

## **BASREC pre-study on transportation and storage solutions for CO<sub>2</sub> in the Baltic Sea region**

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# 1 Introduction

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Institute for Strategic Analysis (INSA) and its project partners Lise Siverts from Kvale Advokatfirma and Reidar Kierulf from IPAN have produced this report. INSA has been the coordinator and contract partner to BASREC.

The consortium possesses long term comprehensive and complementary senior experience from the oil, gas and power business, law and consultancy firms and governmental bodies.

The project goal has been to clarify how a joint regional solution could lead to a rapid and more cost-effective implementation of carbon capture and storage projects in the Baltic Sea region.

The project team will thank the BASREC countries for their contributions to the report. The team has as well made use of several highly valuable recent open reports and presentations on the issue of CCS capture transportation and storage. References to those reports are made both in the text and in the reference list at the end of the report.

## 2 Main findings

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- CCS is considered to be an important cost effective option for mitigating climate change and is by IEA deemed necessary in order to reach the globally agreed target to limit average global temperature increase to 2°C above preindustrial level. The target seems increasingly difficult to achieve due to current lack of international regulations and waste of emissions. As a consequence, a more rapid deployment of CCS may be necessary in order to keep the accumulated emissions below the required global ceiling up to 2050.
- Although several BASREC nations are well endowed with renewable energy, and others have a large nuclear base, the use of CCS seems important for continued cost effective low carbon energy supplies in other key countries. The Fukushima catastrophe has increased the perceived risks of nuclear power, which in turn may increase the demand for CCS as base load solutions in the power markets.
- Cost effective solutions for CO<sub>2</sub> storage may in particular be important to preserve a competitive industrial basis in most BASREC nations. Several countries, like Sweden and Finland, have biogenic industries of considerable size and increased use of bio-energy is expected. Hence CCS offers the opportunity to build a competitive carbon negative industry in the region if suitable regulations and incentives are applied and CO<sub>2</sub> transportation and storage is efficiently developed.
- IEA envisage that CCS roll out should accelerate after 2025 in order to comply with the 2°C target. Development of cost effective transportation and storage solutions will be time consuming. There is need for action now if the roll out vision is to be achieved.

This study reveals that if the ambitions for implementation of CCS projects are to be met, there will be a need for extensive use of joint and transboundary solutions for transportation and storage of CO<sub>2</sub> between BASREC nations in the medium to longer term. The reasons are mainly:

- Sources and potential cost effective storage solutions are unevenly distributed among BASREC nations. Some of the BASREC nations do not have geological

formations suitable for storage of CO<sub>2</sub> at all. This is the case for Finland and Estonia, while only little feasible storage capacity has so far been identified for Lithuania.

- Several nations like Germany, Denmark, Latvia and Poland have considerable onshore storage capacity which may provide the most cost effective solution for their own needs. But recent experience from the legislative processes has demonstrated reluctance to allow storage (particularly onshore) in the short to medium term. This may increase the need for offshore and transboundary solutions.

### **Timelines**

- The BASREC countries are in the early phase of mapping and developing storage sites. Only a few storage sites are currently in operation (i.e. Sleipner /Utsira formation and Snøhvit on the Norwegian Continental Shelf). No potential storage sites have yet been qualified as storage sites in conformity with the CCS directive. It will be time consuming, challenging and require high levels of investments to develop a cost efficient transportation and storage system for the future.
- It may typically take 8 years from decision to start exploring a specific site to injection can commence. Hence there is a need for keeping the pressure on development of transportation and storage.
- The preliminary evaluation of transportation and storage opportunities reveals the need for a transnational pipeline network as well as storages that extend across several borders. Based on experience from natural gas transport, development of treaties for transboundary transport and storage of CO<sub>2</sub> may add considerably to the leadtime. The issue may be more demanding for CO<sub>2</sub> than for natural gas due to leakage risk and transfer of long term liability for CO<sub>2</sub> storage, although transportation of natural gas poses a larger explosion risk.

### **Need for operational coordination**

- Depleted oil and gas fields can be developed into CO<sub>2</sub> storage sites within a shorter time span. This will, however, require intensive coordination of planning, development and operation between the capture and the storage operators. The need for coordination is as well imminent in EOR projects (the use of CO<sub>2</sub> for enhanced oil recovery) since such projects require precise timing and a high level of security of CO<sub>2</sub> supplies.

### **Benefits of joint and cost effective solutions**

- Costs seem in general higher than earlier anticipated, but there is a considerable variance in costs of transportation and storage solutions. As an example at the low end, transportation and storage cost for CCS projects with storage opportunities in safe and well documented depleted oil and gas field close to the plant may be as low as 2 Euro/ton CO<sub>2</sub>. As an example on the high end, the costs may be in the order of 40 Euro/ton CO<sub>2</sub> if CO<sub>2</sub> must be piped in a single purpose pipeline to the coast, liquefied and shipped to offshore saline aquifers, which must be qualified through extensive exploration and development programs. EOR projects may provide opportunities for negative storage costs. In US a willingness to pay 30-40 USD/ton for secure supplies of CO<sub>2</sub> has been reported. In order to reduce overall CCS costs it is consequently important to sort out and develop the most cost effective chains of capture transportation and storage both on and offshore.

- Economics of scale is evident in both pipeline transportation and storage, and should increase the return from planning and cooperation. Transportation costs are about 3 times as high for a pipeline with capacity of 2.5 million tons per annum (Mtpa) as for a pipeline with capacity of 20 Mtpa (if they are both operated at full capacity). Clustering of volumes for long distance transportation in trunk lines may accordingly reduce transportation costs from 15 to 5 Euro/ton for a typical Baltic Sea solution for the region. Transportation in large scale joint trunk lines from a Baltic ring to North Sea destinations may cost in the order of 12 Euro/ton.
- Several joint, transboundary and possible cost effective solutions have been identified in the region.

### **Uncertainty and risks**

- The high level of uncertainty regarding technology, market development, climate policies and environmental and safety concerns may constitute major barriers for exploitations of such opportunities. CCS chain development is in particular sensitive to regulatory risk. This risk has proved to be very high in the BASREC region.
- Recent experiences from the legislative processes in countries with potential storage locations have demonstrated that public engagement may change the policies with regard to development of CCS projects. In several countries the governmental authorities have been forced to amend the draft regulations aimed at implementing the CCS directive, to be much more restrictive than originally intended. This has created serious barriers for the planned demonstration projects and development of the CCS technology in BASREC nations. Hence, it seems most likely that only a limited number of demonstration projects, if any, will take place in these countries before 2020. This is viewed as a serious setback to the plans to start roll-out of CCS projects shortly after 2020.
- The restrictions on onshore storage (creating higher demand, and thereby higher prices for storage services) may in theory benefit nations with abundance of offshore storage but represent a high risk of stranded investments, and therefore a high risk for negative investment decisions.

### 3 Recommendations

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BASREC nations should foster development of safe and cost effective transportation and storage systems by

1. Development and implementation of a coherent and predictable policy and legal framework so as to stimulate investments in the further development of CCS technologies and logistical chains.
2. In particular developing a concessionary system in conformity with the CCS directive that not unduly discourage exploration and development of safe and cost effective CO<sub>2</sub> storage opportunities.
3. Carrying out a public engagement program to identify the real concerns, risks and possible mitigation opportunities involved as a basis for reaching a more rapid regulatory clarification.
4. Stimulating technology development and the common knowledge base by sufficient support to demonstration and commercial scale capture, transportation and storage projects, facilitating storage for ongoing and potential demonstration projects.
5. Stimulating better mapping and pre commercial exploration of storage sites and potentials.
6. Stimulate information sharing about storage opportunities, capacities and costs of transportation and storage.
7. Contributing to business participation and efficient organization of CO<sub>2</sub> transportation and storage.
8. Incentivizing CCS chain development by creating licenses/property rights and possible improved support and market systems.
9. Intensify negotiations of transboundary agreements, regulating joint and transnational transportation and storage issues as described later in this report.

In this way BASREC countries will help pave the way for an efficient roll out of CCS in due time for reaching the climate targets.

The recommendation is based on the view that availability of storage sites is potentially a major constraint to the rapid and widespread deployment of CCS. Priority should consequently be given to regulatory clarification and mapping and characterization of storage opportunities.

Organizing transportation and establishing licenses/property rights for transportation and storage are two key issues. Establishment of storage concessions incentivizes development and supply of storage services. In the CCS Directive, a concession system for storage is envisaged. Such system will create a formal framework for privileges and duties of the concessionaire. In addition, it may create the incentives for development of different storage opportunities. It may be necessary to reinforce a concession system by a support system. This will mobilize resources for storage site development, establish better knowledge of costs and capacity of storage in the region and provide a more efficient supply of storage services. In theory, expected higher and firm prices on emissions may provide sufficient incentives for the required storage development. But such relations are weakened by the high level of uncertainty and considerable lead time in development of storage and transportation.

The development of shared CO<sub>2</sub> transport networks will generate efficiency benefits on a system level, but the costs and benefits of such networks will go well beyond the interests and budgets of individual CCS projects. Consequently infrastructure companies able to execute long term system planning, like in the natural gas and electricity business, should be developed. Governments may need to play a role in fostering such

companies by taking ownership and subsidize in an early phase. In the longer term governments may substitute ownership with transmission company regulations.

## **4 Methodology and approach**

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### **4.1 Project goals**

The project goal is to clarify how joint regional solutions could lead to a rapid and more cost-effective implementation of carbon capture and storage projects in the Baltic Sea region.

The study shall in particular focus upon possible (joint) solutions for transportation and storage with indications and descriptions of costs, economy and handling of risk elements, upsides/downsides and possible transboundary issues to be solved in joint solutions.

The report will serve as an input to the BASREC, CCS Workshop later to take place in the Baltic Sea region.

Generally, there are two main measures that governments can apply to speed up implementation of carbon capture, transportation and storage projects:

- Clarify the regulatory framework for all elements in the CCS chain (capture, transportation and storage).
- Give incentives to the development of CCS projects, both capture, transportation and storage solutions.

### **4.2 Approach**

On this background the report is divided into the following main elements:

Section 5: CCS in the BASREC region is viewed in context of the IEA roadmap for reaching the so called 2°C target. The costs, competitiveness and need for application of the CCS technology in the BASREC area are discussed.

Section 6: Discussion of possible development of CCS projects in the BASREC region up to 2020, 2030 and 2050, as a background for discussing the need for joint transportations and storage solutions.

Section 7: Overview of the storage options in the area, their location and capacities.

Section 8 and 9: Analyses of costs, risk and risk management issues in transportation and storage in order to get a better understanding of the most cost effective solutions for transportation and storage in the Baltic Sea region.

Section 10: Preliminary evaluations of different transportation and storage solutions for the region.

Section 11: Overview of the regulatory development and the situation in the different states around the Baltic Sea as well as the current limitations on storage solutions in the area.

Section 12: Discussion of possible public engagement strategies and solutions. Public opposition has constituted serious barriers to development of CCS storage, and, hence,



CCS projects in Europe, including in some BASREC countries. Such opposition represents a serious cost driver and create risks for development of the CCS chain in general and planning and development of transportation and storage systems in particular.

Section 13: Discussion of how development of optimal transportation and storage solutions could be best incentivised until a sufficiently strong climate policy regime with high and firm emissions permit prices is established. In the section are also discussed organisational issues.

Section 14: Overview and assessment of the transboundary issues that must be solved.

Recommendations are given in section 3 and section 15.

## 5 Background

### 5.1 CCS system description

The main elements of a CCS chain are illustrated in the figure below.

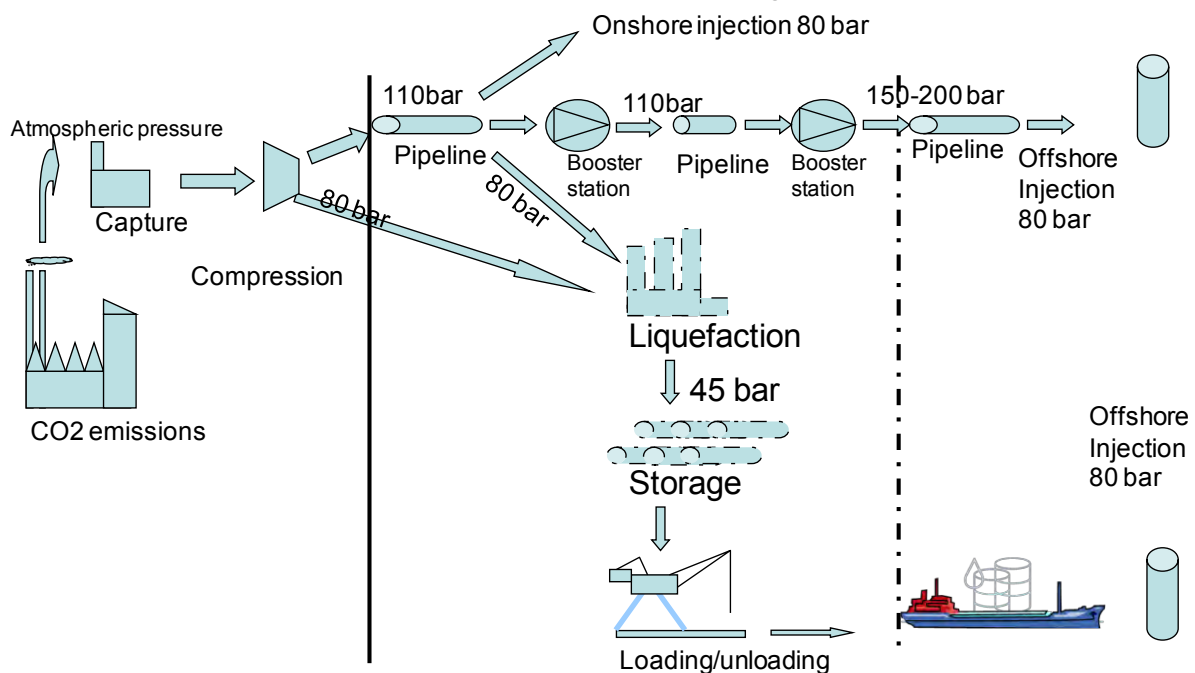


Figure 1: Schematic presentation of the CCS chain.

The CCS system consists of the three main elements capture, transportation and storage.

There are several different capture technologies available. Different technologies will be required dependant on the type of plant from which CO<sub>2</sub> is emitted. Furthermore, capture technologies are still being developed.

Transportation of CO<sub>2</sub> can take place by pipelines or by ship. For both solutions, CO<sub>2</sub> must undergo different processes, like purification, dehydration, pressurization and measurement.

In order for geological sites to be utilised as storage for CO<sub>2</sub>, it is necessary to have a reservoir rock (into which CO<sub>2</sub> can be injected) and some sort of sealing rock (so that CO<sub>2</sub> does not leak from the storage). The main types of storage are the following:

- Active oil and gas fields (CO<sub>2</sub> used for enhanced oil or gas recovery – EOR/EGR)
- Depleted oil and gas fields
- Saline aquifers

Potential storage sites are located both onshore and offshore.

More detailed breakdown of the CO<sub>2</sub> transportation and storage chain is offered in the annexes to this report.

## **5.2 CCS and climate solutions**

Development and deployment of CCS from industry and power production is assumed to constitute an important element of cost effective solutions for reaching the globally agreed 2°C target. The need for CCS is currently increasing, since other, and simpler, CO<sub>2</sub> reduction measures have not been implemented in due time due to lack of sufficient international regulations. As a matter of fact, large parts of the available emissions budget up to 2050 are now wasted on activities where emissions could have been avoided at low or even negative costs.

## **5.3 Costs and competitiveness**

Different studies show large differences in carbon capture cost between industries, between different plants, between existing and new plants, and between different transportation and storage solutions. Hence considerable analytic efforts are needed to find out which CCS projects that will be viable and require transportation and storage the next years.

The next figure illustrates the current knowledge regarding costs of CCS within different industries.

