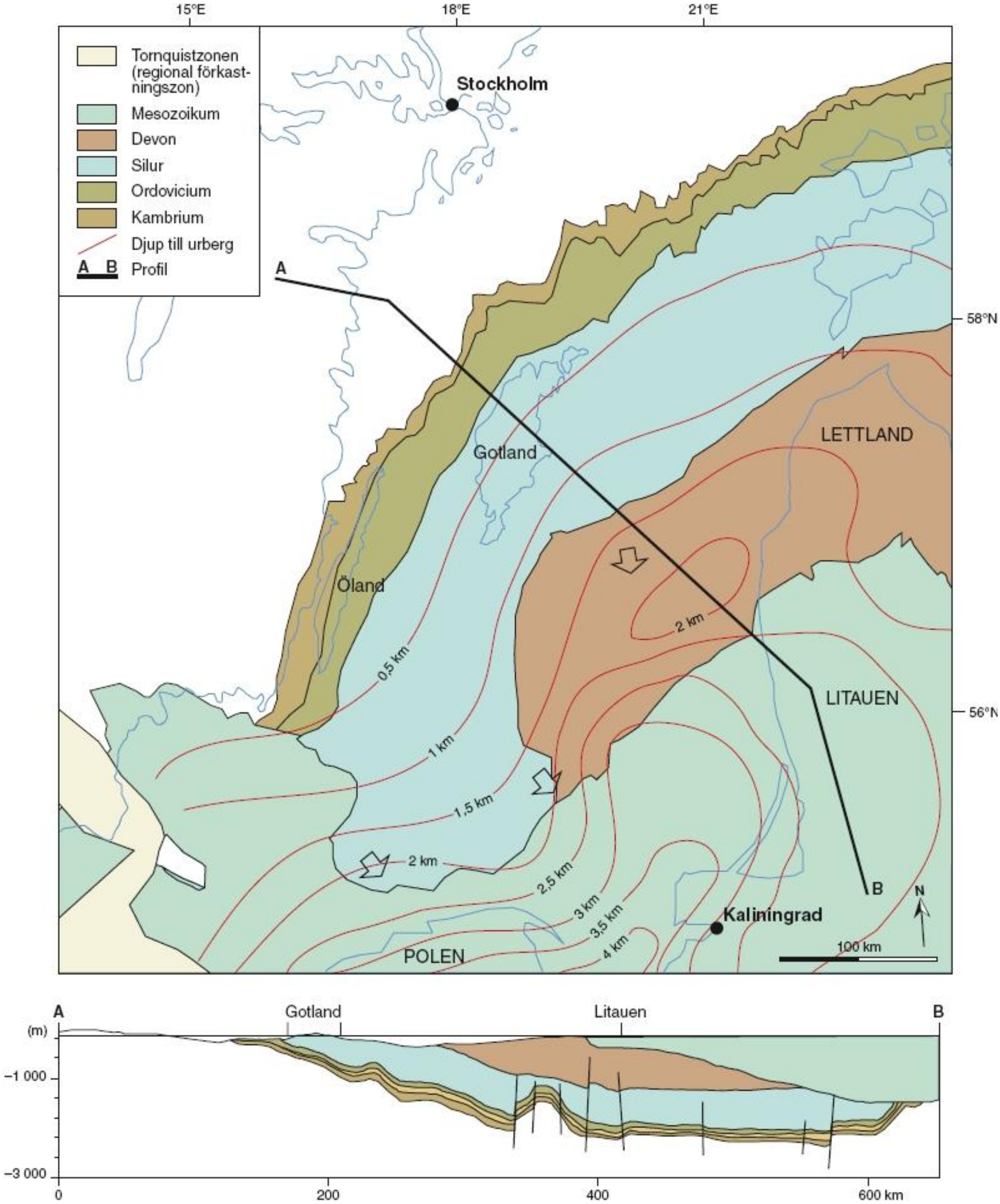

Figure 5-6. Map showing bedrock surface age in the southern Baltic. The profile of the lower part of the figure shows a vertical section of the rock from northwest to southeast (Erlström et al. 2011).

The Paleozoic bedrock is relatively unaffected by faulting. On the Baltic side of the Baltic Sea anticlines in the Cambrian sandstone forms closed structures in the bedrock, in which there is oil. Within the Swedish territory or exclusive economic zone there is an indication of smaller, similar structures. In the area where the sandstone is located at depths greater than 800 m there are fifteen structures that are 5-25 km^2. A larger structure is located in south-eastern part of the Baltic Sea on the border with Poland, Russia, Lithuania and Latvia. It has a size of about 200 km. The Cambrian sandstone sequence is overlain by a thick sequence of Middle Cambrian, Ordovician and Silurian rocks. In the south-eastern part of the Baltic the Silurian rocks are overlain by Devonian sandstones. The physical properties of possible cap rocks are poorly studied. There is very little porosity, permeability or mineralogical investigations performed but initial assessments indicate that cap rocks might have good properties. The presence of the contained oil and gas in the Cambrian sandstone on the Baltic side of the Baltic Sea is a good indication that the overlying layers, at least in these parts of the Baltic Sea, is sufficiently dense (Erlström et al. 2011).

5.3.7 Russia

The potential for storage in Russian saline aquifers is probably very large but has not yet been estimated. I.e. the Moscow Basin (Fig. 5-7) neighboring Estonia could be prospective for CO_2 storage in deep saline aquifers. The Russian Federation is also extremely rich in oil and gas deposits, accounting for 13% of the world oil reserves and more than 30 % of world gas reserves. The north-central European part of Russia includes hydrocarbon fields in the Volgo-Ural and Timan-Pechora oil-gas provinces, Kaliningrad Region and offshore regions including the Barents Sea, Chukotka Sea and Baltic Sea. The north-western region has 10% of all Russian oil and gas reserves. About 50 of hydrocarbon fields of NW Russia have already been depleted and could in the future be of great interest for the East–European countries for enhanced oil and gas recovery (EOR and EGR) (Shogenova et al. 2011).

Preliminary estimations of the potential CO_2 storage capacity by oil and gas deposits in NW Russia were published by Cherepovitsyn & Ilinsky in 2006. According to these estimates there is a theoretical storage potential of 19-25GtCO_2 in oil and gas fields in north-west Russia, assuming an optimistic 1:1 ratio of volumetric replacement between hydrocarbons and CO_2.

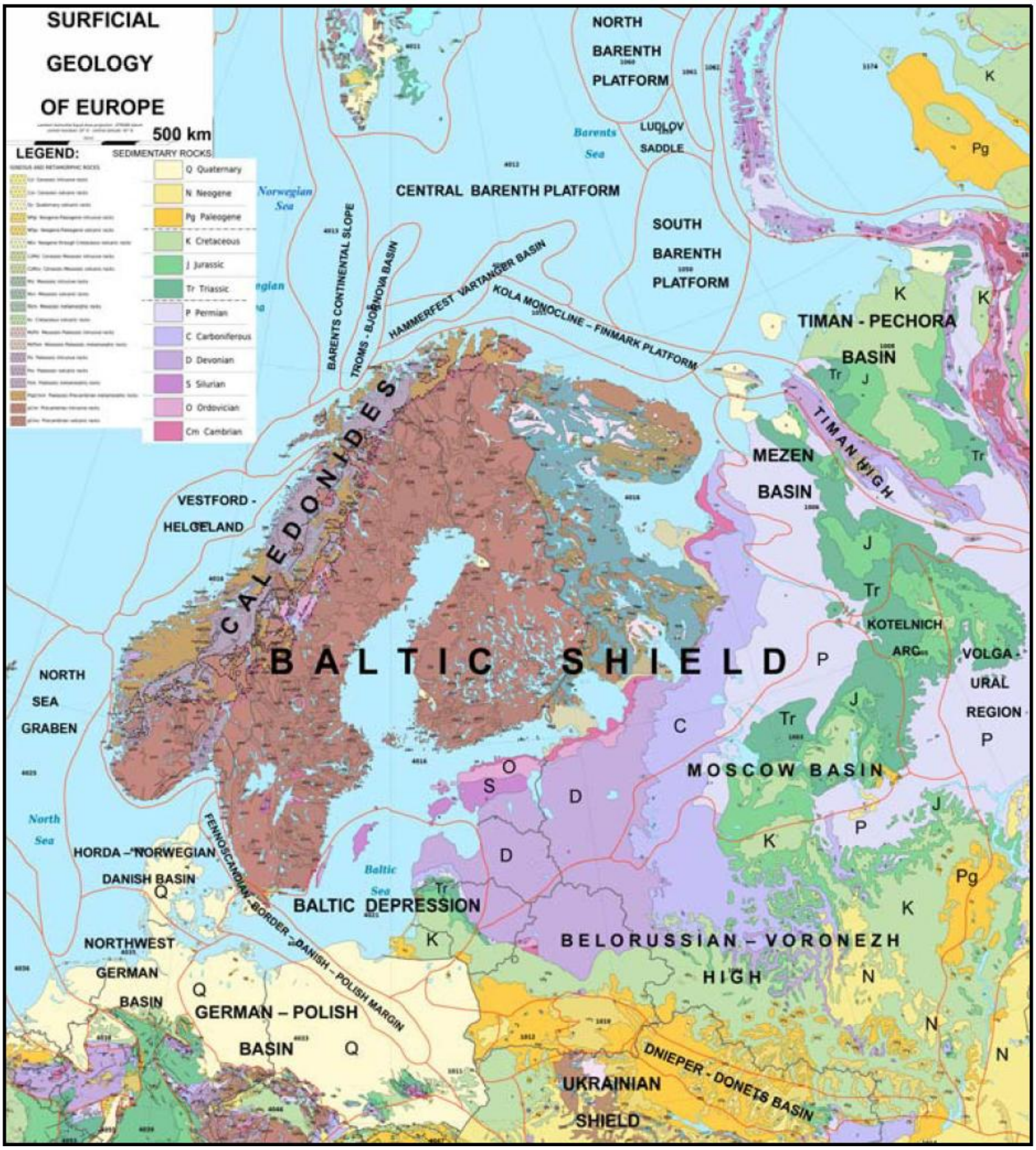

Figure 5-7. Geological map of NE-Europe with borders of oil and gas provinces (Shogenova et al. 2011).

As many as 210 hydrocarbon deposits are found onshore in the Timan-Pechora oil-gas province (Fig. 5-8). All together nearly 100 deposits are in exploitation in the NW region (Shogenova et al. 2011). The Timan-Pechora Basin Province overlies the Arctic Circle west of the Ural Mountains, the Pay-Khoy Ridge, Vaygach Island and the Novaya Zemlya archipelago. To the west of Timan-Pechora is the NW-SE trending Timan-Kanin Ridge, which intersects the Ural Mountains at the southern end of the province. The northern offshore province boundary is the South Barents transitional faultzone, separating the excluded South Barents basin of the Barents Sea from the included Pechora block within the Pechora Sea. Onshore geologic features are known to extend offshore. Hydrocarbons in Timan-Pechora are trapped in Ordovician through Triassic reservoir rocks at 200 to 4500 meter depths (Lindquist 1999).

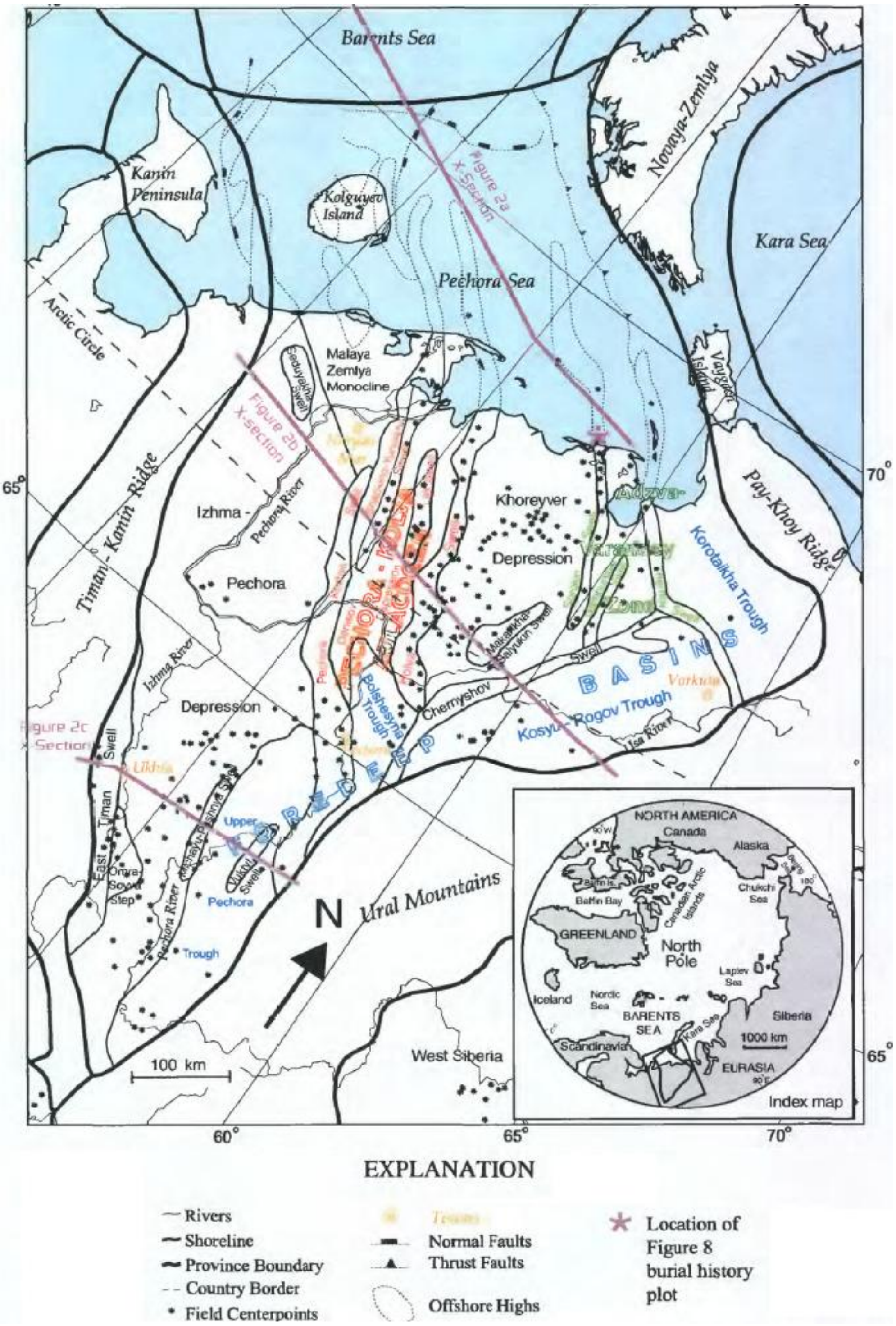

Figure 5-8. Map for Timan-Pechora basin and and province, modified after Lindquist 1999.

6 Global status of CCS

The injection of CO_2 into subsurface geological formations was started in Texas, USA, in the early 1970s, as part of enhanced oil recovery (EOR) projects and has been ongoing there and at many other locations ever since. Geological storage of anthropogenic CO_2 as a greenhouse gas mitigation option was first proposed in the 1970s, but little research was done until the early 1990s, when the idea gained credibility through the work of individuals and research groups. The subsurface disposal of acid gas (a by-product of petroleum production with a CO_2 content of up to 98%) in the Alberta Basin of Canada and in the United States has also provided valuable experience.