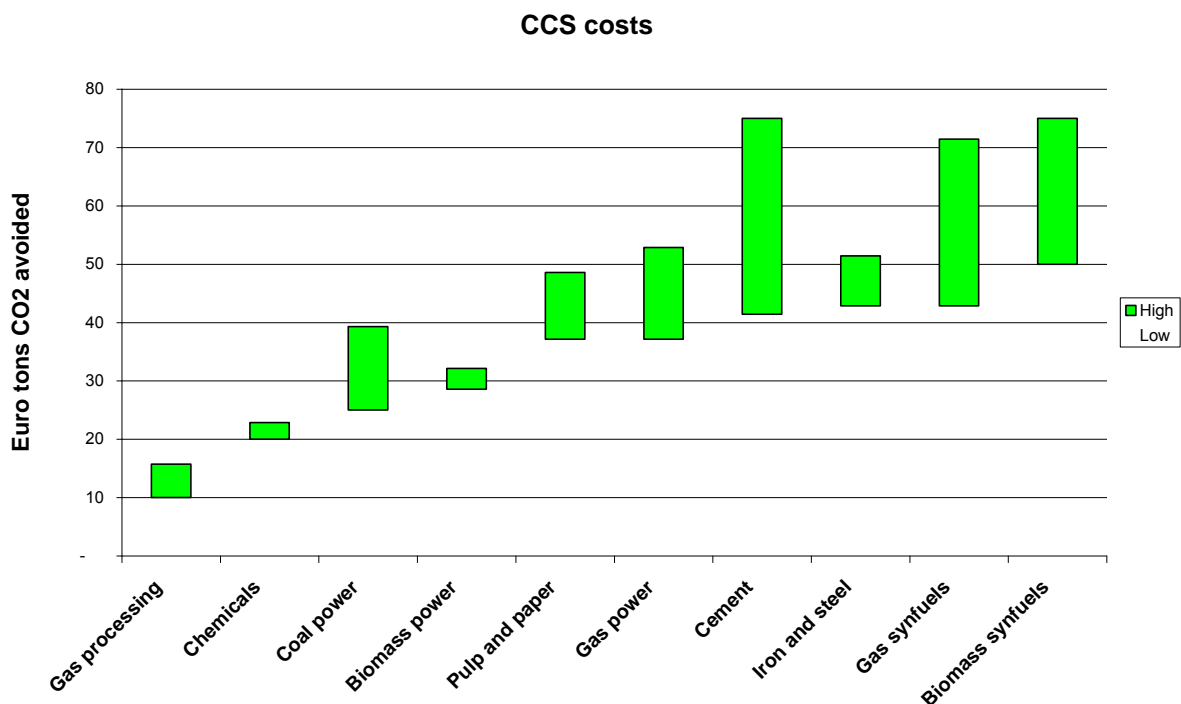


Figure 2: Cost of capture and compression in different industries. (Source: UNIDO, INSA)

The numbers are highly uncertain but give a possible merit order in development of CCS projects.

The future development of CCS projects will be influenced inter alia by development in support systems for renewable energy, nuclear power policies and efforts to reduce energy consumption. These issues increase the uncertainties regarding demand for transportation and storage of CO<sub>2</sub>, complicate planning, and increase the risks connected with investment in transportation and storage systems. The risks involved will hamper development of the system, and will also raise questions regarding risk sharing between industries and societies in the development phase.

Large scale demand for CCS projects requires either a high and firm long term price on CO<sub>2</sub> emission permits, or a large scale CCS financial support system. Neither is in place. Economic drivers for CCS projects, (including storage and transportation systems) are currently weak. Consequently resources within energy companies, consultancies and construction industries are not mobilized to the extent necessary to achieve a massive roll out in accordance with visions presented by IEA (presented below).

The third period of the EU emissions trading system may provide better incentives for development of CCS-projects. The following table summarises projected emission permit prices for 2020.

Prognosis by	Year	Price (Euro/tonne)
Barcklays Capital	2010	40
New Carbon Finance	2009	44 - 63
ICF International	2009	- 70
Point Carbon	2009	25 - 60 (year 2016)
Societe Generale	2008	45-93

In the table above, the higher prices reflect an EU decision to increase emissions reduction from 20% to 30% by 2020. The recent EU finance study PLANETS S30 estimated emission permit prices to be about 16 Euro/ton in 2020 and concluded that emissions prices would not be sufficient to finance CCS roll out without additional supports.

### 5.4 Roll out visions

The figure below shows a possible roll out of CCS projects as envisaged by the IEA roadmap to 2050. As can be seen, major roll out is expected to start after 2020.

Figure 4: Global deployment of CCS 2010–2050 (CO<sub>2</sub> captured and number of projects)

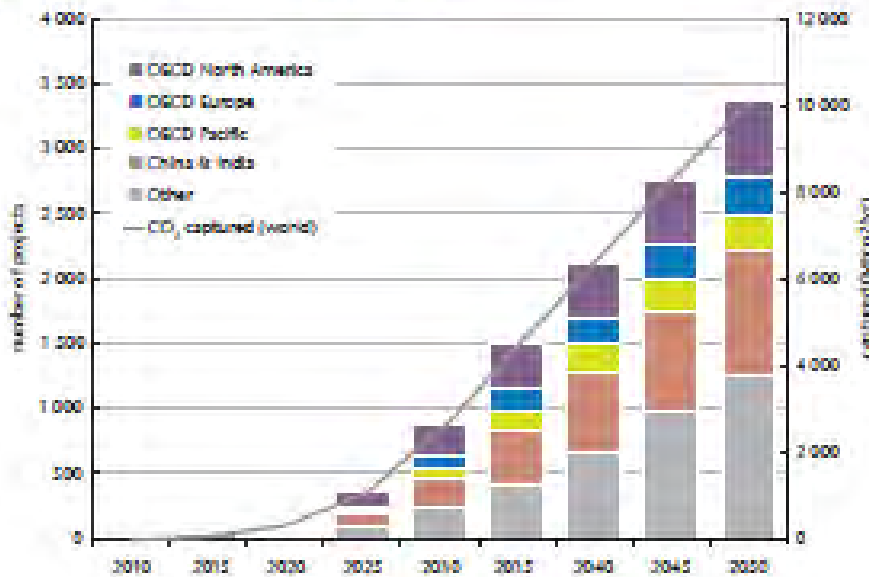
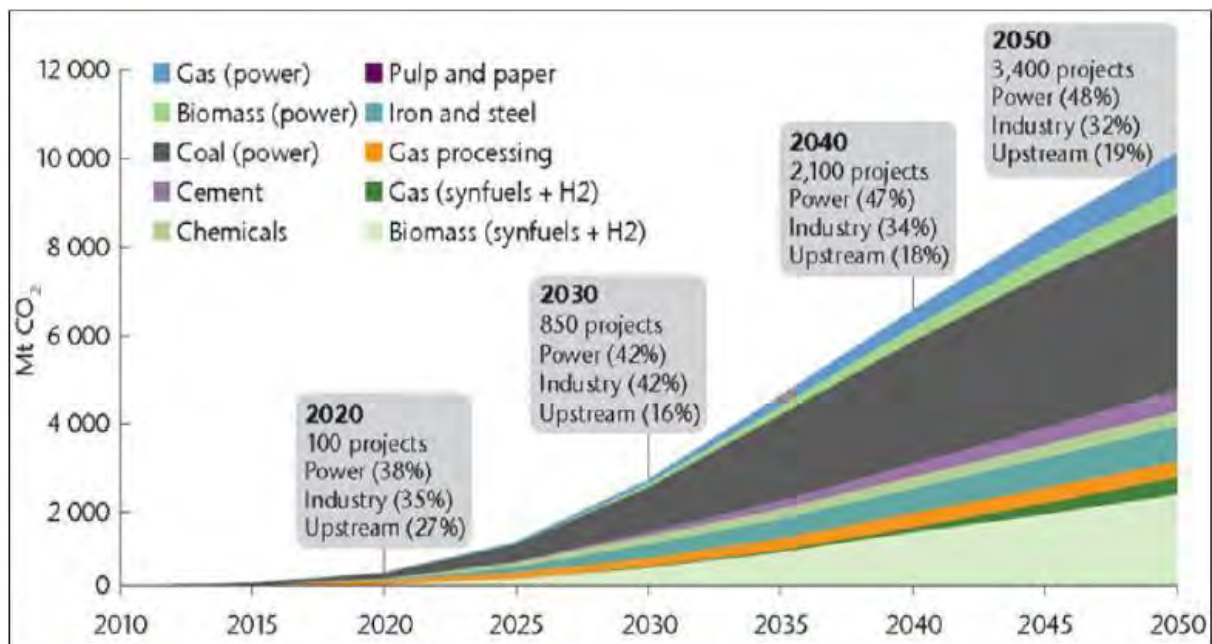


Figure 3: Number of CCS projects deployed in the period 2010-2050 envisaged by IEA. (Source:IEA)



Source: IEA. CCS Technology Roadmap to 2050, 2009

Figure 4: Volumes of CO<sub>2</sub> captured transported and stored in the IEA CCS Technology Roadmap to 2050. (Source: IEA)

Even in order to be able to achieve major roll out starting from 2025, the timeframe for development of CCS technologies, transportation and storage solutions is very short.

There are long lead times for development of international legal agreements and major infrastructure projects covering two or several nations. Cross border agreements may take several years to negotiate. Lead times for CO<sub>2</sub> storage exploration, permitting and licensing can be as high as 8 years while lead time for CO<sub>2</sub> transportation planning, permitting, engineering and construction can be 8-10 years. Hence it is necessary to speed up development of regulatory frameworks, storage site clarification and transportation planning and development.

## 6 Emission sources and potential for CCS

### 6.1 Overview over mapped emission sources

During the last years several studies have mapped sources of CO<sub>2</sub>-emissions with potentials to apply CCS technology in Europe. The following three figures summarise the main current sources of emissions.

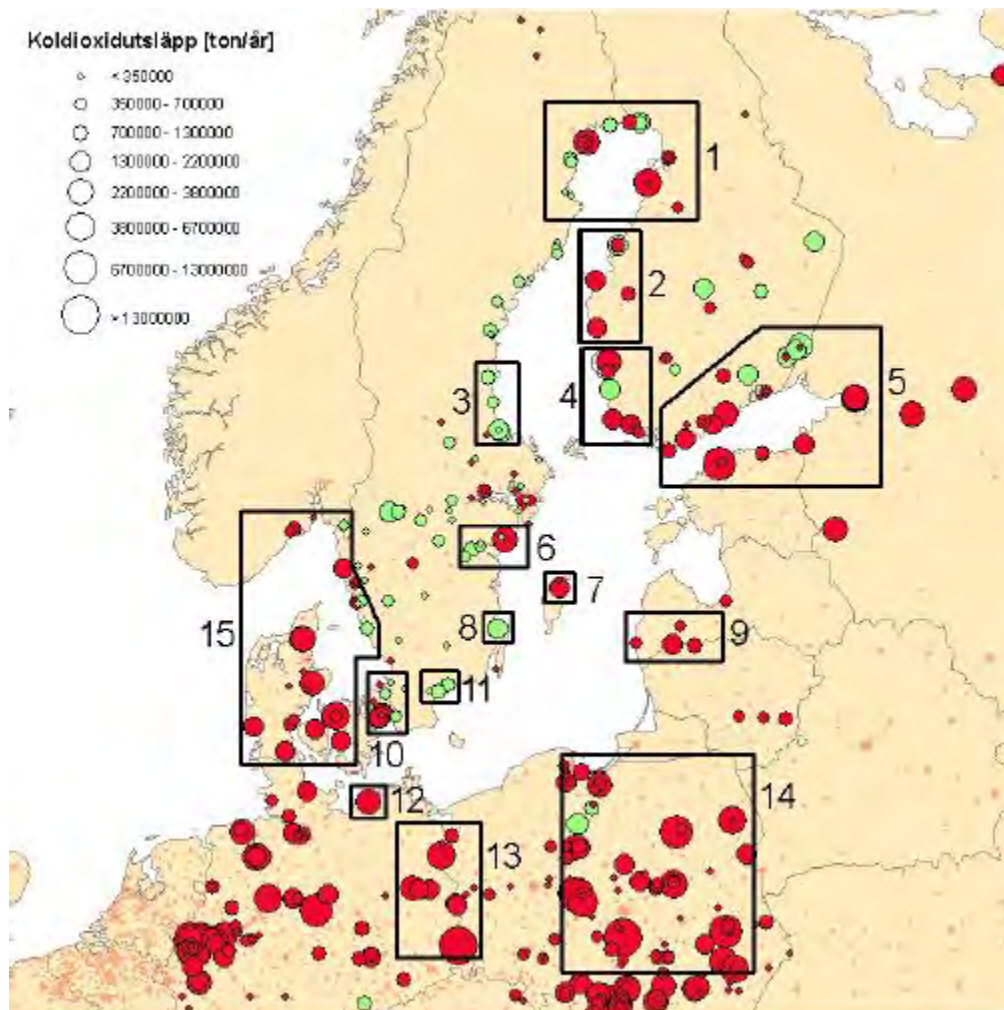


Figure 5: Clusters of emissions in the Baltic Sea region. (Source: Elforsk 2010)

The above map shows the main emissions sources in the countries in the Baltic Sea area. The green circles represent the biomass based plants and the red circles represent fossil fuel and fossil process based plants.

Finland and Sweden are large emitters of biogenic CO<sub>2</sub> and have the potential to develop bio-power. By application of CCS these sources will become CO<sub>2</sub> negative. Currently there are only limited incentives since negative net emissions are not awarded the EU emissions trading system (ETS). CO<sub>2</sub> stored is counted as not emitted. Hence fossil fuel plants only need allowances for net emissions. Since CO<sub>2</sub> from biogenic sources are not included in the first place storage of CO<sub>2</sub> originating from biomass is not counted. For co-firing plants emissions stored can be deducted up to the CO<sub>2</sub> originating from the coal combustion. It would contribute to increased deployment of CCS if the ETS was amended in order to provide the same incentives to capture and store CO<sub>2</sub> from all sources.

For the rest of the BASREC countries, CO<sub>2</sub> emissions mainly stem from fossil fuel and fossil process based plants.

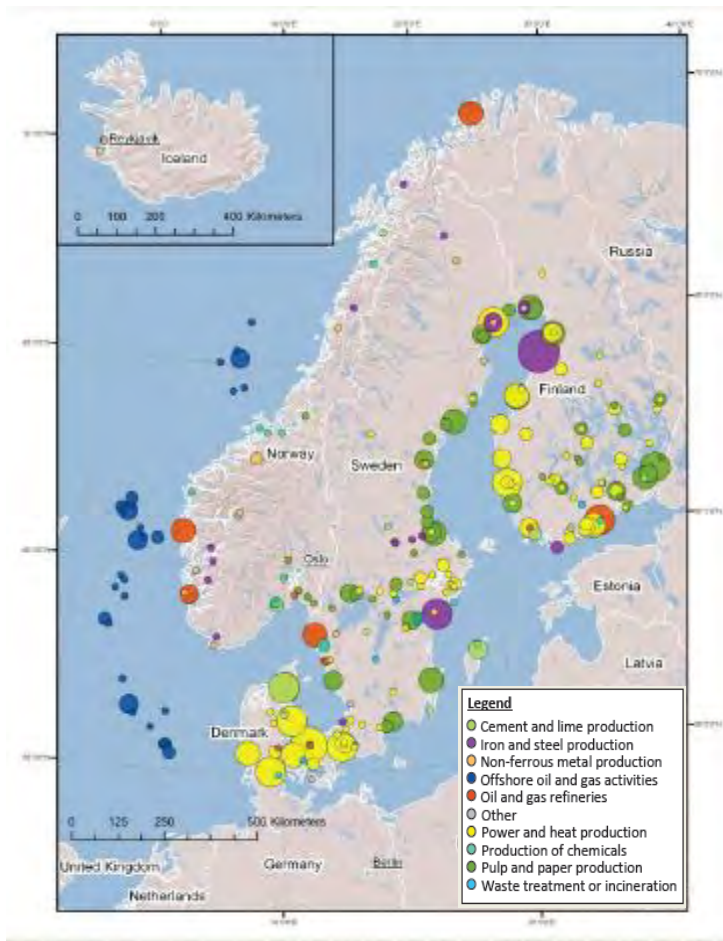


Figure 6: Emission sources by industry in the Nordic countries. (Source: VTT)

As can be seen from the above figure, emissions from large point sources in Norway are to a large extent linked to the petroleum sector. Norway has, like Sweden and Finland, dispersed sources of CO<sub>2</sub> along the whole coastline. Norway has, however, the benefit of offshore storage possibilities almost at the doorstep. (See next section).

From the figure below it is evident that emissions are highly concentrated in certain areas of West Germany, Belgium and Netherlands. This creates the basis for economics of scale in the whole CCS chain from large industrial and power plants to transportation in large trunk-lines to the most cost effective storage sites onshore and offshore in the North Sea or Baltic Sea.