In 1991 the IEA (International Energy Association) established the Greenhouse Gas R&D Programme (IEAGHG). IEAGHG studies and evaluates technologies that can reduce greenhouse gas emissions derived from the use of fossil fuels. In 1996, the world's first large-scale storage project was initiated by Statoil and its partners at the Sleipner Gas Field in the North Sea. By the late 1990s, a number of publicly and privately funded research programmes were under way in the United States, Canada, Japan, Europe and Australia. Throughout this time a number of oil companies became increasingly interested in geological storage as a mitigation option, particularly for gas fields with a high natural CO_2 content such as Natuna in Indonesia, In Salah in Algeria and Gorgon in Australia. More recently, coal mining companies and electricity-generation companies have started to investigate geological storage as a mitigation option of relevance to their industry (IPCC 2005).

The Global CCS institute defines a CCS project as large scale integrated CCS project (LSIP) if it involves the capture, transport and storage of not less than 0.8Mt CO_2 per year for coal-based power plants and not less than 0.4 Mt CO_2 per year for other emission-intensive industrial facilities. In 2009 there was 64 LSIPs in the world, this number was 77 in 2010 and in October 2011 there was 74 LSIPs across the world (Fig. 5-1). These projects are concentrated to North America, Europe, Australia and China with few large-scale projects planned in developing countries. Most of the projects are in the stages of evaluation and definition, 14 projects are either in operation or under construction and have a total CO_2 storage capacity of over 33 million tonnes a year (MtPA) (Table 5-1) which is an increase by 7.6MtPA since 2010. Nearly all of the operating or committed capture projects are either CO_2 EOR related and/or based on gas processing. The only exceptions are the Illinois-ICCS project and Gorgon Carbon Dioxide Injection Project, though the Illinois-ICCS project has indicated that after a period of storage in a deep saline formation, revenue opportunities from CO_2 for EOR will be sought. This illustrates the challenge that presently confronts projects which do not have access to either EOR revenues and/or capture which is already part of the industrial process, such as in gas processing. Should opportunities for hydrocarbon production be available, many of the large-scale early mover capture projects are likely to include CO_2 for EOR to support a positive business case (GCCSI 2011).

Figure 6-1. Map with the 74 large scale CCS projects in December 2011 (Global CCS Institute).

Of the 14 projects in operation or under construction, there are only six projects considered full CCS projects in that they demonstrate the capture, transport and permanent storage of CO_2 utilising sufficient monitoring, measurement and verification (MMV) systems and processes to demonstrate permanent storage – Sleipner, Great Plains/Weyburn-Midale, In Salah, Snøhvit, Illinois-ICCS and Gorgon. The remaining projects display the capture, transport and injection of CO_2 but would need to apply further MMV systems and processes to be consistent with the demonstration of permanent storage. Similar needs exist for many of the projects in the planning stages (GCCSI 2011).

Table 6-1. Large scale integrated CCS projects in operation or under construction

Name	Location	Capture type	Volume CO_2 (MTPA)	Storage Type	Date of operation
In operation					
Val Verde Natural Gas Plants	USA	Pre-combustion (gas processing)	1.3	EOR	1972
Enid Fertilizer Plant	USA	Pre-combustion (fertilizer)	0.7	EOR	1982
Shute Creek Gas Processing Facility	USA	Pre-combustion (gas processing)	7	EOR	1986
Sleipner CO_2 Injection	Norway	Pre-combustion (gas processing)	1	Deep saline formation	1996
Great Plains Synfuels Plant and Weyburn-Midale Project	USA/Canada	Pre-combustion (synfuels)	3	EOR with MMV	2000
In Salah CO_2 Storage	Algeria	Pre-combustion (gas processing)	1	Deep saline formation	2004
Snøhvit CO_2 Injection	Norway	Pre-combustion (gas processing)	0.7	Deep saline formation	2008
Century Plalnt	USA	Pre-combustion (gas processing)	5 (3.5 in construction)	EOR	2010
Under construction					
Lost Cabin Gas Plant	USA	Pre-combustion (gas processing)	1	EOR	2012
Illinois Industrial Carbon Capture and sequestration (ICCS)	USA	Industrial (ethanol production)	1	Deep saline formation	2013
Boundary Dam with CCS Demonstration	Canada	Post-combustion (power)	1	EOR	2014
Agrium CO_2 Capture with ACTL	Canada	Pre-combustion (fertilizer)	0.6	EOR	2014
Kemper County IGCC Project	United States	Pre-combustion (power)	3.5	EOR	2014
Gorgon Carbon Dioxide Injection Project	Australia	Pre-combustion (gas processing)	3.4	Deep saline formation	2015

6.1 Europe

6.1.1 European R&D on geological CO_2 storage

The EU has supported research, development and demonstration of clean coal and CCS technologies for about 20 years, starting in the Third Framework Programme (1990-1994). Since 1998 (FP5), the EU supported almost 40 projects in the area of CCS and clean coal. Between 1998 and 2002 (FP5), the majority of projects have focussed on CO_2 storage and its monitoring, while projects addressing the capture part were prominent in FP6 (2002-2006). The EU's current strategic energy technology roadmap foresees an important role for CCS and the EU is at the moment directing resources towards developing the political, economic, social, technological, legal and environmental foundations for safe and successful CCS demonstration and deployment. Under the 7th Framework Programme, research and demonstration activities include the whole CCS chain.

Significant past European R&D activities

The **Joule II** Project "Underground Diposal of Carbon Dioxide" (1993-1995) was the first European research project examining issues associated with underground CO_2 disposal. Its aim was to assess quality and quantity of CO_2 available from fossil fuel power plants, to examine pipeline transport of CO_2 and to examine options for underground storage. UK, France, Netherlands, Norway and Germany were represented in the Joule II consortium coordinated by the British Geological Survey.

The **GESTCO** (GEological STorage of CO_2) project (1999-2003) was initiated to assess the European potential for geological storage of CO_2 from fossil fuel combustion. GESTCO was coordinated by GEUS and participants were the Geological Surveys of Belgium, Denmark, France, Germany, Greece, Norway, Netherlands and UK.

SACS (Saline Aquifer CO_2 storage) project (2000-2002) was established to monitor and research the storage of CO_2 in the Utsira formation, 800 m below the sea bed at Sleipner. The **CO2STORE** project (2003-2006) aimed at transferring the experience gained in the offshore SACS project to onshore potential storage sites with different geological conditions.

The **NASCENT** (Natural Analogues for the Storage of CO_2 in the Geological Environment) project (2001-2004) was a project where natural emissions and occurrences of CO_2 were studied in detail to analyse the conditions, effects and processes related to long term underground storage of CO_2.

RECOPOL project (Reduction of CO_2 emissions by means of CO_2 storage in unmineable coal seams in the Silesian Coal Basin of Poland) (2001-2005) was initiated and co-ordinated the Netherlands Institute of applied Geoscience in co-operation with the Polish Central Mining Institute to investigate the feasibility of CO_2 underground storage in unmineable coal seams in combination with the production of coal bed methane (CBM).

CASTOR (CO_2 from Capture to Storage) project (2004-2008) aimed at the development of new technologies for the separation of CO_2 from flue gases and its geological storage, thirty parties from industry, research organisations and universities participated in this integrated project.

EU GeoCapacity (Assessing European Capacity for Geological Storage of Carbon Dioxide) project (2006-2008) was designed to assess the European capacity for geological storage. An extension of the project including a updating of the existing data, adding of new data and construction of database is currently being planned.

CO2SINK (2004-2010) is a research project which on research scale investigated the storage of CO_2, in a deep saline aquifer in Ketzin, Germany. One of the CO2SINK participants is Vibrometric Oy from Finland.

Current European R&D activities

In 2004 the EU initiated the **CO2GeoNet** as a Network of Excellence for CO_2 capture and storage to get a better co-ordination of research activities. The network joins together 13 partners from 7 European countries, ranging from national geological surveys and research institutes, through to universities and associated “spin out” research companies. The CO2GeoNet was originally launched under the EC FP6 programme (2004-2009) but in 2008 registered under French Law to continue the networking accomplished under the European Commission's contract. A three-year coordination action, **CGS Europe**, was launched on 1st November 2010, financed by the EC FP7 programme. CGS Europe, the "Pan-European coordination action on CO_2 Geological Storage", is a project for research, technological development and demonstration activities. CGS Europe pools together the expertise of the key research institutes in the area of CO_2 geological storage in European member states and associated countries. It sets up coordination and integration mechanisms between the CO2GeoNet and 23 other participants, thus covering most of Europe with 24 EU Member States and 4 associated countries. Finland is represented in CGS Europe by the Geological Survey of Finland

The European Technology Platform for Zero Emission Fossil Fuel Power Plants (known as ‘**ZEP**’) was founded by the European Commission in 2005. ZEP is a coalition of European utilities, power companies, equipment suppliers, academics, and environmental NGOs. ZEP has three main goals: enable CCS as a key technology for combating climate change, make CCS technology commercially viable by 2020 via an EU-backed demonstration programme and accelerate R&D into next-generation CCS technology and its wide deployment post-2020. ZEP serves as advisor to the European Commission on the research, demonstration and deployment of CCS.

MUSTANG is a four year large-scale integrating project (2009-2013) funded by the EU FP7, under the coordination of the Uppsala University. The MUSTANG consortium comprises 19 institutions. One of the MUSTANG participants is Vibrometric Oy from Finland. MUSTANG aims at developing guidelines, methods and tools for the characterization of deep saline aquifers for long term storage of CO_2, based on a solid scientific understanding of the underlying critical processes. Field investigation technologies specifically suited to CO_2 storage will be improved and developed. These are destined to improve the determination of the relevant physical and chemical properties of the site, and enabling short response times in the detection and monitoring of CO_2 plumes in the reservoir and overburden during both the injection and containment phases. An improved understanding of the relevant processes of CO_2 spreading is aimed at by means of theoretical investigations, laboratory experiments, natural analogue studies as well as a dedicated field scale injection test, taking place at the Heletz site in Israel.

6.1.2 European CCS demonstration incentives

The European Emissions Trading Scheme (EU-ETS)

The European Emissions Trading Scheme (EU-ETS) that creates a carbon market will be important for the development and implementation of CCS in Europe. The reason is that the funding of CCS is meant to primarily be via the system of emissions trading. Emission trading is one of the Kyoto Protocol's mechanisms to reduce greenhouse gas emissions. The principle of the EU ETS is that the EU gives a number of allowances (an allowance equivalent to emissions of one ton of carbon dioxide) to the countries included in the system. The individual countries then distribute allowances in their trading sectors. From 2013 a proportion of allowances will be auctioned. Allowances can be bought and sold. The principle is that the total allocation shall be less than need, for this reason, each allowance gets a market price. The idea behind the system is that the plants with the easiest options to reduce their emissions will do it first, and then will sell their unused allowances. This will provide the system of maximum emission reductions at least cost. After 2013, the plan is that CCS should be included in the trading system by the requirement of carbon stored geologically. However, the value of the emission credits has fallen significantly since emissions reduced around Europe during the economic downturn. The cost of emissions is therefore still too low and so does not create a large enough incentive for the private sector to install CCS.

The CCS Directive

Investments in power plants and CCS are very long-term, so certainty about future legislation is important. Since 2009, EU legislation on geological storage of CO_2 is in place. The European Commission has issued four guidance documents to support coherent implementation of Directive 2009/31/EC on the geological storage of carbon dioxide ("CCS Directive") across EU Member States. The four guidance documents, mainly addressed to competent authorities and relevant stakeholders, elaborate on key provisions of the CCS Directive: the first guidance document outlines a CO_2 storage life cycle risk management framework, whereas the other three address in more detail issues such as the characterisation of the storage complex, CO_2 stream composition, monitoring and corrective measures, the criteria for transfer of responsibility to the Member State, and financial security. By addressing these issues, the guidance documents will help to ensure environmentally safe geological storage of CO_2. The EU legislation now needs to be transposed into national laws in Member States.

The CCS Directive forms the central legal pillar for the widespread introduction of commercial CCS technology, supported by amendments to other legal instruments that are intended to remove a number of legal barriers to the deployment of CCS technology. Both the CCS Directive and the associated amendments to other legal instruments must be transposed into the national laws of Member States. Member States retain the right to determine suitable areas in their jurisdiction for storage and, ultimately, Member States are entitled to refuse storage in any part or all of their territory. Effective and consistent transposition could be an important factor in the success of any European cross-border CCS projects (GCCSI 2009).

The Finnish implementation of the European Parliament and Council Directive 2009/31/EC on the geological storage of carbon dioxide has been underway since 2010. The implementation work has been organized by a task force appointed by the Ministry of Environment (MoE). Based on this work the government has recently put forward a bill to the parliament regarding legislation of capture, transport and geological storage of CO_2. If accepted the law will prohibit geological storage of CO_2 in Finland and the Finnish economic zone. According to this law the recovered carbon dioxide may however, be intermediately stored, transported abroad and stored in underground geological formations, which are located in a foreign country but within the European Economic Area.

Demonstration programmes

In March 2007, European heads of state endorsed the European Commission's intention to stimulate the construction and operation of up to 12 CCS demonstration projects by 2015. On the basis of ZEP's 2009 CCS knowledge sharing proposal, the EU is launching its CCS project network. The goal of the network is to achieve commercially viable CCS by 2020. The EU launched in 2009 an EU Energy Programme for Recovery (EEPR) in which €1 billion was set aside for CCS demonstration projects in Poland, Germany, the Netherlands, Spain, Italy and the UK. The EU agreed in 2010 to set aside 300 million emission unit allowances (EUAs) from the New Entrance Reserve ("NER 300") to demonstrate CCS and innovative renewable energy technologies – including funding for up to 12 large-scale CCS demonstration projects. This is currently valued at €4-5 billion for CCS demonstration. 200 of the EUAs will be awarded for selected projects at the end of 2011 and 100 allowances at the end of 2013. Of the total 13 CCS project proposals submitted to the NER 300 in May 2011, 7 were from the UK and single projects from other member states.

6.1.3 European CCS Projects

At the end of 2011 there was a total of 19 LSIPs in Europe (Table 5-2) of which 2 are in operation and 18 are in the planning stages. Both projects in operation are situated in Norway. Many projects are being planned in the UK and Netherlands but also Poland, Germany, Spain, France, Norway, Italy, Bulgaria and Romania have large CCS projects in planning. In addition to the large projects smaller research scale projects have been underway in Europe i.e. CO_2 injection in connection to CO2SINK & MUSTANG at Ketzin (Germany) and Heletz (Israel) respectively.