Figure 7: 3D presentation of CO<sub>2</sub> emissions in European countries. (Source: Tel-Tek, Haugen 2005)

The volumes of current emissions from BASREC countries are summarised in the below figure:

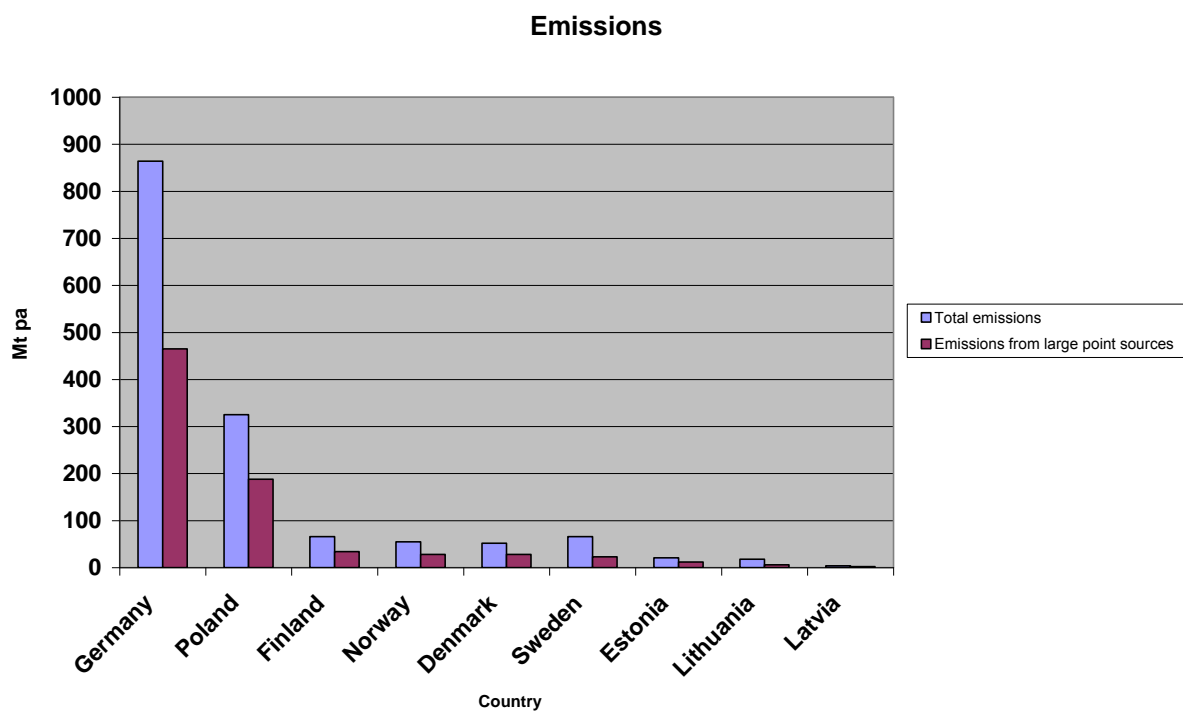


Figure 8: Current emissions, total and from large point sources in BASREC countries. (Source: INSA-compilation, Geocapacity etc.)

In an evaluation of the need for transportation it is, as previously stated, important to take into account the ability of the plants to carry CCS abatement costs. Both the cost of CCS and the lead time for technological maturity varies considerably within industries.



Suitability and competitiveness for CCS investments will also vary dependent on the

- Remaining technical and economical lifetime of equipment.
- Capture, transportation and storage cost for the actual source.
- Possibilities for and competitiveness of add on investments compared to new and integrated solutions.
- Market basis in a carbon restricted world. For instance there may be less need for petroleum refineries and increased need for bio-refineries with strong limitations on CO<sub>2</sub> emissions.

The ability of different industries within the BASREC countries to carry costs of CCS will also depend on climate policies and measures in competing areas of the world, since most industries eligible for CCS in BASREC countries compete in the international marketplace. Climate policies may result in structural changes and relocation of industries. In a world with internationally firm and levelized emissions costs, industries may decide to locate close to sites suitable for joint transportation and storage of CO<sub>2</sub>.

In planning of transportation systems it is necessary to get an overview of the current status of potential projects.

- Under construction
- Planned, and funded, but uncertain timelines
- Planned, unfunded
- Market dependent

Furthermore, it is necessary to have knowledge of the type of project, such as

- Small scale demonstration project
- Full scale demonstration project
- Commercial full scale project

Development in the Baltic Sea region may look different from development in other parts of the world due to the following reasons

- geological conditions beneficial for CO<sub>2</sub> storage are confined to a few potential areas,
- large point emissions originate from basic industries and to a less degree from power production as compared to the rest of the world
- a large part of the sources are biogenic and
- the emission sources are relatively small and geographically dispersed.

All these factors tend to increase costs of transportation and storage as well as to delay the phasing of CCS applications.

A model simulation at Chalmers showed that no power plants in the Nordic area will apply CCS in the period up to 2050 (because CCS would not be economic for these plants), while almost all coal fired power plants in continental Europe would apply CCS in scenarios to reach 80-90% reduction by 2050. The simulations did not cover industrial sources which probably are the most important sources in the Nordic countries. The same prognosis is highlighted in a Swedish report from Elforsk<sup>1</sup>

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<sup>1</sup> There is need for more assessments of the likely competitiveness of the different industrial sources in BASREC countries.

## 6.2 Current status of previously planned CCS projects

The list below gives an overview of commercial-, demonstration and pilot projects as well as proposed projects for CCS, as of 2009. This list is already severely outdated. Almost none of the projects which are not already in operation will come on stream within the given dates. It is questionable how many will be in operation before 2020. These delays illustrate one of the challenges in transportation and storage planning.

<b>Commercial injection Projects</b>
Sleipner West (Norway). Statoil began injecting CO <sub>2</sub> from a natural gas field into a saline formation under the North Sea in 1996. Currently, more than one million tons of CO <sub>2</sub> is stored per year. The projected cost is more than €350 million. <b>(Storage)</b>
Snøhvit (Norway). Statoil began storing CO <sub>2</sub> from gas production beneath the seabed in April 2008. At full capacity, planned storage is estimated at 700,000 tons of CO <sub>2</sub> a year. The projected cost is \$110 million. <b>(Storage)</b>
<b>Pilot Projects</b>
Ketzin (Germany). GFZ Potsdam, as part of the European research project, CO <sub>2</sub> SINK, began storing CO <sub>2</sub> in aquifers at a depth of 600 meters on June 30, 2008. It plans to store up to 75,000 tons of CO <sub>2</sub> over two years, at a cost of €15 million. <b>(Storage)</b>
Schwarze Pumpe (Germany). Vattenfall opened its pilot 30Mw coal oxyfuel combustion plant with CO <sub>2</sub> capture on Sept. 9, 2008. <b>(Coal plant with capture)</b>
<b>Proposed Projects as of 2009</b>
Kaarsto (Norway). A 420 MW gas-fired plant is being retrofitted with post-combustion capture technology by Naturkraft, and 1.2 million tons of CO <sub>2</sub> will be stored per year. <b>(CCS, EOR)</b>
Mongstad (Norway). StatoilHydro plans to store 100,000 tons of CO <sub>2</sub> a year starting in 2010 from a combined heat and power facility. <b>(CCS)</b>
Sargas Husnes (Norway). Sargas will store 2.6 million tons of CO <sub>2</sub> per year starting in 2011 from a post-combustion coal plant. <b>(Coal CCS, EOR)</b>
Belchatow (Poland). In 2011, Alstom and PGE planned to start work on a coal CCS plant that will store 100,000 tons of CO <sub>2</sub> per year. <b>(Coal CCS)</b>
Aalborg (Denmark). Beginning in 2013, Vattenfall will capture and store 1.8 million tons of CO <sub>2</sub> per year. <b>(Coal CCS)</b>

Huerth (Germany). RWE will capture and store 2.8 million tons of CO <sub>2</sub> per year starting in 2014. <b>(Coal CCS)</b> .
Kedzierzyn (Poland). PKE and ZAK planned capture and store 2.4 million tons of CO <sub>2</sub> per year starting in 2014. <b>(Coal CCS)</b>
RWE (Germany). IGCC plant (400-450MW) at which CO <sub>2</sub> will be captured and stored in a saline formation or gas reservoir beginning in 2015. <b>(Coal CCS)</b>
Jänschwalde (Germany). Vattenfall will store about 1,7 million tons of CO <sub>2</sub> per year beginning in 2015. <b>(Coal Capture)</b>
Vattenfall (Germany). A large-scale commercial plant (1000MW) will have CCS in 2020. <b>(Coal CCS)</b>
Fortum Meri-Pori 500 MW coal fired power plant. Injections ( 3 Mtpa)- The project did not apply for (NER 300) and was discontinued.

Of the above proposed projects only two projects in BASREC, Belchatów Power Plant, in Poland and Jänschwalde Power Plant in Germany applied for and achieved funding via the European Energy Programme for Recovery (EEPR). Four other projects in other EU countries received funding. The two mentioned BASREC projects which are described below have also applied for funding through the NER300 funding mechanism. No other BASREC CCS projects have applied for NER300. The other 11 CCS applicants for NER300 funding are distributed as follows: UK 7, France 1, Italy 1, Netherlands 1, Romania 1. Decisions on final awards are expected in the second half of 2012.

Almost all these projects have since this list was made been discontinued or seriously delayed. The Fortum Meri-pori project was discontinued early in 2011. Vattenfalls project in Aalborg is discontinued inter alia due to the storage situation in Denmark.

Vattenfall has officially abandoned its demonstration project in Jänschwalde on Dec. 5th, 2011 and there are no officially announced plans regarding the full scale project.

RWE has stopped the Project in Huerth at the end of 2012. The company is continuing R&D in smaller scale projects (bench scale testing rather than pilot scale). The company have placed the following statement on their website:

"The implementation of the IGCC-CCS project requires an adequate legal basis and the promotion of acceptance of the CCS technology by policy-makers. Without this framework, the exploration of suitable storage sites is not possible.

The Carbon Storage Law (KSpG) passed by the German federal cabinet in April 2011, which is to enable the construction of demonstration plants in principle, unfortunately considerably tightens the existing CCS Directive of the EU. Shifting the decision on carbon storage from the federal government to the states ("Länder veto clause") as provided for by the law makes CO<sub>2</sub> storage seem impossible for RWE in Germany.

Without a CO<sub>2</sub> storage facility, the route for the pipeline cannot be planned. Without the pipeline and storage facility, on the other hand, the construction of a power plant designed for CCS is neither viable nor sensible from the perspective of climate

protection. Thus, RWE has to defer the first steps necessary to implement the IGCC project in Hürth and until further notice has discontinued the power plant project.”

As regards the Belchatow (Poland)., Alstom and PGE planned to start work on a coal pilot CCS plant that would store 100,000 tons of CO<sub>2</sub> per year in 2011. (Coal CCS) . The plans are suspended pending a decision on funds for the full CCS demonstration projects from the NER 300 instrument.

In Kedzierzyn (Poland) PKE and ZAK planned to capture and store 2.4 million tons of CO<sub>2</sub> per year starting in 2014. The project has now been suspended (Coal CCS).

### **Belchatów Power Plant, Poland**

Belchatów Power Plant has been working on the preparatory task to develop a demonstration scale CCS installation integrated with the newly-built 858 MW unit at Belchatów Power Plant since 2007. The Carbon Capture Plant (CCP) unit will capture approximately 1.8 million tonnes of CO<sub>2</sub> per annum. The new 858MW unit has already been modified to obtain the status "Capture Ready". A pipeline and the associated infrastructure to transport the compressed CO<sub>2</sub> from the plant to a deep saline aquifer are planned.

The following time line for the permitting process was envisaged:

Building permit capture: 22 Feb 2010 Building permit pipeline: Aug 2013 Construction start-up permit for storage: Dec 2012.

### **Jämschalde Power Plant capture project and storage in Brandenburg**

Vattenfall has been developing demonstration projects in Brandenburg. These include the CCS demonstration project Jämschalde, (capture project related to 250 MW Power Plant in Jämschalde) and exploration of two potential storage sites. All in all, 1.7 million tons of CO<sub>2</sub> is planned to be captured and stored underground each year. As the German CCS Law has not yet been enacted, the future of the project has become more uncertain.

As of September 2011, the number of probable projects for CCS within the BASREC countries with start up before 2020 is rather limited. Furthermore, it can be commented that previous plans have proven to be too optimistic.

## **6.3 CCS projects 2030 and 2050**

An assessment of the future need for CO<sub>2</sub> storage in European countries based on the PRIMES model was made for the CCS directive impact study and was later used inter alia by the CO<sub>2</sub> Europe project. This study estimated the likely CCS activities in the 2°C target scenario as in the following figure:

## CCS -scenarios 2020-2030-2050 BASREC

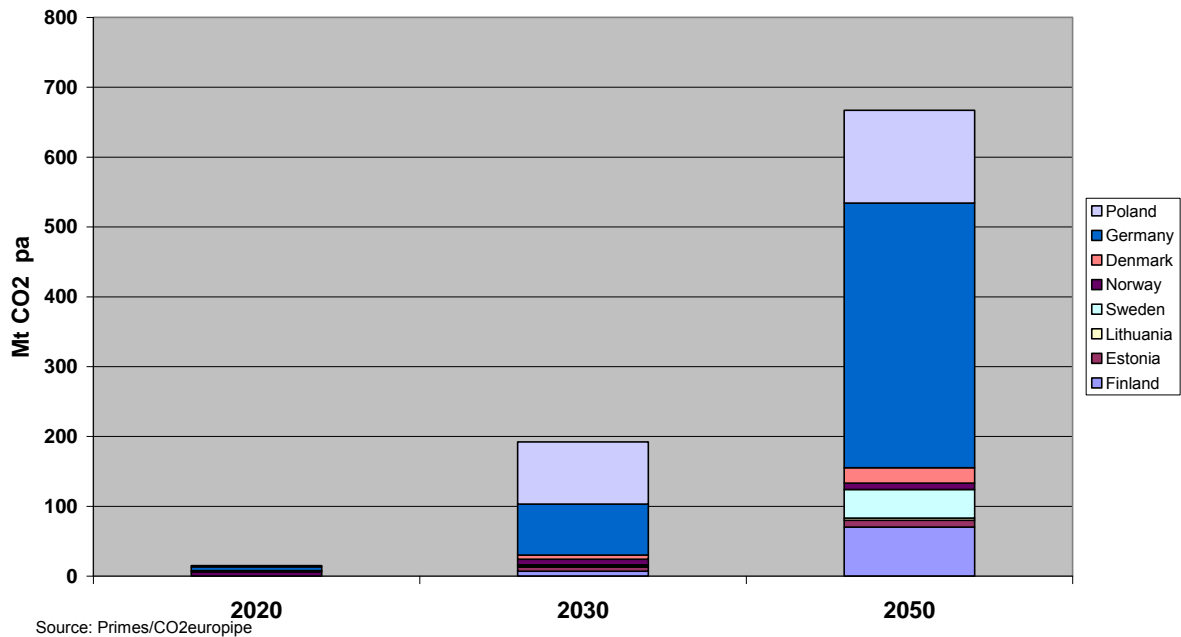


Figure 9: Volumes of CCS projects simulated by the PRIMES model.