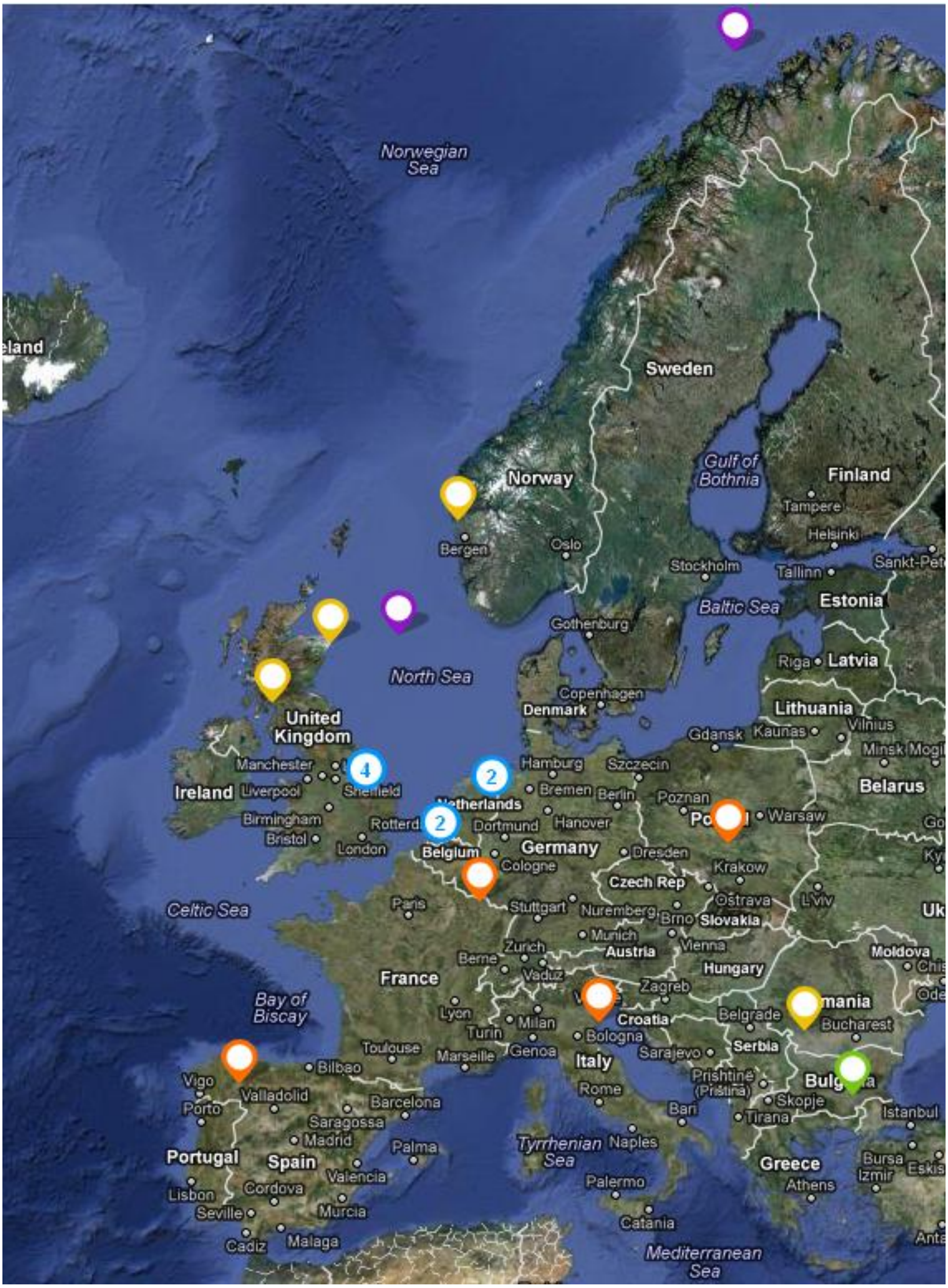

Figure 6-2. Map with the 19 large scale CCS projects in Europe in December 2011 (Global CCS Institute).

Table 6-2. Large scale integrated CCS projects in Europe.

Name	Location	Capture type	Volume CO_2 (MTPA)	Storage Type	Date of operation
In operation					
Sleipner CO_2 Injection	Norway	Pre-combustion (gas processing)	1	Saline formation (offshore)	1996
Snøhvit CO_2 Injection	Norway	Pre-combustion (gas processing)	0.7	Saline formation (offshore)	2008
Definition stage					
Be³chatów CCS	Poland	Post-combustion (power)	1.8	Saline formation (onshore)	2015
OXYCFB 300 Compostilla Project	Spain	Oxyfuel combustion	1.1	Saline formation (onshore)	2015
Porto Tolle	Italy	Post-combustion (power)	1	Saline formation (offshore)	2015
ROAD	Netherlands	Post-combustion (power)	1.1	Depleted oil & gas field (offshore)	2015
Green Hydrogen	Netherlands	Industrial separation	0.55	EOR (offshore)	2016
ULCOS	France	Industrial separation	0.7	Saline formation (onshore)	2016
Eemshaven CCS	Netherlands	Post-combustion (power)	1.2	EOR (offshore)	2017
Evaluate stage					
Peterhead Gas CCS Project	UK	Post-combustion (power)	1	Depleted oil & gas field (offshore)	2015
Don Valley Power Project	UK	Pre-combustion (power)	4.8	EOR (offshore)	2016
Eston Grange CCS Plant	UK	Pre-combustion (power)	5	Saline formation (offshore)	2016
C.GEN North Killingholme Power Project	UK	Pre-combustion (power)	2.5	Saline formation (offshore)	2016
UK Oxy CCS Demonstration Project	UK	Oxyfuel combustion	2	Saline formation (offshore)	2016
Pegasus Rotterdam	Netherlands	Oxyfuel combustion	2.5	Depleted oil & gas field (offshore)	2017
Full-scale CO2 Capture Mongstad (CCM)	Norway	Post-combustion (power)	1	Not specified	2020
Getica CCS Demonstration Project	Romania	Post-combustion (power)	1.5	Saline formation (onshore)	Not specified
Peel Energy CCS Project	UK	Post-combustion (power)	2	Depleted oil & gas field (offshore)	Not specified
Identify stage					
Maritsa Thermal Power Plant CCS Project	Bulgaria	Post-combustion (power)	2.5	Saline formation (onshore)	2020

Norway

Norway has long been active in CCS and invests considerable resources to CCS development. Norway is considered by many to be a world leader in CCS development and deployment. The government of Norway established in 2005 the publicly-funded Gassnova Corporation. Gassnova stimulates technology research, development and demonstration and contributes to the realisation of technology in industrial, full-scale pioneer plants. Furthermore, Gassnova provides advice to the authorities in matters relating to carbon capture and storage. Gassnova and the Research Council of Norway have jointly established the Climit program, which covers the entire innovation chain from research to technology development to pilot and demonstration projects.

The only two European CCS projects in operation are gas-processing projects situated in Norway. The Sleipner capture and storage gas processing facility is one of the global pioneers of CCS. Located in the middle of the North Sea, Norway, the capture and storage locations are in the same area. The injection at Sleipner started in 1996 and at the moment approximately 1 MtPA of CO_2 is separated from produced gas. The CO_2 is re-injected into a deep saline formation above the hydrocarbon reservoir zone below 800 m of impermeable cap rock. Maximum injection is planned for 20 Mt, with 8 Mt injected to date. Snøhvit CO_2 injection, Norways other operational CCS project, has been in operation since 2008. At Snøhvit 0.7 MtPA is being removed from the gas stream and injected and stored in the Tubåen sandstone some 2,600 metres beneath the seabed.

A third storage project is currently being planned in Norway, namely the Full-scale CO_2 Capture Mongstad. Capture, transport and storage components of the Mongstad power plant project are being developed separately by different parties in partnership with the Norwegian state, with the development of transport and storage components following the same time schedule as the capture plant. It is expected that CO_2 captured at the Mongstad plant will be stored in offshore saline formations on the Norwegian continental shelf. Concerns about the use of amine technology and possible effects on health and the environment have delayed this project and capture technologies is now being studied. Statoil, which is responsible for carrying out the project, estimates that the technology qualification will be in progress up to 3 years. The following engineering phase will last approximately two years, leading up to a basis for an investment decision presented for the Parliament no later than 2016.

Another full scale capture project at the Kårstø gas fired powerplant was halted in 2009. The CCS-project at Kårstø was along with Mongstad one of the most important promises made in the Government platform of 2005. The gas-fired power plant at Kårstø has had an irregular operational pattern since it was commissioned in the fall of 2007. Irregular operation of the power plant in the years to come would limit the environmental benefit of a CO_2 capture facility. The problems with Kårstø and Mongstad are a major setback in the process of CCS in Norway.

UK

The UK Government is supporting CCS and is focused on developing a good framework for CCS. The UK also has world-class academic expertise in CCS with 18 universities in the UK engaged with CCS research projects.