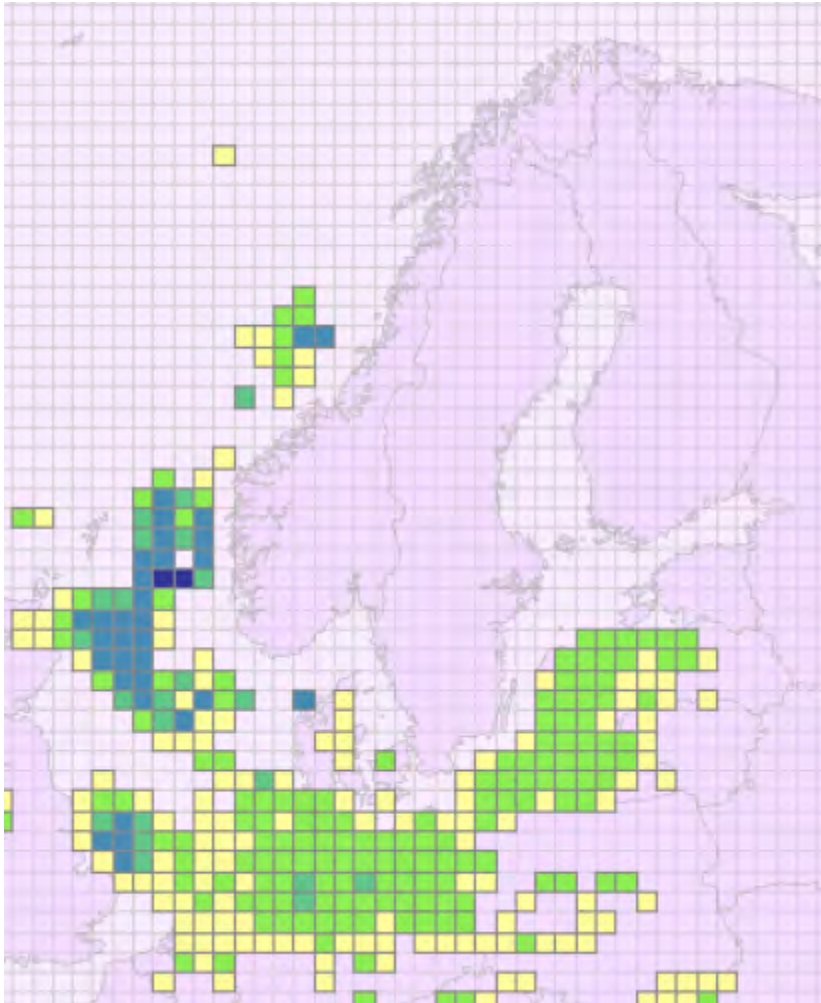
In this scenario there is an anticipated need for yearly storage capacity of 14 Mt in 2020, 190 Mt in 2030 and 660 Mt in 2050 in the BASREC countries. The absolute majority originates from CCS projects in Germany and Poland. The larger part of the CO<sub>2</sub> captured in 2050 originates from biomass, as it was assumed that after 2030 only few new coal-fired power plants will be built. Instead, biomass fired power plants or multi-fuel coal/biomass power plants using woody biomass as fuel are assumed to be the preferred option for new technologies and investments in the transition towards a sustainable energy supply in the period 2030-2050. This development enables a CO<sub>2</sub> reduction of 80% or more in the year 2050 compared to 1990 levels.

## 7 Storage capacity and emissions in the BASREC countries

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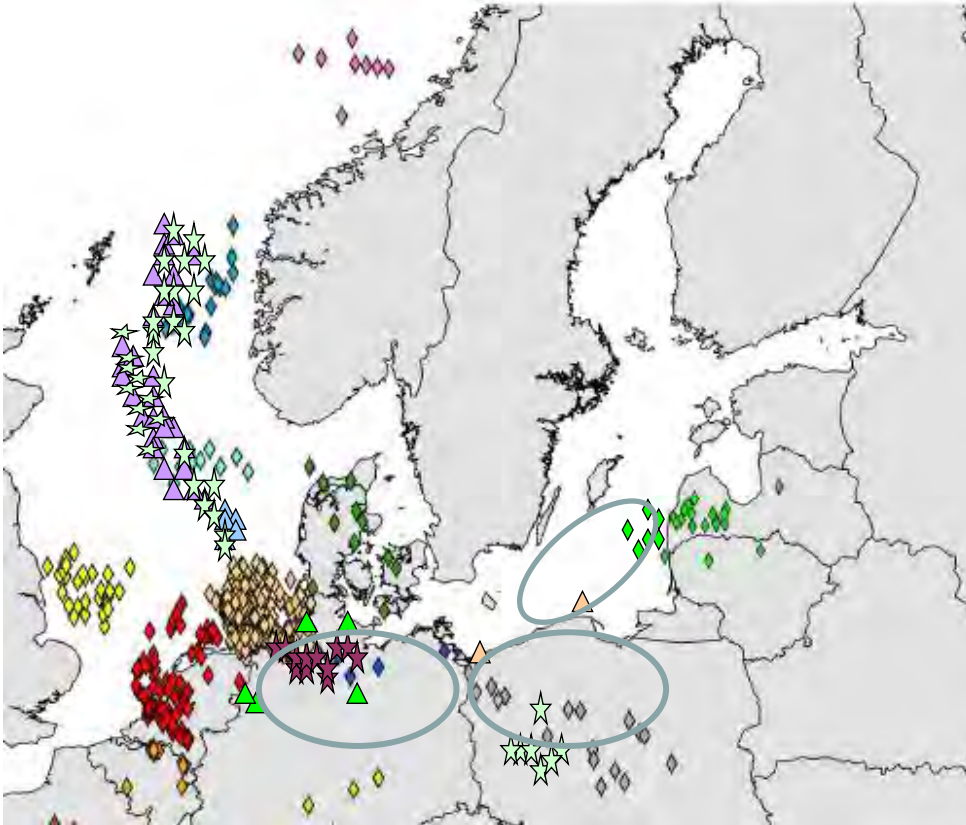
### 7.1 Introduction

In this section, we give a preliminary summary of the storage opportunities in the BASREC countries, the Baltic Sea, the North Sea and Norwegian Sea. The main message from the analysis is that storage opportunities are far from clarified. Further work is necessary in order to make a better assessment of the storage cost and capacity and the future restriction on actual use.



*Figure 10: Map of potential CO<sub>2</sub> storage, combining published GESTCO and GeoCapacity "conservative" studies, with DG-Energy database, and augmented by new estimates for Scottish North Sea, Baltic offshore, Ireland onshore and offshore, North German Distribution. (Source: Arup)*

The above map gives a rough but rather comprehensive picture of the assumed storage situation in the BASREC countries. A series of aquifers were identified through the above mentioned projects and the following maps identifying aquifers and depleted oil and gas fields make a usable starting point for transportation and storage planning in the Baltic Sea region.



*Figure 11: Geographical distribution of storage sites in BASREC countries identified in the GeoCapacity and GESTCO project. Diamonds represent saline aquifers, stars depleted gas fields, and triangles depleted oil fields. Circles show prospective areas for finding additional storage capacity. (Source: GeoCapacity, GESTCO, CO<sub>2</sub> Europe, INSA etc.)*

The above map provides an overview of possible storage sites in European countries. In this map, few spots are found in the Baltic Sea. That is because they are not yet identified in the GeoCapacity database.

Ideally such maps should be combined with costs and lead time for development in order to establish a basis for efficient planning of transportation and storage. A possible joint BASREC project could be to finance an electronic dynamic map containing accumulated information about storage opportunities, storage and injection capacities as well as cost classification.

The above map reveals that potential storage capacities are unevenly distributed among BASREC nations. Some of the nations do not have geological formations suitable for storage of CO<sub>2</sub> at all. This is the case for Finland and Estonia, while Lithuania may have limited economically suitable storage capacity (source: GeoCapacity). Germany and Poland will probably have sufficient and cost effective storage capacity onshore to cover their need for the decades ahead, but issues regarding public acceptance create uncertainty. The reluctance to allow for onshore storage may aggravate the needs for transboundary transportation and storage solutions. Actual storage capacity in the different region is highly uncertain. Estimates of storage capacity/emissions ratios in the different nations vary accordingly.

## **7.2 Storage possibilities per nation**

In the following subsections, potential storage capacity is presented for each of the BASREC nations. However, the potential storage capacity under the seabed of the Baltic

Sea is presented separately; as the distribution of capacity between the different nations is not known (several aquifers are assumed to stretch over several borders). The information in this chapter is mostly retrieved from the GeoCapacity project, but is updated by the answers to our inquiry, as well as recent papers and estimates from the different countries. Additional information about Russia has been obtained from open sources.

Most estimates of storage capacity are based on analysis of existing geological surveys and geological information obtained in connection with oil and gas explorations. The quality of the information, in particular regarding saline aquifers, is highly variable and it is difficult to compare estimates from different sources. More seismic data and exploratory drilling will be necessary to improve estimates. The capacity data from the GeoCapacity project is based on identified storage sites in the analysed material. Further analysis in prospective areas will reveal additional capacity. The conservative estimates are based on highly conservative assumptions regarding parameters deciding the capacity of the identified storage sites. It is important to be aware of the difficulties in assessing the actual bedrock ceilings of the structures. Analogously, several potential oil and gas fields prove to be empty since reservoirs turns out not to be sufficiently ceiled off.

## 7.2.1 Baltic Sea

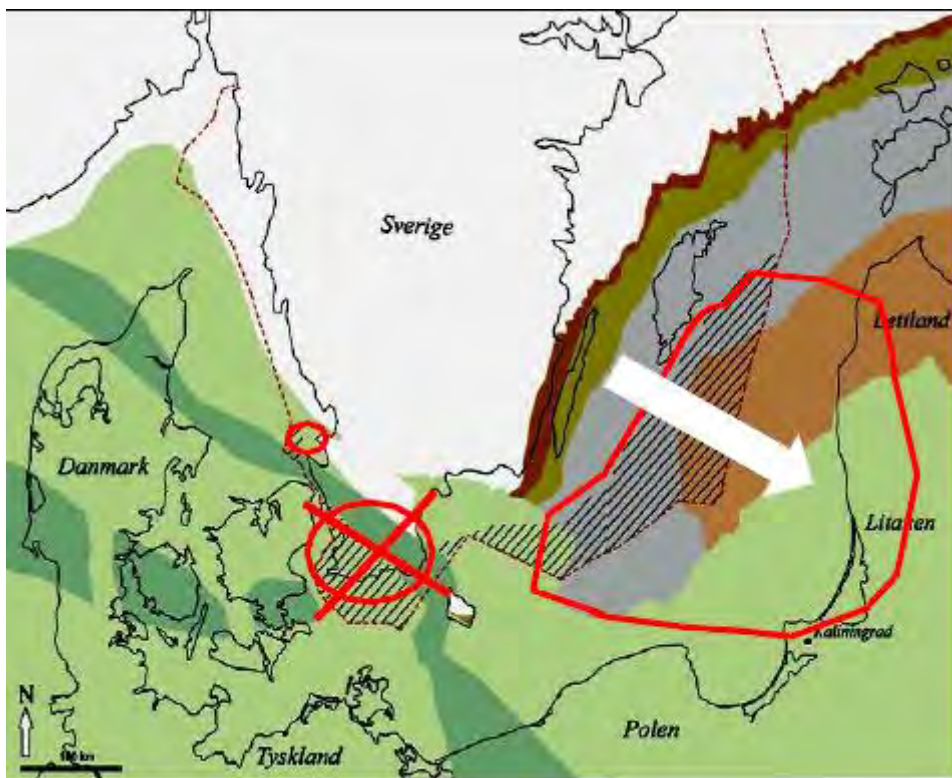


Figure 12: Source: Ekstrøm, SGU, (OPAB)

In the Baltic Sea underground, the most promising storage options for Sweden, Finland, Estonia and Lithuania are located in three areas: the Swedish zone, the South East and towards the shore of Lithuania.

The options for Baltic Sea storage are highly uncertain. For example, estimates of storage potentials in the "Faluddensandstenen" in the Baltic Sea vary between 450 Mt and 4.5 Gt.



This potential storage basin requires significant exploration efforts, in order to make assessment of porosity, volume potential and containment. Consequently this is a risky storage prospect despite the significant exploration efforts that has been made to map the geology in the area. But it is critical to improve the understanding of the storage opportunities in the Baltic Sea in the strategic planning of transportation and storage systems in the region.

In our preliminary transport analysis, see Section 9, we assume injection point for the Baltic Sea underground close to the Lithuanian shore (at the tip of the arrow on the map above). Structures with promising storage potentials may extend into the Kaliningrad sector of the Baltic Sea. Storage in this area of the Baltic Sea has to be coordinated with the other jurisdictions, and may conflict with the CCS directive as regards storage outside EU.

### 7.2.2 Denmark

Denmark has identified considerable potential capacity for storage of CO<sub>2</sub> in saline aquifers (mainly onshore), as well as some capacity in depleted oil and gas fields offshore.

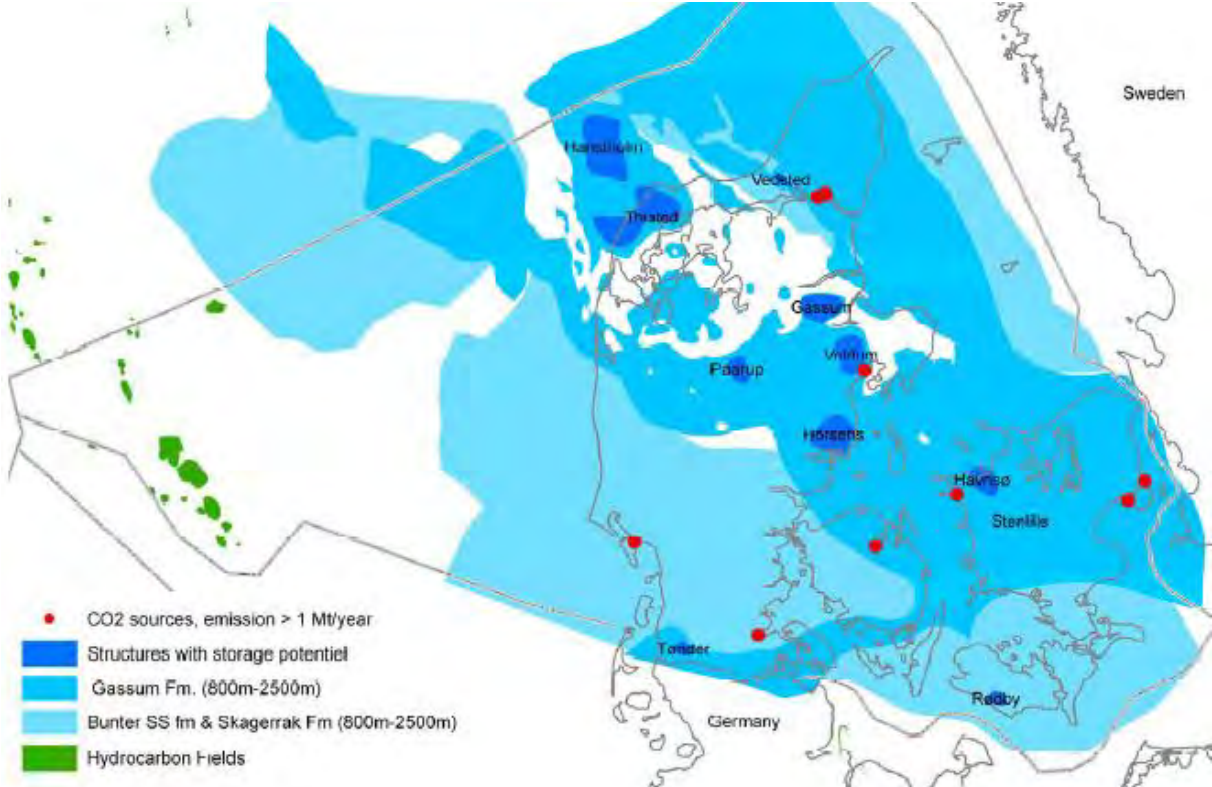


Figure 13: Locations with potential storage capability in deeper sand layers in Denmark. (Source: GEUS 2009).

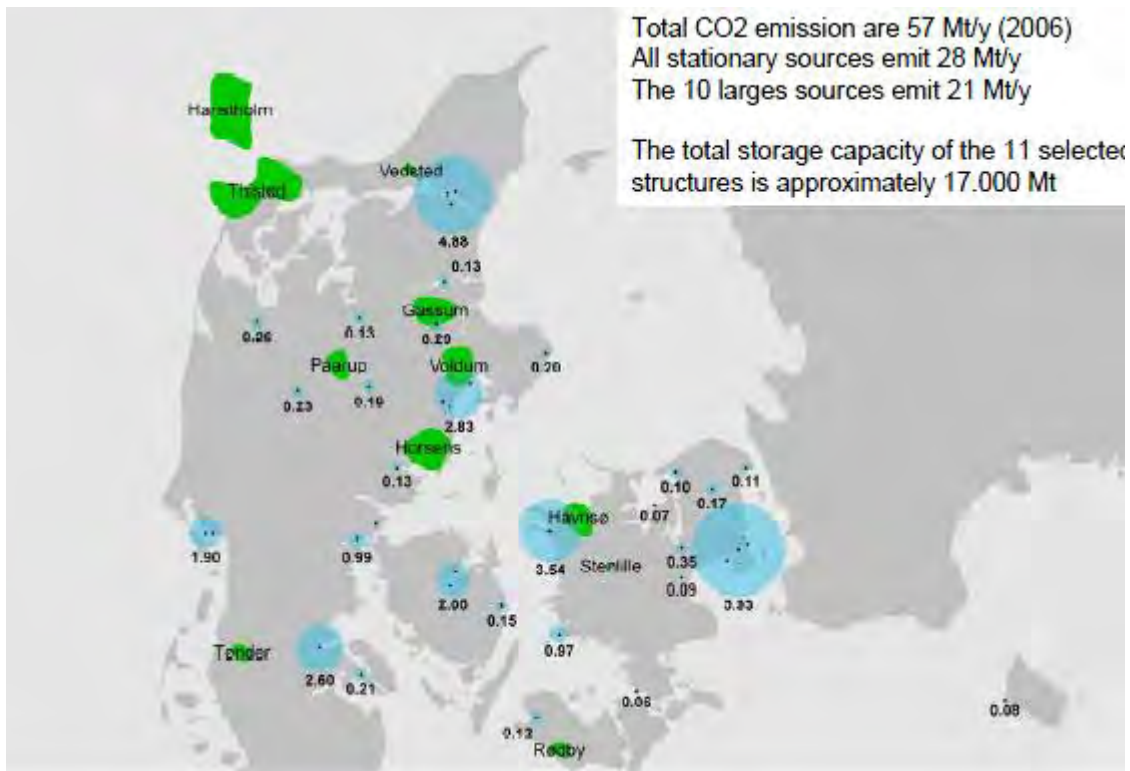


Figure 14: Location of sources and identified saline aquifers storage sites in Denmark. (Source: GEUS presentation)

So far, eleven aquifers have been identified onshore, and one is identified offshore. The total storage capacity is assumed to be in the range of 17 Gt CO<sub>2</sub> with the standardized methodology of GeoCapacity. This storage capacity roughly corresponds to the demand of the Danish power industry over the next 400 years (at current load).