In 2007 a national CCS demonstration program was launched in the UK (The UK CCS Demonstration Programme). The UK programme will, in addition to possible EU funding, award up to £1 billion each for 1-4 UK projects. Merit to the national CCS demonstration programme 6 CCS projects is currently being planned in the UK. All of the UK projects have applied for funding under the EUs NER 300 program. Almost all of the projects currently planned, involve coal-fired power plants. The CO_2 from the plants in the UK would be transported to deep aquifers, depleted oil and gas fields or used in enhanced oil recovery in the Southern North Sea via a common user pipeline infrastructure. Most projects are planned to be operational by 2016.

The UK decided in 2009 on the coal-fired power station Longannet in Scotland as the first project for funding under the national CCS demonstration programme but on the 19th of October in 2011 a decision was made not to proceed with the Longannet CCS project. The £1bn will now be available for a new process. On the 30th of November 2011 the pilot programme CCPilot100+ was lauched at Ferrybridge where a carbon capture plant will extract up to 100tCO_2/day from a power station flue gas stream. The UK Government funds this project with £20m.

Netherlands

There are four demonstration projects currently being planned in the Netherlands. Through the national research programme CATO2 (CO_2 Afgang Transport Opslag), various groups in the Netherlands are performing dedicated research studies to support these projects.

The Rotterdam Maasvlakte CCS demonstration project of E.ON Benelux and Electrabel, generally referred to as the ROAD project (Rotterdam Opslag Afvang Demonstratieproject) is one of the six selected EEPR projects in Europe. ROAD aims at capturing CO_2 from a power plant in the Rotterdam harbour and storing offshore in the depleted gas field P18. Transport will be executed through a 25 km long pipeline.

The Green Hydrogen project is being planned by Air Liquide which is building a new hydrogen plant at its site in the Botlek area of Rotterdam. The plant will be "capture-ready", having the potential to incorporate a cryogenic purification unit (CPU) that could capture up to 0.55 million tonnes per annum of CO_2. It is envisaged that the captured CO_2 is utilised for enhanced oil recovery operations in the North Sea. Air Liquide is also a partner in the CINTRA consortium, together with Vopak, Anthony Veder and Gasunie. This consortium aims to create a CO_2 pipeline infrastructure and terminal (‘hub’) in the Rotterdam Port Area.

Eemshaven CCS project located in Groningen is considering amine-based post-combustion technology. Offshore storage options involving shipping are being investigated, especially through enhanced oil recovery. Plans are also under development to create a CO_2 hub in the North of the Netherlands, combining CO_2 streams from different sources, and creating possible linkages with the CO_2 hub in the Rotterdam area.

In Pegasus Rotterdam SEQ International BV is proposing to build a new oxy-fuel natural gas-based power plant with CO_2 capture. The plant will use low calorific natural gas supplied from UK and Dutch fields in the North Sea as a feedstock and the CO_2 would be transported back to the gas field via a 100-150 km pipeline.

Germany

German climate policy focuses on sustainable energies and the reduction of fossil energy consumption but the decision of the German government to phase out the use of nuclear power will have great affect on the energy supply of Germany. Trading of CO_2 emissions has further increased the interest in R&D on CO_2 storage in Germany during the past 10 years.

Germany is now in the process of implementing the European CCS Directive. On 7 July 2011 the German Parliament approved a bill for a CCS Act that regulates CCS demonstration projects. The Bundesrat, the legal body that represents the German federal states, on 23 September 2011 rejected the bill. The German legislative bodies now need to reach a compromise to avoid infringement procedures for non-implementation of the European law requirements but was not able to do so during 2011. CCS technology is a highly controversial topic of discussion in Germany.

A small pilot program for CCS has been completed in Ketzin in the federal state of Brandenburg where storage of CO_2 in a deep saline aquifer has been studied. Vattenfall also operates an oxyfuel pilot plant located near its existing lignite fired power plant in Schwarze Pumpe. E.ON and Siemens also launched a pilot plant that tests post-combustion carbon capture at E.ON’s hard coal-fired power plant near Hanau in September 2009. Vattenfall wanted to start operating a power plant in Jänschwalde (Brandenburg), where CCS technology would have been implemented for the first time on a power plant scale. Pipeline transport of CO_2 for onshore storage in deep saline formations was being considered. In December 2009, Vattenfall received Euro 180 million from the EEPR to support further concept definition studies for the demonstration plant at Jänschwalde but in December 2011 Vattenfall was forced to stop plans for its CCS demonstration project due to the ongoing impasse in the German CCS law. The EU-supported project would have been operational by 2015/16.

France

France already has a decarbonised electricity sector, producing almost 75 per cent of its electricity from nuclear power and up to 90 per cent when hydro is included. France is also working on a regulatory framework for development of CCS and especially in connection to steel industry.

The ULCOS demonstration project by ArcelorMittal is at its Florange steel plant in Lorraine. The project involves post-combustion technology and transportation of CO_2 via 60-80 km pipeline for storage in onshore deep saline formations. The project is supported by a consortium of European steel producers and has been proposed by the French government for the NER300 funding. It is a key part in the UCOS II programme that aims at developing technologies that reduce CO_2 emissions of steel industry by at least 50 %. Rautaruukki Oyj was one of the partners of the ULCOS I programme which established the scientific and technical basis for the ULCOS project. BRGM (Bureau de Recherches Géologiques et Minières) is now studying aspects of the CO_2 geological storage as a part of the ULCOS II programme.

Spain

Spain was one of the first countries in Europe to transpose the EC Directive on CCS into national legislation. Spain is also at the forefront of Europe's CCS developments.

CIUDEN (Fundación Ciudad de la Energía/City of energy) is an initiative of the Spanish administration that is leading Spain's CCS efforts and has constructed a technology development centre in north-west Spain in the province of Leon, close to the 1,312 MWe Compostilla Power Station. Main interests relate to the research, development and demonstration of efficient, cost effective and reliable CCS. The current pilot installation in Leon is Phase I (2009-2012) of the Compostilla OXYCFB300 project, which is one of the demonstrations funded through the EEPR. The OXYCFB 300 Compostilla Project involves oxyfuel combustion where the captured CO_2 would be transported 120km by pipeline for storage in onshore deep saline formations. Phase II (2013-2015) includes the construction of a 300 MWe demo plant at the Compostilla site together with the corresponding CO_2 transport and storage infrastructure. Final investment decision for the second phase is expected to be made in 2012.

Italy

Currently, the political situation for CCS in Italy is good and progress has been made on several issues. There are laws already where funding of CCS is mentioned as a priority within energy R&D. However, the funding mechanism has not yet been described. Also there is a law that refers to the revenues from the auctioning of Italian ETS allowances that could be used for funding CCS projects in Italy – this is funding in addition to the NER 300 funding mechanism. The transposition of the EC Directive on geological storage of CO_2 is also progressing well in Italy.

The Italian Porto Tolle project by Enel involves replacing of an oil fired power plant by retrofitting coal fired power plant equipped with post-combustion capture. The CO_2 will be transported approximately 100 km by pipeline for storage within a deep saline formation in the northern Adriatic Sea. The project received 100 million Euros in funding through the EEPR. Detailed engineering on the CCS plant is expected to be finalised by the end of 2012 and operation to start in the fourth quarter of 2015.

An Italian integrated CCS pilot project is also under development in the frame of an Eni-Enel cooperation agreement. The project involves capture at Enel's post-combustion power plant in Brindisi that has been in operation since October 2010. Liquefaction and cryogenic storage system are planned to be built in Brindisi, transport of CO_2 by truck and storage at the Eni's pilot CO_2 injection project in an exhausted gas field in Cortemaggiore, starting in summer 2012. A pilot closed loop CO_2 pipeline is also to be constructed in Brindisi to develop knowledge in transportation system design.

Poland

Assessement of possible storage sites in Poland is being conducted by the CCS project of PGE and also within the Polish National Programme on safe CO_2 storage, ordered by the Ministry of Environment and lead by PGI-NRI.