In the "conservative" estimate by GeoCapacity, which represents a minimum scenario, the storage capacity in the selected reservoirs is assessed to 2.5 Gt, hence still corresponding to about 100 years of storage from large stationary sources. According to GEUS in Denmark, these storage reservoirs were considered the most promising storage sites, and were analysed more extensively on the basis of available geological information and seismic data. Further mapping and exploration may reveal more storage capacity and sites.

The capacity of the offshore Hanstholm reservoir is estimated to 2.7 Gt with standard methodology, and between 130 and 270 Mt in the conservative estimate.

The Danish political parties have agreed that storage of CO<sub>2</sub> shall be permitted neither onshore nor offshore until more experience is gained, probably not before 2020. Hence it is difficult to take Danish storage into account before after 2020.

### 7.2.3 Estonia

Storage capacity for CO<sub>2</sub> in Estonia is estimated to zero, while the nine biggest sources emit in total about 11.5 Mtpa.

## 7.2.4 Finland

After extensive geological research, it is concluded that Finland has no suitable storage sites for CO<sub>2</sub>.

## 7.2.5 Germany

For Germany, onshore and offshore storage in saline aquifers and onshore storage in depleted gas fields are key options. The estimated capacity of depleted gas field, which are found onshore in Northern Germany, is 2.8 Gt. The capacity in the depleted gas field is considered certain and storage security for practical purposes already proven, since the reservoirs have contained natural gas for millions of years.

All sedimentary basins in Germany contain gas and oil fields. However, the large hydrocarbon fields are almost exclusively bound to the North German Basin. For the EU projects "GESTCO" (Christensen & Holloway 2004) and "GeoCapacity" (Vangkilde-Pedersen 2009) Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) has estimated the CO<sub>2</sub> storage capacity of selected hydrocarbon fields in Germany. It should be noted that most of the selected fields are not depleted yet. It is estimated that 13 aggregated oil fields yield a potential CO<sub>2</sub> storage capacity of ca. 150 Mt (May et al 2009). Furthermore, it has been estimated that 39 aggregated natural gas fields yield a potential CO<sub>2</sub> storage capacity of ca. 2.75 Gt (Gerling et al. 2008).

Based on the above information, German oil fields do not provide a significant CO<sub>2</sub> storage capacity, and CO<sub>2</sub> storage in natural gas fields in Germany is a far more interesting option.

Large onshore depleted gas fields are considered to belong to the most cost effective storage options and can be developed within a short time span comparable to for instance saline aquifers.

Storage capacity in saline aquifers is estimated to between 6.3 and 12.8 Gt. 45 storage sites with capacity estimated above 50 Mt (economical viable) have been identified, of which 43 are located in Northern Germany or the North Sea.

German emissions from large sources suitable for CCS are estimated to about 0.45 Gt per annum. Hence, the recent estimates of storage capacity in German territory (offshore and onshore), equals between 20 and 35 years of storage. Industrial emissions are estimated to 0.075 Gt, hence 40 years of storage requires 3 Gt of capacity.

Development of the legal framework and public acceptance in Germany will consequently have a great impact on the combined future supply of onshore storage services and the need for joint transboundary transportation and storage systems in the BASREC region.

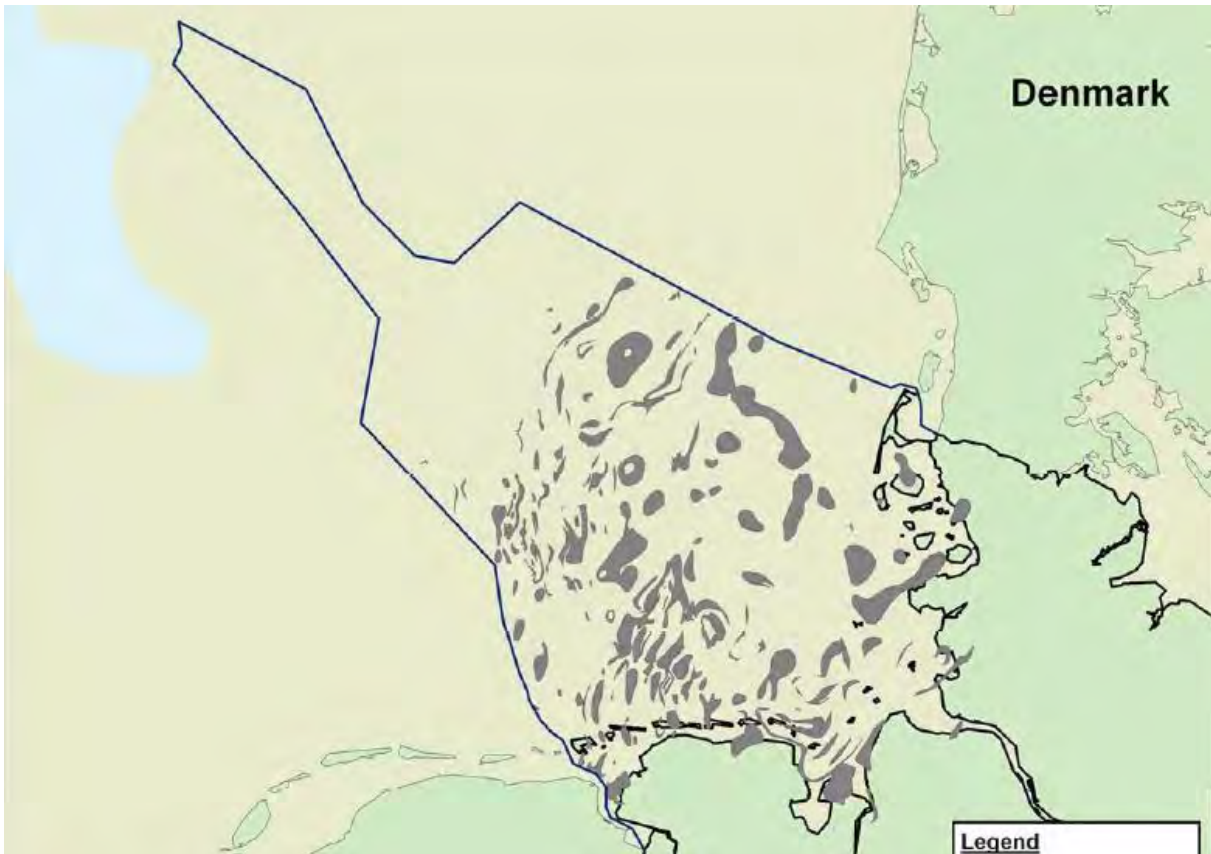
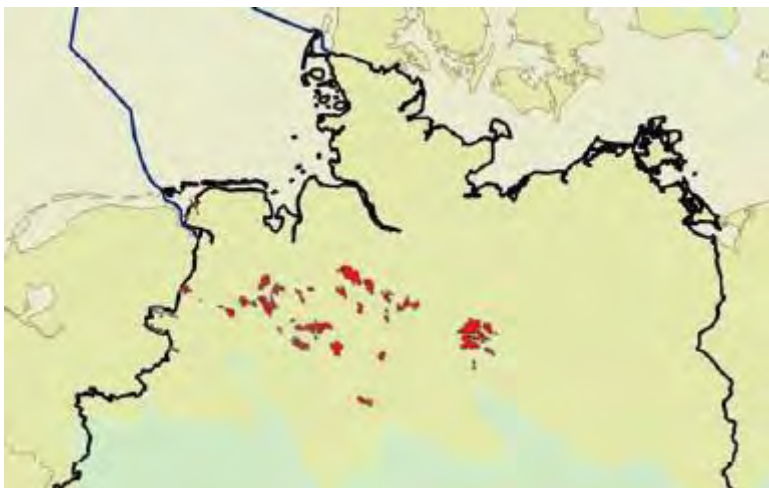
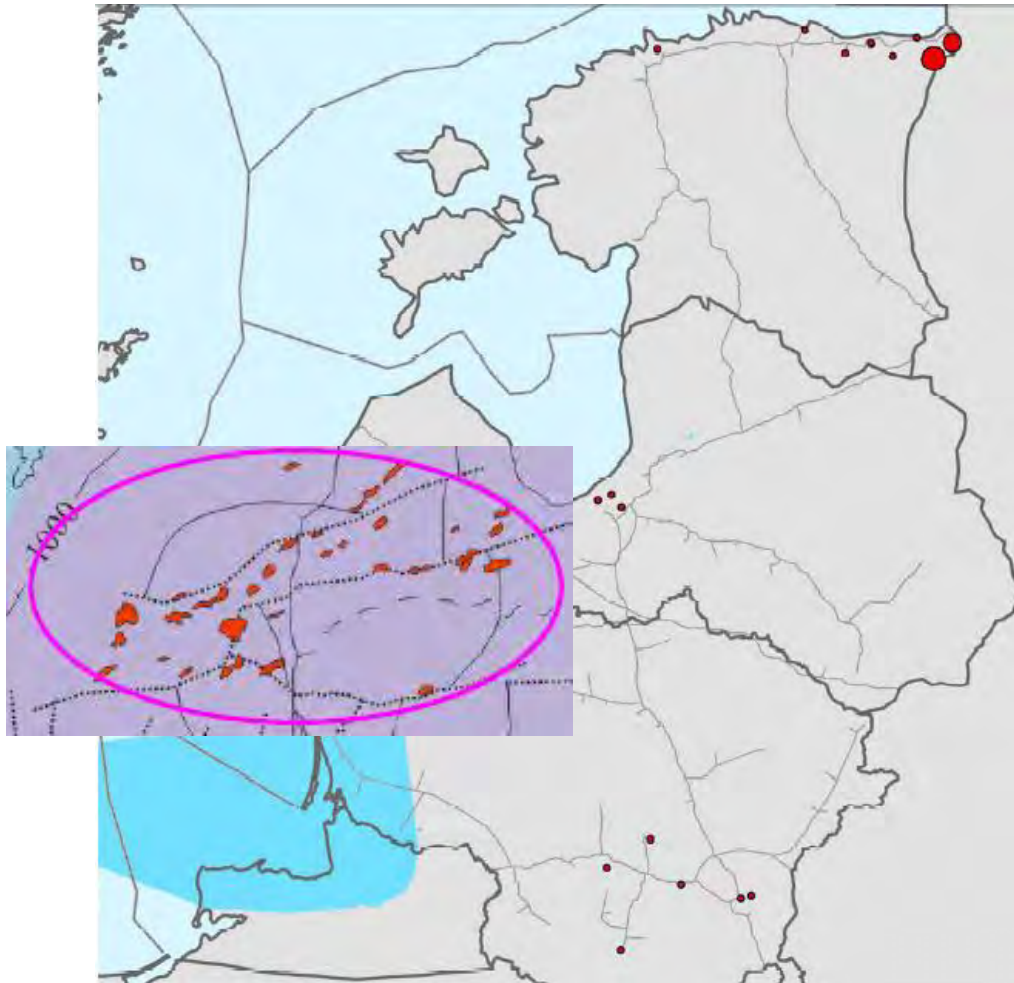


Figure 15 above and 16 below: The two maps show locations of offshore saline aquifers and onshore depleted oil and gas fields in Germany. (Source: BGR, Germany)



### 7.2.6 Latvia

The storage capacity in Latvia is conservatively estimated to 700 Mt in 34 confined traps, of which 400 Mt in 16 traps are located onshore. These estimates have been made by Latvia on the basis of seismic data gathered under the former Soviet period in order to find oil and gas. Some of these reservoirs appear to be of high quality, since reservoirs in the same area are already used for gas storage.



*Figure 17: Identified onshore and offshore storage sites in Latvia. (Source: Uldis Nulle et al. LEGMC, Latvia)*

Yearly CO<sub>2</sub> emissions from large point sources in the database are about 2 million tons. Hence, Latvia has the physical potential to export storage services. Based on the above estimates, saline aquifer capacity in Latvia may be sufficient to store all actual CO<sub>2</sub>-emissions from the Baltic States for 40 Years, and could be a good starting point for storage planning in the region.

## 7.2.7 Lithuania

The GeoCapacity report concludes that although the theoretical storage capacity of the two largest saline aquifers in Lithuania are as high as 17 Gt and 13.7 Gt, only a very small fraction can be counted as estimated capacity. There are a few structures which are estimated to have a total potential of 37.5 Mt, which covers 7 years of Lithuanian emissions. However, according to GeoCapacity, the small estimated capacities render the practical potential for storage onshore Lithuania close to zero. The main explanation is found in the figure below showing the distribution of onshore and offshore aquifers according to size. Storage sites should have a capacity in the order of 25-50 Mt to be considered economical.

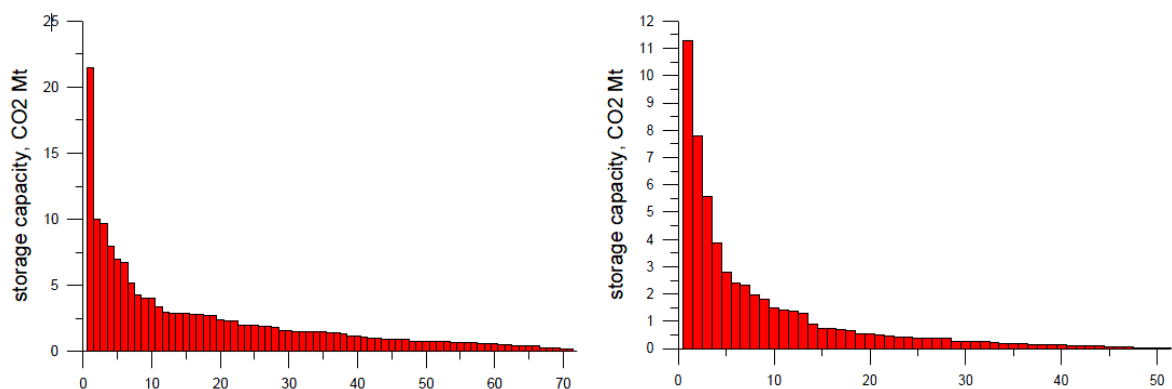


Figure 18: Onshore and offshore Saline Aquifers in Lithuania distributed according to size. (Source: GeoCapacity)

But as in Denmark, further geological investigations may reveal suitable storage sites in Lithuania.

## 7.2.8 Norway

In Norway, two large-scale capture and storage of CO<sub>2</sub> projects are already being carried out. At a natural gas field in the North Sea (Sleipner), CO<sub>2</sub> is captured and injected into the Utsira formation. Likewise, CO<sub>2</sub> from LNG production at the Melkøya plant is captured and transported out to the Snøhvit condensate field, where it is injected into an aquifer.

It has earlier been estimated that geological formations deep beneath the North Sea Basin (both on the UK and Norwegian side) are capable of securely storing a huge proportion of European CO<sub>2</sub> emissions for thousands of years. For example, the Utsira deep saline formation, covering 26000 km<sup>2</sup>, was estimated to have a storage capacity of about 600 Gt of CO<sub>2</sub>. This is equivalent to all the CO<sub>2</sub> emissions from all the power stations in Europe for the next 500 years. (Source: One North Sea Report)

These estimates now seem exaggerated. The Norwegian Petroleum Directorate (NPD) has provided updated data on North Sea capacity. Due to the potential for conflicts of interest with existing hydrocarbon production the estimated overall aquifer capacity on the Norwegian Continental Shelf was estimated to 100 Gt. About 50 Gt of this capacity may be available by 2030. The remainder would be available by 2050 when conflicts with existing hydrocarbon production are likely to have ceased. These figures will be further scrutinized in the upcoming CO<sub>2</sub> storage atlas for the Norwegian offshore continental shelf.

The lead time for development of storage capacity in order to qualify for a storage permit in conformity with the CCS directive is estimated to be 5-10 years for most of the mentioned capacity. Development of "Johansen-formasjonen" in connection with storage of CO<sub>2</sub> from the test center at Mongstad was started in 2008 and it is estimated that it will be possible to start injection 8 years later, in 2016.

### Depleted oil and gas fields

Depleted oil and gas fields represent about half the estimated storage capacity in North Sea by 2050 and may offer excellent opportunities for safe storage. The Frigg field and some other fields are already depleted and may in theory be clarified for storage in conformity with the CCS directive within a relatively short time span.

Storage in depleted oil and gas fields offshore offers both challenges and opportunities. If CO<sub>2</sub> injection commences shortly after hydrocarbon production stops, wells and platforms

may be re-used. Re-use of existing infrastructure would significantly decrease the costs for CO<sub>2</sub> storage, even though both platforms and wells would need some adaptation. The possibility for re-use of both platforms and wells would have to be investigated on a case-to-case basis (BERR, 2007).

According to current abandonment regulations for hydrocarbon fields, the fields must be abandoned within two years after production ends. Furthermore, maintenance of the platform is costly. Abandonment of hydrocarbon fields implies breakdown of platforms and plugging of wells. Consequently, if a completely abandoned field is to be reopened for CO<sub>2</sub> storage, new platforms must be built and new wells drilled. If, however, there are possibilities in existing regulations to apply for postponement of abandonment, plans for other use will make this a realistic option.

The construction of new offshore infrastructure could render CO<sub>2</sub> storage in depleted oil and gas field economically unfeasible. This implies that CO<sub>2</sub> storage in a hydrocarbon field must commence as soon as possible after the end of production. Since it is difficult to predict when production will end, re-use of infrastructure requires a great deal of flexibility in the organization of large-scale CCS as well as co-operation of the operators.

Close cooperation between BASREC nations may significantly enhance the possibilities for development of timely and cost effective storage opportunities.

## **EOR**

In addition to storage capacity in aquifers and depleted oil and gas fields, CO<sub>2</sub> may also be used for EOR purposes in producing oil fields. The estimated storage capacity related to EOR projects in the North Sea is estimated to 7 Gt. The window of opportunity for this alternative is reported to be brief, as production from many fields is now at a stage when EOR may be appropriate.

## **7.2.9 Poland**

The challenge with CO<sub>2</sub> storage site selection is to identify geologic formations that are well-suited to long-term CO<sub>2</sub> retention. The underground must be explored to identify the most appropriate storage places. Theoretically, Poland has a large number of potential locations for underground CO<sub>2</sub> storage. They can be divided into:

- EGR/EOR with operated sites in Borzecin and Kamien Pomorski, including the possibility of Baltic offshore storage
- Depleted oil and gas fields in Western Poland and South-Eastern Poland
- Closed hard coal mines (PMG Nowa Ruda - 0.1 billion m<sup>3</sup>, KWK Krupinski and KWK Silesia - 0.9 billion m<sup>3</sup>, Wodzislaw)
- Central Poland aquifers (Ponetow - 14 billion m<sup>3</sup>, Jezow, Justynow, Wartkowice)

According to information presented by the Polish Geological Institute, preliminary estimate of CO<sub>2</sub> storage capacity for Poland is between 6 to 7 Gt (conservative estimates). Earlier GeoCapacity estimates of total capacity for CO<sub>2</sub> storage was 4.2 Gt CO<sub>2</sub>, corresponding to about 16 years of total Polish CO<sub>2</sub>-emissions.

The latest information of storage capacity from the Polish Geological Institute equals about 35 years of emissions from large point sources. Consequently, Poland will probably not be a major exporter or importer of storage services, but further development of storage sites will depend on public acceptance.

Regional aquifers represent the biggest volume of national storage capacity. Their huge potential, would enable storage of emissions from big power plants and other industrial installations for decades. Hydrocarbon fields (of rather small capacity) are of local importance. These are mostly gas fields and only a few suitable oil fields. Methane-

bearing coal seams are quite common in the Silesian Coal Basin and possibly have a potential to store emissions of some industrial installations. However, this is a sensitive issue because of safety of coal underground exploitation and conflicts with coal gasification.

Saline aquifers account for over 80% of the total storage capacity, while depleted oil and gas field account for the rest (i.e. somewhat less than 20%). Possible injection points to the saline aquifers and the depleted oil and gas fields are shown in the two figures below.

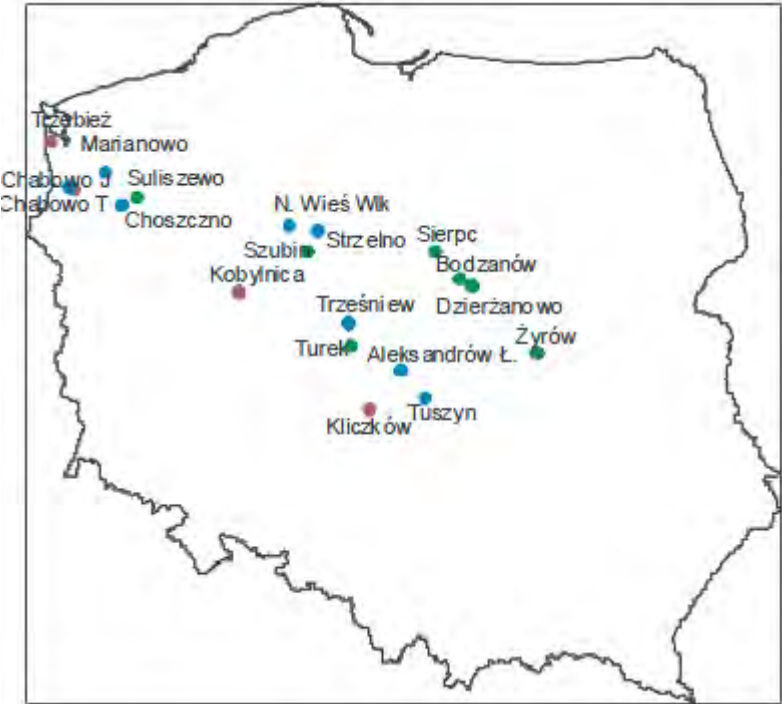


Figure 19: Potential injection points into saline aquifers in Poland. (SOURCE: Geocapacity country review Poland).



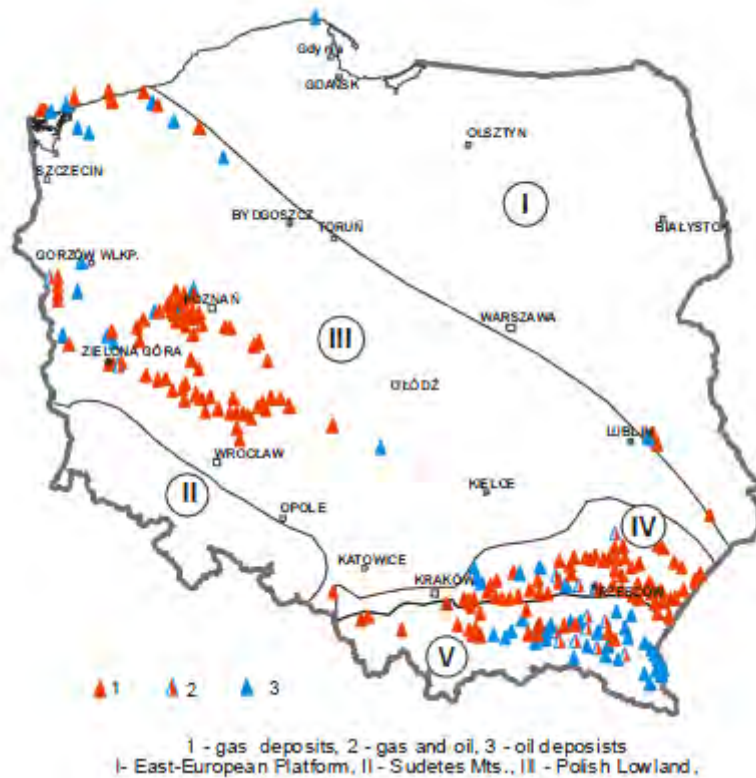


Figure 20: Depleted oil and gas field in Poland. (SOURCE: Geocapacity country review Poland).

## 7.2.10 Russia

In Russia oil and gas depleted deposits, onshore and shelf aquifer storages (confined or unconfined), coal mines can be used for carbon dioxide disposal. B. Russia has high carbon dioxide storage capacity. According to the specialists' research the accessible carbon dioxide storage capacity is more than 2 000 Gt. The volume capacity of Oil and gas depleted deposits, for example in West-Siberian basin, is 150-200 Gt.. However, the major sources of CO<sub>2</sub> emission are situated on the west of Russia far from the location of prospective storages. Consequently we need to pipeline 2 000 – 4 000 km for CO<sub>2</sub> transportation. The Kaliningrad Region, the Krasnodar Territory (an oil deposit is close to Krasnodar), Bashkortostan (near Ufa), Tatarstan and Permian oil deposits can be considered as the most suitable regions for the execution of the projects on carbon capture and disposal. There is an opportunity for the construction of carbon dioxide storages on the south of Russia. The construction of carbon dioxide storages in the permafrost on the north of Russia is taken into consideration. Generally, there are conditions and opportunities for CO<sub>2</sub> disposal, based on physical-chemical binding of CO<sub>2</sub> with mine carbon at great depth using gas injection into contaminated coal-bearing layer, over the whole territory of Russia, particularly in the Baltic region.

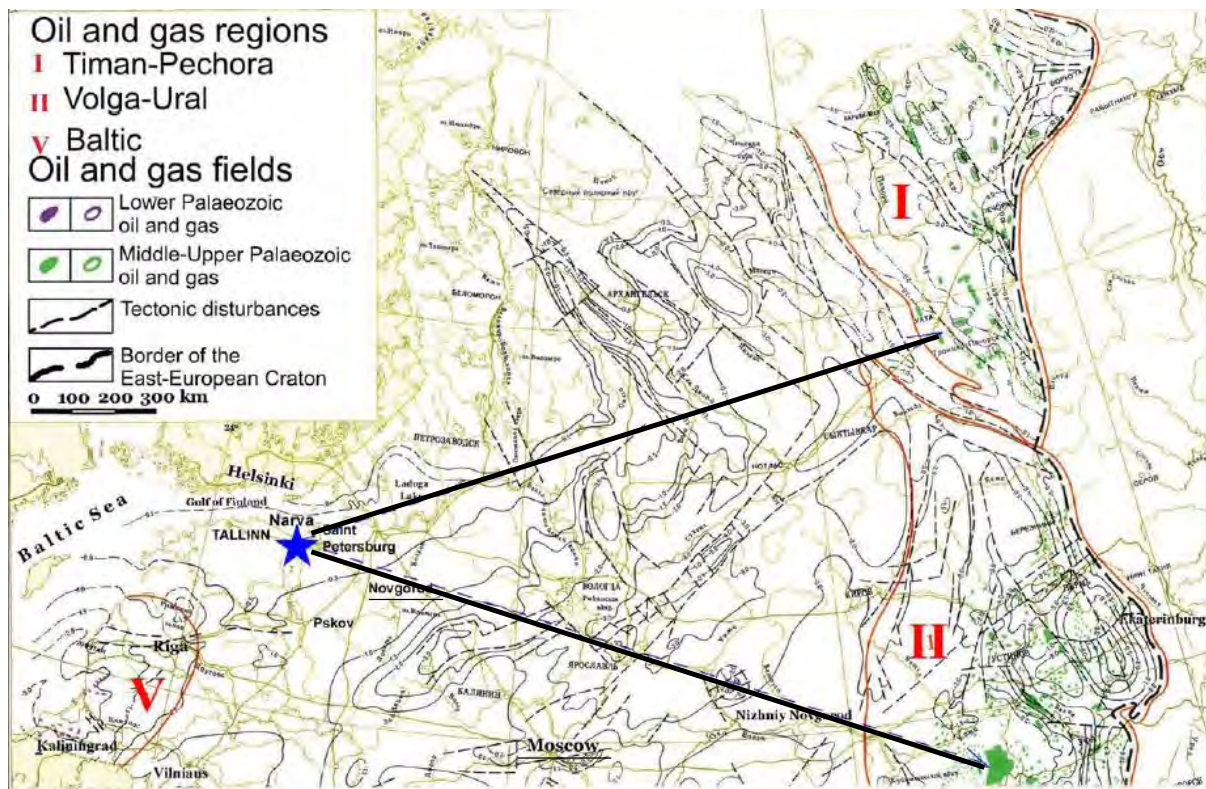


Figure 21: Depleted oil and gas field opportunities in Russia. (Map: Geological structure and economic minerals of USSR, Nedra 1985, Alla Shogonova et. al, References [3])

## 7.2.11 Sweden

In the Swedish underground (offshore), two aquifers which may constitute storage opportunities are identified. One aquifer is located southwest of Sweden, and stretches into the northern part of the German sector of the Baltic Sea. The other aquifer is located southeast of Gotland, and stretches into the Russian sector of the Baltic Sea.

The storage capacity in the southern part of Skåne is estimated at between 1 and 10 Gt. This potential capacity is preliminary excluded from CCS regulation in Sweden.

## 7.2.12 Iceland

Iceland is currently assessing the viability of storing CO<sub>2</sub> underground by artificially creating seams of limestone. The project takes place at Hellisheidi in south west Iceland, near Reykjavik Energy's geothermal power stations. If it is successful, the carbon dioxide pumped down into the basalt rock will turn into limestone and be locked away underground forever. The technique involves creating so-called seltzer water which reacts with basalt and forces the dissolved CO<sub>2</sub> into harmless limestone. The basalt, which is ancient volcanic lava, is porous, and contains as much as 30 percent open space and water. The seltzer water is to be forced into the pores and will hopefully react with the calcium in the basalt to form calcium carbonate, otherwise known as limestone. Huge areas of the world's land sit on top of basalt, meaning the technique could be carried out on a massive scale. The short term goal is to allow geothermal power stations to get rid of the carbon dioxide they bring up from the depths and thereby become truly carbon neutral.

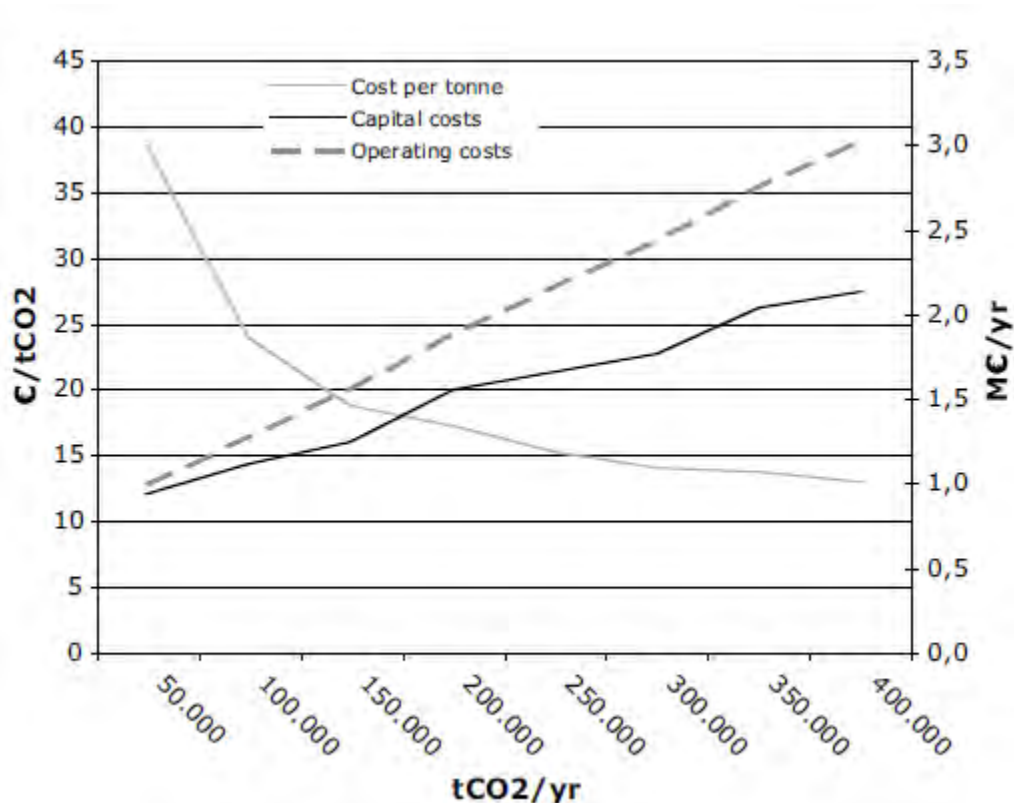


Figure: Anticipated costs of storing in basalt formations. Storage of 400 kt at one site may cost 12 Euro/tonne.