The Belchatów CCS Demo project has been supported by the Polish government since the EU Flagship Programme was announced in 2007. The project received EEPR support in 2009 and has been proposed by the government for the NER300 financial mechanism. Belchatów is the biggest lignite fired power plant and single emission source in the EU. The project involves a post-combustion capture plant integrated with a new CCS-ready lignite fired block. The captured CO_2 will be transported by pipeline to an onshore saline aquifer.

Romania

The CCS Directive will be transposed through a law in Romania which will be submitted to the Parliament in 2011. Romania has lately been active in searching solutions through CCS for their lignite fired power plants and energy intensive industry.

In 2010 a decision was made to create a CCS demonstration project in Romania. The Ministry of Economy, Trade and the Business Environment (METBE) called for proposals and Getica CCS demonstration project was selected from the energy sector, and launched in December 2010. The Romanian CCS Demo Project is a governmental project, officially sustained by the prime minister, coordinated by the METBE and supported by the Global CCS Institute.

The Romanian CCS Demonstration Project is to implement a full chain operational CCS system capturing 1.5 million tonnes CO_2 per annum of emissions from an existing 330 MW unit of the Turceni Power Plant in Oltenia, Romania. The CO_2 from the capture plant will be transported using (where possible) existing onshore natural gas pipelines and stored underground in onshore deep saline formations within a 50 km radius of the power plant. There is now on-going feasibility study and NER300 submission documentation has been submitted.

Bulgaria

Coal is important for the security of energy supplies as well as the economic competitiveness of electricity generated by domestic coal combustion in Bulgaria. Therefore the Bulgarian Government prioritises the development of clean coal technologies as key aspects for technological development. Towards Zero Emission Demonstration Power Plant with CCS in Bulgaria is an initiative of the Bulgarian Government. The project is being carried out by WorleyParsons and INYPSA, who are working closely with the European Bank for Reconstruction and Development (EBRD) and the Ministry of Economy, Energy and Tourism of Bulgaria.

The Maritsa Thermal Power Plant CCS Project is currently being planned in Bulgaria. The project will involve post-combustion CO_2 capture at a 120 MW lignite-based thermal power plant. The CO_2 would be transported by pipeline for storage in onshore deep saline formations and potential suitable storage sites have been identified. Feasibility study for the project is being conducted by Toshiba Corporation and is expected to be completed in the first half of 2012. This study is being sponsored by Japan's New Energy and Industrial Technology The project has received financial support from the Spanish Fund for Sustainable Development through the EBRD. The CO_2 capture unit is scheduled to be operational in 2020.

6.2 North America

The United States has the highest number of projects in operation, in construction and in development planning and the largest number of projects being put on-hold or cancelled over the past year. This high level of activity is due to the opportunities provided by CO_2 for EOR systems and by the United States government grants to specific projects, which have been the highest in the world. In the US there is a drive in industries where CO_2 is already separated as part of the industrial process, such as gas processing and fertiliser production, and where an opportunity is found to use that CO_2 for EOR.

However, where the cost of capture is relatively high, such as power generation, developing a strong business case for CCS is a challenge. Many projects have been halted, even with substantial government funding. Absence of national carbon legislation is a big problem for projects in the US.

The Department of Energy (DOE) has created a network of seven Regional Carbon Sequestration Partnerships (RCSPs) to help develop the technology, infrastructure, and regulations to implement large-scale CO_2 sequestration in different regions and geologic formations within the US. One Partnership project: the Midwest Geological Sequestration Consortium's (MGSC) Illinois Basin-Decatur Test Injection began injection in November of 2011. The CO_2 will be captured from the Archer Daniels Midland (ADM) ethanol plant in Decatur, Illinois, compressed and then injected into a nearby deep saline formation. The planned capture and injection rate, at 1 000 tonnes of CO_2 per day or 365 000 tonnes per year and is expected to operate for three years, for a total CO_2 injected of around one million tonnes. A second project with storage in a deep saline aquifer at larger scale: the Illinois-ICCS project with 1MtPA of CO_2 captured from the ADM plant is under construction and will start operation by late summer 2013

CCS continues to play a major role also in Canada's carbon emission reduction strategy, and significant strides have been made at the provincial level in advancing the policy regime and financial support base for projects. The possibility for CO_2 EOR and oil sands continues to motivate CCS project development. Canada has a strong large-scale CCS demonstration program, including the Great Plains/Weyburn-Midale project continuing to inject around 3MtPA of CO_2, two projects under construction and three projects which may be in a position to decide whether to progress towards final investment decision in 2012.

6.3 Australia

Near-term storage options are not readily available in Australia, which does not have significant access to EOR potential or depleted oil and gas fields. Because of this, the search for suitable saline formation storage is a requirement for all large-scale CCS projects. Saline formation storage is being used in the only Australian project under construction – the Gorgon Carbon Dioxide Injection Project.

In June 2011 the Australian Government announced AU$60.9 million in funding for a National CO_2 Infrastructure Plan to study potentially suitable sites to store captured CO_2 and speed up the development of transport infrastructure near major CO_2 emission sources. The Australian Government also announced that it had selected the Collie Hub project for funding under the AU$1.68bn CCS Flagships Program. The Collie Hub project aims to capture around 2.5MtPA of CO_2 from an industrial source south of Perth in Western Australia. The Australian Government is to provide up to AU$52 million to support the studies required to move the project to the next phase of decision making. A key aspect of the next phase of project development is the completion of a detailed storage viability study. Initial studies have identified the Lesueur formation in the Southern Perth Basin as the best potential CO_2 storage site. The Australian Government also announced that it will continue to progress other large-scale Australian CCS projects, including the CarbonNet project in Victoria and the Wandoan project in Queensland. As with the Collie Hub project, these two projects will initially focus on the development of CO_2 storage reservoirs and associated community engagement (GCCSI 2011).

6.4 Asia (China, Japan, Korea)

China is an important and challenging country for CCS deployment. The high cost of CCS technologies is the major concern to Chinese stakeholders. The current measures for reducing China's GHG emissions are focused on improving energy efficiency, energy conservation and increasing the share of non-fossil fuel energy sources. However, there is growing recognition by the Chinese central government that while these technological options remain important, they will only go so far and CCS will also need to play a key role in China's climate change abatement strategies, particularly in the medium to long term. This recognition will continue to drive CCS development in China.

Six large projects are in the planning stages in China. These projects are generally being undertaken by China's large state-owned power utilities and oil and gas companies. Some of the most important projects are the Greengen IGCC project and the Shenhua Coal-to-Liquids (CTL) Plant (Ordos City). These projects have the support of government agencies such as the National Development and Reform Commission (NDRC), as well as involvement from international partners such as development banks, non-government organisations (NGOs) and industry. CO_2 utilisation is considered to be critical to making CCS a commercially viable option. A number of companies in China are already capturing and using CO_2, including in the production of food and beverages, fertiliser, algae and for EOR. For example, Sinopec is currently operating an integrated pilot plant that captures 0.04MtPA of CO_2 for EOR. Based on this experience, Sinopec has started a program to expand the capacity of this facility up to 1Mtpa CO_2 capture (Phase II). A series of research programs will be conducted on petroleum geology investigation, environment impact and other areas concerning CO_2 EOR. Phase II of this EOR facility is expected to be completed in 2014.

The Japanese Government is committed to reducing its CO_2 emissions. Since the March 2011 earthquake and tsunami, the Government has revised its Basic Energy Plan, which will likely include an increased reliance on fossil fuels, at least in the short term. The revision of the plan is being considered in line with the emissions reduction target, and could include the adoption of CCS. The Ministry of Economy, Trade and Industry (METI) is currently funding the development of a demonstration project in Hokkaido. The project aims to capture more than 0.1 MtPA of CO_2 for storage in an offshore deep saline formation more than 1 000 metres under the seabed in the North of Japan. In support of this project, Japan CCS Co. Ltd is undertaking a 3D seismic survey and drilling a test borehole to identify and explore suitable formations for CO_2 storage.