### 7.3 Further discussion of estimates for storage possibilities in northern Europe (including BASREC countries)

Detailed studies of potential storage sites are complicated and costly. Therefore, the GeoCapacity database only includes results from feasibility studies for few of the identified potential storage sites. While almost all of the saline aquifer storage capacity in the database should be considered "theoretical", the database is considered to contain "effective capacity" estimates for hydrocarbon fields, for which the storage capacity estimate is based on production data and, perhaps more importantly, which have proven to store hydrocarbons for millions of years.

Due to the high uncertainty level GeoCapacity has established a so called "conservative estimate" which can be considered a minimum storage capacity estimate. But even this minimum estimate for the whole of Europe of 117 Gt corresponds to 62 years of current emissions from large point sources in EU, and 100 years of a possible capture level of 1.2 Gt in 2050. Of this total storage capacity, 95 Gt is estimated to be in saline aquifers, while 20 Gt is estimated to be in depleted hydrocarbon fields. Depleted coal field capacity is estimated to constitute capacity of only 1 Gt. In the total figure of 117 Gt, possible Skåne and Baltic Sea storage opportunities are not included. Recent estimates of South Skåne vary between 1 and 10 Gt while estimates for Baltic Sea varies between 0.5 and 4.5 Gt.

In the below figure, GeoCapacity's "conservative estimate" for the BASREC countries and North Sea are shown. In this figure conservative estimates are used for all countries.

## Storage capacity BASREC + North Sea

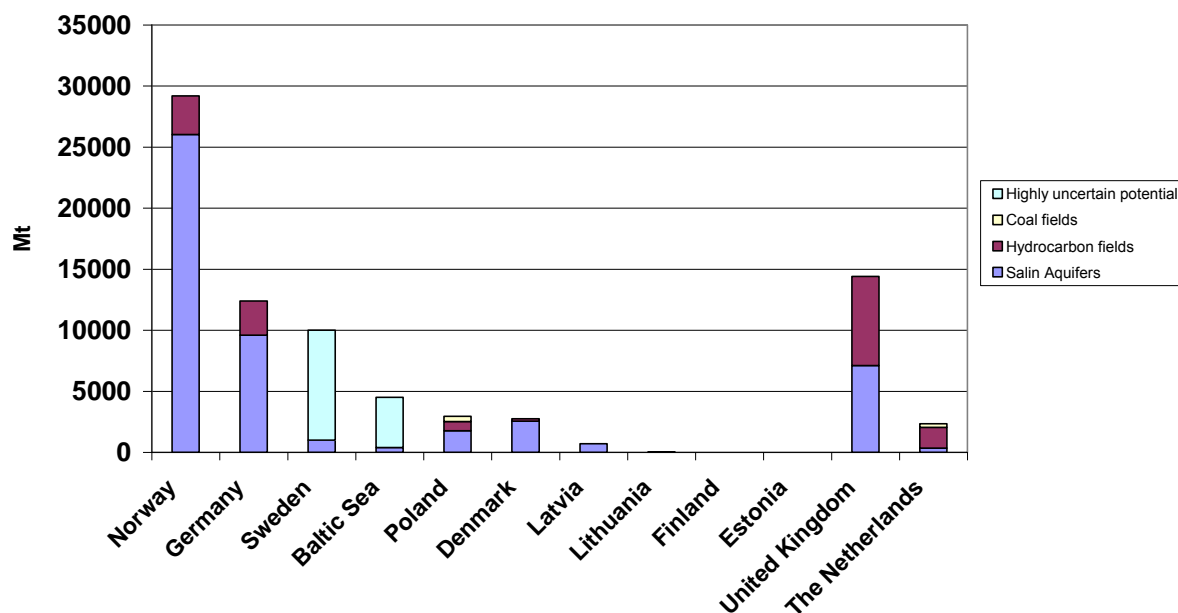


Figure 22: Conservatively estimated storage capacity in BASREC countries and adjacent North Sea countries. Potential but highly uncertain capacity in South Baltic Sea is added in order to illustrate the current uncertainty. (Source: INSA-compilation of several sources)

The conservative storage capacity estimate for the BASREC region is 54 Gt, while the capture level in 2050 is estimated to reach about 0.6 Gt. Hence the minimum capacity estimate gives sufficient storage capacity for 72 years if we assume the roll out scenario for the BASREC region in as in figure 9. There are also higher estimates developed for potential storage capacity in Europe, but these are only partially referred to in this report.

The quality of estimates for storage capacity varies considerably between different storage types. The best datasets are available for oil and gas fields. These fields have already been analysed for production purposes. The quality of the available datasets for deep saline aquifers and deep unmineable coal fields is far poorer.

In a recent study conducted by Zero Emissions Platform (ZEP) the costs of storage in the EU GeoCapacity database, comprising 991 potential storage sites in deep saline aquifers (SA) and 1,388 depleted oil and gas fields (DOGF) in Europe have been estimated. For the majority of these storage sites, estimated capacity is below 25-50 Mt. These sites are assumed to be uneconomical.

However, the majority of estimated *capacity* is found in very large depleted oil and gas fields and saline aquifers (>200 Mt capacity) which are much more cost effective. Hence BASREC transportation and storage development policies should focus on solutions based on large reservoirs which are capable of storing CO<sub>2</sub> from both single *and* multiple sources.

Cost estimates for the different storage categories are presented in Section 9. Many of the identified storage sites presented in the previous subsection may prove unusable because they either carry too high costs pr. unit stored CO<sub>2</sub>, or because political decisions render them unusable.

For instance, as demonstration CCS projects are proposed, public engagement has arisen, and this has caused delay and also temporary stop in activities, both with respect to regulations and technological development. These issues are further commented upon in section 11.

The degree of potential self sufficiency in storage capacity in the different countries is presented in the following table summarising the ratio of storage capacity to current emissions from large point sources. Conservative storage estimates are used. Since the table is constructed from different sources, the numbers are not entirely comparable. The table gives however an idea of which countries are potential exporters, importers and self sufficient in storage services. ("Storcap/emissions" means the ratio of storage capacity to annual emissions from large point sources).

	Storcap/ emissions
Norway	1 042
Germany	27
Sweden	43
Poland	36
Denmark	98
Latvia	202
Lithuania	6
Finland	-
Estonia	-

## 8 Storage economics

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### 8.1 Introduction

Cost structures and economics of transportation and storage will be of great importance for future choices of transportation and storage solutions for nations around the Baltic Sea. In the following two sections the main cost elements and economics of scale and scope are analysed. These analyses serve as background for and input to the preliminary evaluation of possible and cost effective joint solutions for storage and transportation of CO<sub>2</sub> within BASREC nations. Cost estimates are based on several sources, but the recent ZEP studies seem to be the most authoritative and up to date and our own generic calculation tools developed for this study are aligned with the ZEP estimates.

### 8.2 Storage operations

Storage costs consist of the following main components:

#### **Pre investment exploration, characterization and permitting, which include**

- Seismic survey
- Modelling and logging costs
- New exploration wells
- Injection testing
- Permitting

#### **Development**

- Platform, reuse of existing or building of new

- Remediation of existing wells
- Drilling new wells

**Operation**

- Operation and maintenance during the injection period

**Measuring, monitoring and verification**

- Drilling and operation of new observation wells
- Post closure monitoring
- Final seismic survey

**Close down**

- Decommissioning
- Liability transfer

**8.3 Storage cost structure and variation**

Several storage cost studies have been carried out by IEA, by IPCC and others. The recent ZEP-report on storage costs seems to be the most comprehensive and up to date. The typical costs for main categories of different storage opportunities are summarised in the next figure.

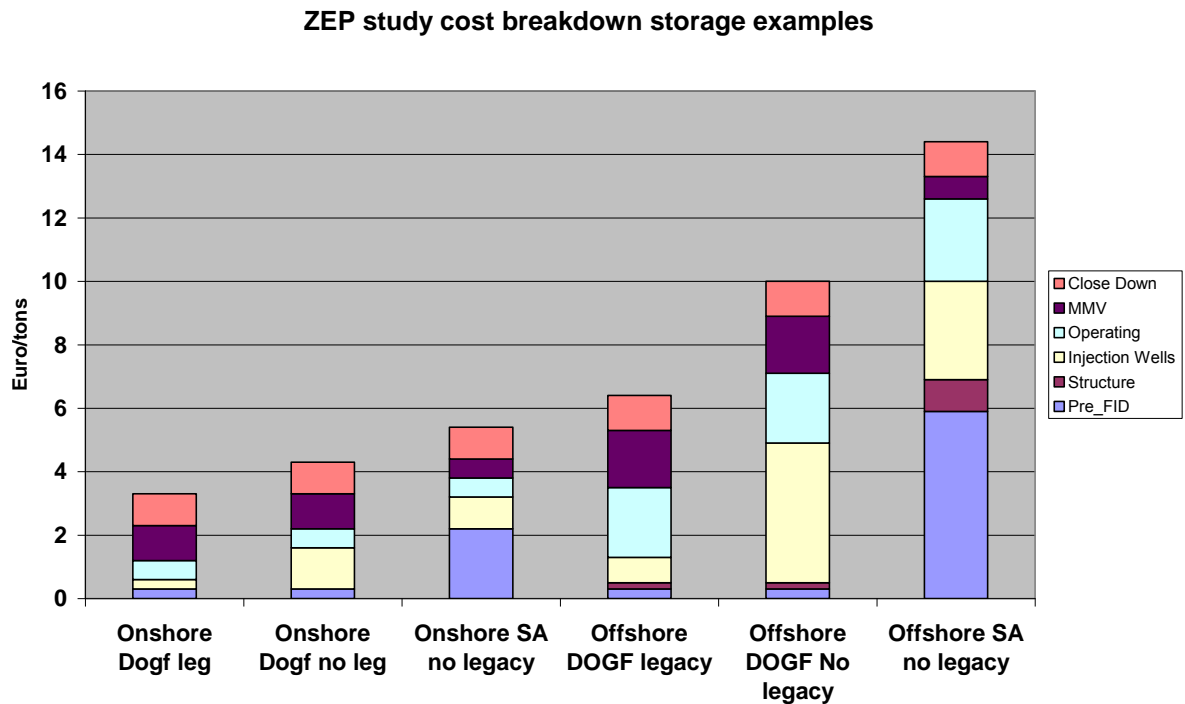


Figure 23: Costs and cost structures for different storage categories. (Source:ZEP)

In the above figure, "DOGF" means depleted oil and gas fields. "Leg" (legacy) means that part of the existing infrastructure can be reused for CO<sub>2</sub> injection.

The important message from the ZEP survey is that offshore saline aquifers in the Baltic Sea and North Sea may prove to be very expensive to develop with resulting high unit costs for CO<sub>2</sub> storage.

The ZEP study reveals large variation in costs within each class of storage options. Combining the cost figures shown above with the cost variance within the different categories gives a rather comprehensive view of storage costs - as can be seen from the figure below. Further efforts should be made to connect these costs with actual storage opportunities in the Baltic Sea region and the North Sea.

### Storage costs in Europe

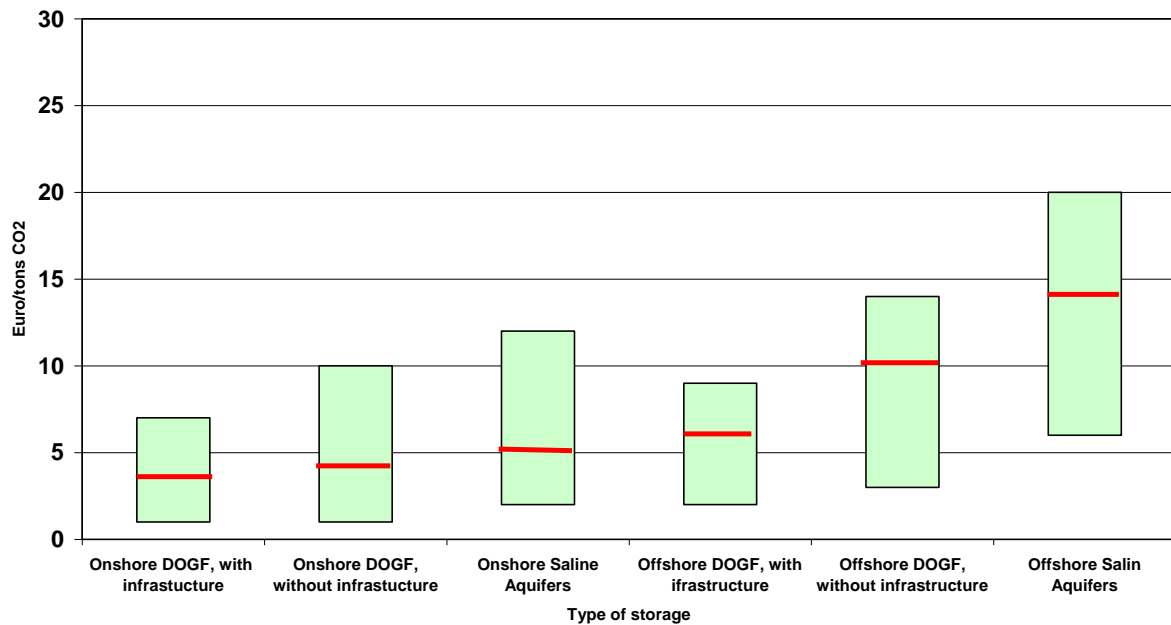


Figure 24: Typical cost and variance in cost of CO<sub>2</sub> storage in different storage categories. (INSA-compilation, ZEP-study, etc.)

The resulting total storage cost ranges are presented in the figure above. A key conclusion is that there is a wide cost range within each case, the "High" cost alternative being between three and ten times more expensive than the "Low" cost alternative.

Despite the wide cost range, the following trends stand out:

- Onshore is cheaper than offshore.
- Depleted oil and gas fields are cheaper than saline aquifers – even more so when they have re-usable wells.
- The highest costs, as well as the widest cost range, occur for offshore saline aquifers.

The cost of CO<sub>2</sub> geological storage is site-specific, which leads to a high degree of variability. The cost variance is mainly due to natural variability between storage reservoirs field capacity and well injectivity and only to a lesser degree to uncertainty in cost elements.

The higher unit costs offshore are usually reflecting the need for platforms or sub-sea facilities and higher operating costs.

In line with several other studies, the ZEP study shows that the largest single component of the total levelized cost variation for saline aquifers is the cost of site characterization. Post characterization cost is driven primarily by differences in aquifer geology and so called petrophysical properties. Considering only the costs of well drilling and completion,

and injection equipment, the capital costs of all of the cases were relatively similar; however, inclusion of the cost of site characterization changed the results considerably.

As can be seen from figure 24 costs for storage vary from 1 to 20 Euro/ton CO<sub>2</sub>. Costs in the upper end can easily make CCS uneconomical. This implies that even though offshore saline aquifers are identified as a storage option in the southern part of the Baltic Sea and the North Sea, it may turn out to be too costly.

According to the GeoCapacity database, the largest potential storage capacities are found in saline aquifers. Most of these are located offshore. Also capacity in depleted oil and gas fields are larger offshore than onshore. The least costly storage options, i.e. depleted onshore gas and oil field, are hence the ones with the least total capacity. They are a scarce resource, which will only cover a small portion of the total demand for CO<sub>2</sub> storage, if a full roll out of CCS is realized. Furthermore, the onshore storage sites are generally subject to public protests.