Korea aims to achieve commercial deployment of CCS plants and global technology competitiveness by 2020. Two large projects are currently under development: Korea-CCS 1 proposes to use post-combustion technology to capture up to 1.2MtPA of CO_2 from a 300MW coal-fired power plant and store in a deep saline formation by 2017; and Korea-CCS 2 proposes to use oxyfuel combustion or IGCC with pre-combustion technology to capture 1.2MtPA of CO_2 and store in a deep saline formation by 2019. The Korean Government has commenced a storage capacity assessment and geological survey of the offshore Ulleung basin and is exploring shipping transport (GCCSI 2011).

6.5 Africa

The In Salah industrial-scale CCS project in Algeria has been in operation since 2004. More than three million tonnes of CO_2, separated during gas production, have to date been stored in a deep saline formation. BP, Sonatrach and Statoil, the project operators, aim to store a total of 17 Mt CO_2 over the next 20 years.

The South African Centre for Carbon Capture and Storage's (SACCCS's) started a CCS potential study in 2004 that showed great potential for CCS. In 2010, a 'carbon atlas' was completed, pointing out specific areas suitable for carbon capture.

Currently, a scoping study for test injection is being undertaken and will be followed by the compilation of a business plan. Test injection is planned to start in 2016. In addition to geological modeling of storage sites, financial opportunities for CCS in South Africa are also being investigated.

6.6 Russia

During the period of 1980 – 1990 large scale pilot tests were carried out in Russia where CO_2 formed at petrochemical plants was used for EOR. The tests consisted of injection of carbonated water, CO_2 and water. The tests were effective (up to 12% increase in recovery) in fields containing heavy oil, highly mineralized waters, and in steeply dipping layers with low permeability. Problems were related to CO_2 capture and corrosion of the equipment and transport systems. It seems that most of the injected CO_2 was recovered from production wells during the experiments (Kuvshinov, 2006).

Russia is not at this point considering CCS as a priority GHG (greenhouse gas) mitigation technology. Currently the focus is on energy efficiency. The Russian energy strategy highlights nuclear, hydro, renewable, and coal energy. Supercritical and IGCC (Integrated Gasification Combined Cycle) plants are priority developments. CCS plays only a marginal role in this strategic thinking. There are opportunities for CCS in Russia and they could be realized in the longer timeframe under the conditions of international cooperation, availability of financial resources and state policy support. Implementation of CCS on coal-fired power plants is being considered theoretically, it would allow to reduce GHG emissions which otherwise will continue to grow with increased coal consumption. However, the focus areas in the coal sector now are improvement of the quality of coal, reducing cost of transportation, and addressing the issue of large quantities of ash sludge.

Russia is aware of a growing interest to CCS around the world and follows global CCS-related developments and discussions. It also devotes some limited resources to CCS-related R&D. The Ministry of Education and Science is funding several research programmes, including the assessment of geological capacity for CO_2 storage, and the research into capture technologies. The goals that the Ministry has set for CCS are: assessment of CCS potential for Russia, scientific justification, geological and economic assessment of storage capacity; development of geological models and atlases. Several issues that have already been looked at are: identification of large point pollution sources and links to potential storage sites, risk assessment of geological storage, monitoring of storage sites, and opportunities for the development of a pilot project. In addition, the Russian State University of Oil and Gas is looking into EOR and ECBM opportunities (Elliina 2012).

7 Summary and discussion

CCS is a technology that can prevent large quantities of CO_2 from being released into the atmosphere, typically from large industrial processes. The CO_2 is transported to a carefully selected and safe storage site, and injected deep into a rock formation in a sedimentary basin where it remains permanently stored away from the atmosphere. Possible storage sites include depleted oil or gas fields, or rocks which contain undrinkable saline water formations with an impermeable trap or cap-rock above them. The seal and other geological features prevent the CO_2 from migrating to the surface. Such sites have been demonstrated to securely contain fluids and gases for millions of years. Because of the significant emission reductions CCS can achieve, it is considered a key option to reduce greenhouse gas emissions.

The global storage capacity for CO_2 in geological formations is many times larger than the annual CO_2 emissions globally. Potential storage sites in sedimentary basins are however quite unevenly distributed worldwide. Storage can be done either in onshore or offshore formations. Characterization and monitoring of onshore storage sites is easier and cheaper but public acceptance issues regarding onshore storage may restrict available storage options in some countries.

Finland does not have any known suitable storage sites but there is good capacity for storage in neighbouring countries. The offshore capacity in Scandinavia is particularly good compared to the rest of Europe. Deep saline aquifers in Norway and Denmark have large capacity, good properties and are well studied. There are probably also possibilities for storage in Sweden and the Baltic Sea region but the potential storage formations need to be studied in more detail. A large capacity in deep saline aquifers in Russia may also exist but any investigations or capacity estimations have not yet been made. Storage in depleted oil and gas fields or in connection to EOR holds a great potential in Russia and could become an attractive option in the future.

A number of CCS projects have been in operation since the mid-1990s but the technology would still need to be developed and improved to make it more economical. Nearly all of the operating or committed capture projects are either CO_2 EOR related and/or based on gas processing. Coal mining companies and electricity-generation companies are currently investigating geological storage as a mitigation option. However, where the cost of capture is relatively high, such as power generation, developing a strong business case for CCS is still a big challenge. At the end of 2011, there were 74 large scale projects across the world (8 in operation, 6 under construction and 60 planned). The 14 committed projects have a total CO_2 storage capacity of 33 MtPA.

The international community has set a goal to have a broad deployment of CCS projects by year 2020 and governments around the world have provided a range of different types of support to CCS demonstration projects, including tax credits, allocations and grants. North America and Europe have most of the large CCS projects (25 and 21 projects respectively) followed by Canada (nine projects), Australia (six projects) and China (six projects). Within Europe, the United Kingdom has the largest number of projects (seven) followed by the Netherlands (four) and Norway (three). There are currently no projects in large emitting countries such as Japan, India or Russia. At the moment no projects are planned in developing countries. The inclusion of CCS under the CDM (Cleen Development Mechanism) at the UNFCCC COP-17 in Durban, South Africa in December 2011 could potentially help the deployment of CCS in both developed and developing countries alike.

In addition to the economic aspects also a clear regulatory framework is needed. The European Commission has issued a CCS Directive that forms the legal platform for the widespread introduction of commercial CCS technology in Europe. The CCS Directive must be transposed into the national laws of Member States but Member States are entitled to refuse storage in any part or all of their territory. Even though the European approach to CCS policy and legislation is one of the most advanced proposals for the regulation of commercial CCS, uncertainty about national legislation and project costs still hamper the CCS development in Europe. Another issue is the link between the technology and the European Union Emissions Trading Scheme (ETS). Policymakers had hoped to incentivise companies to invest in CCS by designing the legislation to allow CO_2 captured and stored safely to be considered as 'not emitted' under the ETS but as carbon price is expected to rise steadily over the next decades, companies may have to put up large security sums to cover any potential future carbon leakages from their projects. Currently, most CCS activities in the EU remain at the research and development level but there are a number of pilot or early stage CCS projects that are underway.

Lately there has been a trend of cancellations of big CCS projects in Europe. Cancellation of the Longannet Project (Scotland) was announced in October 2011, following a decision by the UK Government not to fund the construction of the project due to commercial issues, highlighting the economical uncertainty surrounding projects. In addition to economics also regulation and public acceptance issues regarding onshore CO_2 storages is a problem in some parts of Europe. The Vattenfall Jänschwalde (Germany) project was cancelled in December 2011, due to a lack of progress in resolving regulatory issues around CCS in Germany, particularly with respect to the permanent onshore storage of CO_2. The Jänschwalde project was also faced with opposition from the local community towards the chosen storage site. Both Longannet and Jänschwalde were early-mover power generation projects in the advanced stages of development.

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