The above facts about costs and storage options have some important policy implications:

1. Further screening and exploration of storage sites is very important in development of economic viable CCS projects for the BASREC countries. Such information is highly valuable and it should be discussed whether information should be developed by and belong to the public domain or to companies. Experience from the oil and gas industry indicates that basic seismic data is best collected by public funding and made publicly available to all parties interested. Societies may be best suited to carry the risks involved, and to exploit economics of scale as regards new prospects. It may be assumed that such an approach, securing better screening of potential storage sites, may provide a more efficient competition for the best storage sites.
2. In order to stimulate broad interest and participation, effective incentive programs should be considered. Establishment of storage licenses may trigger activities in screening, exploring and clarifying the expectedly most cost effective storage sites including transportation cost since owners of license may be able to achieve a resource rent. Activities in this field will increase considerably if long term CO<sub>2</sub> pricing system in conformity with the 2°C target is established since CCS then becomes profitable. Currently, expectations may be too low and incentives too weak.

## **8.4 Enhanced oil recovery**

CO<sub>2</sub>-EOR can enhance oil production substantially, depending on the characteristics of the hydrocarbon reservoir. Oil and gas field operators may consequently be willing to pay for storage of CO<sub>2</sub> and such opportunities may play an important role in CCS chain development. Unfortunately the Baltic Sea seems to offer few, if any such opportunities. Storage in connection with EOR or EGR requires CO<sub>2</sub> to be shipped in sufficient quantities to EOR projects in the North Sea.

An estimate made for Norway indicates that EOR can increase ultimate oil production by 300 million m<sup>3</sup> (Mathiassen, 2003) or about 10% of production to date plus the remaining reserves. This suggests that CO<sub>2</sub>-EOR can increase long-term conventional oil production substantially. Such recovery may require the purchase of 750 Mt CO<sub>2</sub>, equivalent to storage of CO<sub>2</sub> from eight 800 MW coal power plants in 30 Years. The current high prices of oil and increasing resource scarcity should as well contribute to profitability of CO<sub>2</sub> injection for the purpose of EOR.



Detailed field-by-field assessments are necessary to accurately estimate the potential benefits of CO<sub>2</sub>-EOR.

CO<sub>2</sub>-EOR is commercially viable in several onshore fields in the US. The costs of offshore CO<sub>2</sub> recycling facilities and additional CO<sub>2</sub> injection wells may make CO<sub>2</sub>-EOR substantially more expensive to carry out in the North Sea. The economics of enhanced oil recovery will depend strongly on site specific issues and technology development, but also on the prevailing taxation and incentive systems for tertiary oil recovery, and whether supplied CO<sub>2</sub> represents a cost or a revenue source. The below figure give some insight to the economics of EOR in US.

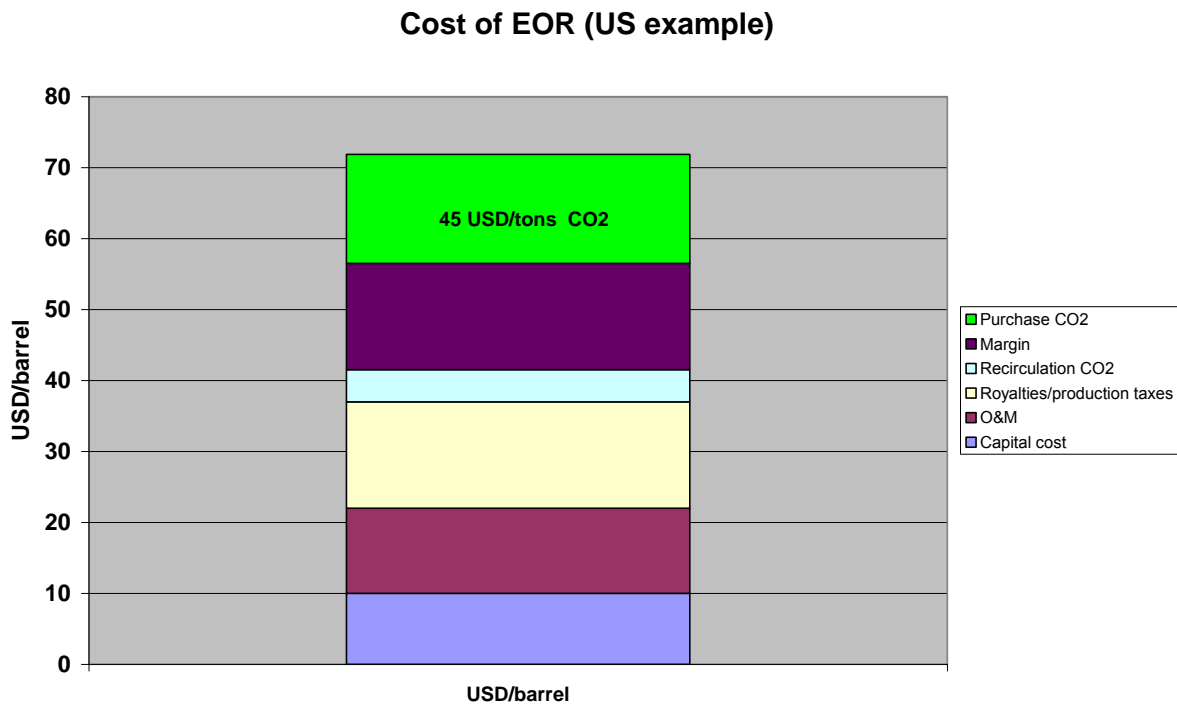


Figure 25: Example of cost structure for enhanced oil recovery. (Source:INSA)

There seems to be considerable interest in EOR projects on the Norwegian Continental shelf, but companies are so far hesitant due to the security of CO<sub>2</sub>-supplies. There may be need for an intermediate storage close to the field in order to secure sufficient supplies for the operations. So far, there are technological challenges in retrieving CO<sub>2</sub> from such storages.

Exploitation of CCS opportunities will require substantial cooperation in order to facilitate jointly planned development of larger CCS projects and the actual EOR project.

## 9 Transportation economics

### 9.1 Pipeline transportation

#### 9.1.1 Overview

Transportation of CO<sub>2</sub> via pipelines is an established technology. Pipelines routinely carry large volumes of natural gas, oil, condensate and water over distances of thousands of kilometres, both on land and in the sea. Pipelines are laid in deserts, mountain ranges, heavily populated areas, farmland and the open range, in the Arctic and sub-Arctic, and in seas and oceans up to 2200 m deep. Transportation of CO<sub>2</sub> does pose some challenges compared to transportation of petroleum, but these challenges have been overcome, and large amounts of CO<sub>2</sub> is currently transported by pipeline in the US.

Economics of pipeline transportation has some features of great importance for system planning. The cost pr. km is almost independent of distance since costs related to planning and engineering, purification and dehydration constitute minor elements compared to the highly distance dependent costs like pipes, other materials, welding, establishments of construction roads, ditching, padding, reinforcements and other construction costs.

The operational costs are mostly the cost of energy needed for booster stations compensating for frictional loss in the pipes. Net positive elevation change may as well require energy for mass movements while net reduction contributes to energy needed for compensation for the frictional loss. Operational cost of a pipeline constitutes only a small fraction, about 1%, of unit cost.

Today typical cost of a 24 inch (61 cm) diameter pipeline, capable of transporting about 10 Mtpa, will vary between 1000 and 3000 Euro/meter depending mainly on differences in the terrain dependent construction costs.

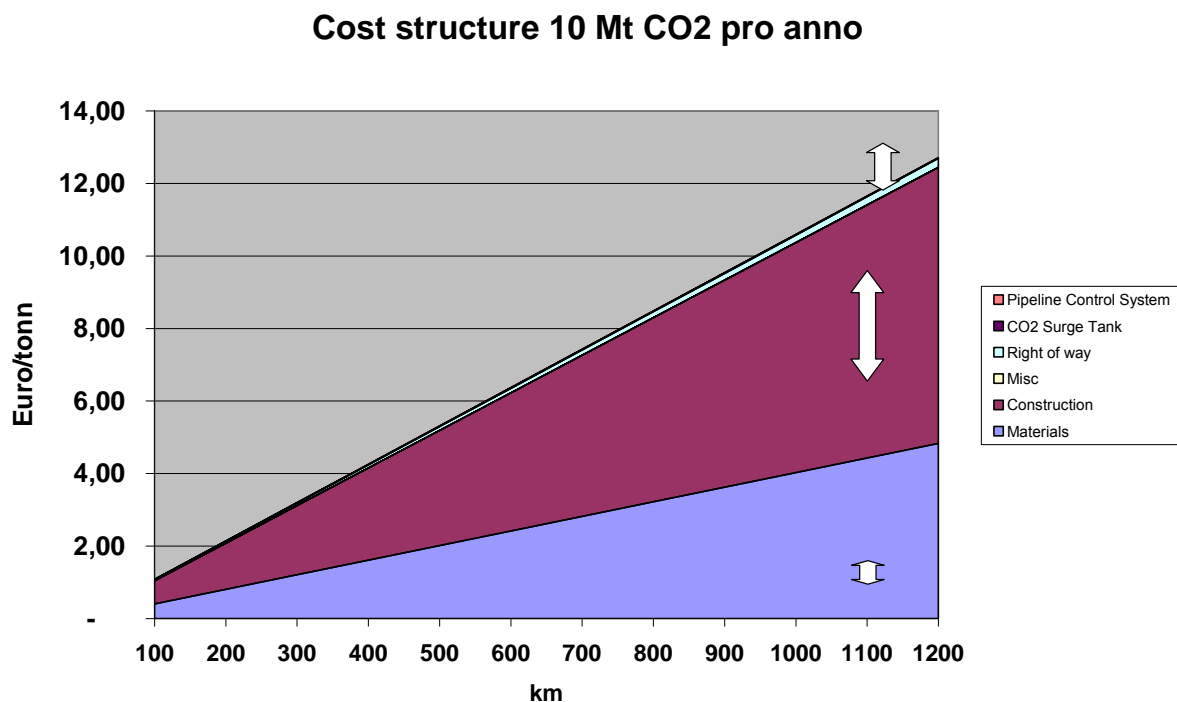


Figure 26: Cost structure onshore pipeline. (Source:INSA)

The current cost figures imply a transportation cost pr. ton CO<sub>2</sub> as in the above figure.

Costs will increase in mountains and other rocky areas that require intensive blasting, in nature reserve areas, in areas with obstacles such as rivers and freeways, and in heavily urbanized areas because of accessibility to construction and additional required safety measures. IEA operates with a multiplier of 1.5 if more than 50% of the pipeline passes mountainous areas (compared to flat grassland).

A recent feasibility study of a new 24" pipeline through Alaska may illuminate variations in pipeline construction costs:

Analysis of the work and cost breakdown of the different segments of the pipeline unveils that costs for materials are almost independent of route characterisation, while costs for construction, padding and pipeline welding vary according to the complexity of the route, both with respect to the ground conditions, steepness and variation in elevation, need for reinforcement and supporting constructions, access and possibilities for the usages of different types of machines and equipment.

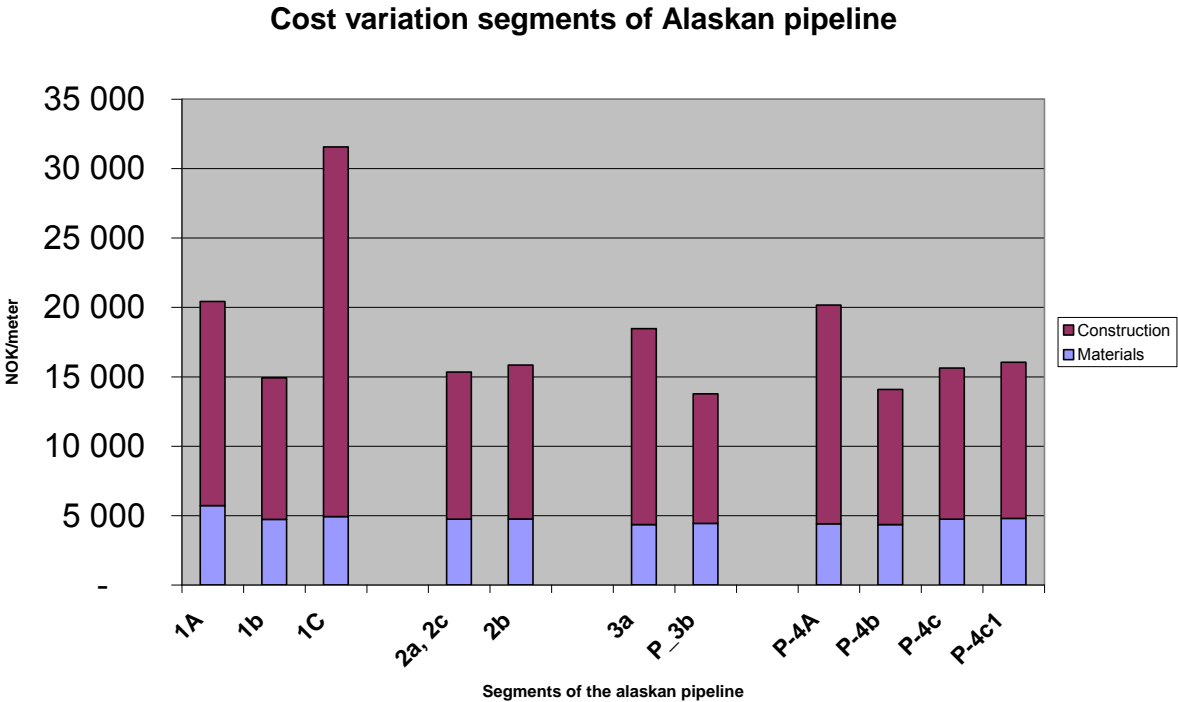


Figure 27: Costs for different segments of an Alaskan natural gas pipeline. (Source: INSA based on Alaskan pipeline project study)

The bars in the above figure represent different segments of the pipeline. Segment 1 C goes through mountainous area while for instance segment P-3b goes along a road in a valley. Hence route cost estimation requires rather detailed geographical information, which must then be combined with experience with costing of different types of operations including machines- and man-hours.

**Co-routing**

Co-routing with other pipelines and infrastructure may save costs related to establishment of construction roads, cost of land and permitting processes.

## Right of way

The cost of right of way is a minor element in the above example. However, transportation infrastructure that carries CO<sub>2</sub> in large enough quantities to make a significant contribution to climate change mitigation will require a large network of pipelines. As growth continues it may become more difficult to secure right-of-way for the pipelines, particularly in highly populated zones that produce large amounts of CO<sub>2</sub>. In such areas governments could facilitate infrastructure development by securing right of way for future infrastructure development.

Cost multipliers between a flat unpopulated area and a populated area can be as high as 30 (pr km of routing). Normally, and if possible, pipeline constructors will avoid urban and rockbed areas, since circumvention will normally be much cheaper. But never the less onshore pipeline costs may increase by 50 to 100% or more in congested areas and demanding terrain.

In the Jämschalde project in Germany, it is recommended that CO<sub>2</sub> pipelines follow the main roads to storage sites. In addition to the expected increase in costs, transporting CO<sub>2</sub> through highly populated areas will most probably give rise to more safety related issues.

## Business cycles

Costs of pipes and construction are highly dependent on business cycles and the capacity situation within the steel industry and construction businesses. From 2003 to 2008, pipeline costs tripled.

## Offshore pipelines

Offshore pipeline construction is normally more costly than onshore. The ZEP figures indicate that offshore costs are about 20% higher than onshore costs. Other sources operate with 40% higher offshore costs. ZEP figures are probably more relevant for the Baltic and North Sea due to the flat and sandy seabed in this area.

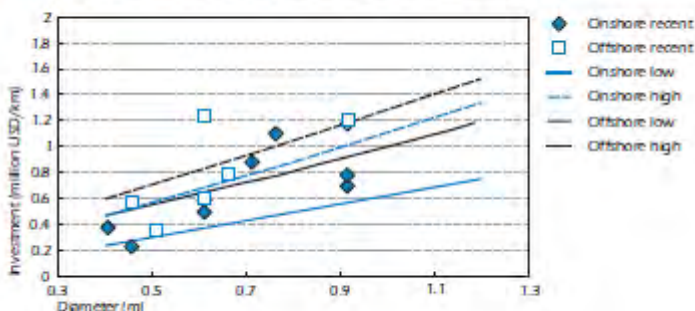
In the Scandinavian area, it is experienced that offshore pipelines can be more cost effective than onshore pipelines. Gassco in Norway conclude in their studies that offshore pipelines in the North Sea are cheaper than onshore pipelines in most Nordic countries.

The following figure illustrates the large variation in costs of pipeline construction.

**Figure 4.2** Estimated Costs for Recent Gas Pipelines, 2005-2007

### Key point

Cost of gas pipelines has increased significantly due to the cost of materials.



Sources: IPCC, 2005; IGG, 2007.

**Figure 28:** Cost pr km pipeline (vertical axis) according to diameter (horizontal axis) (Source: IEA/IPCC)

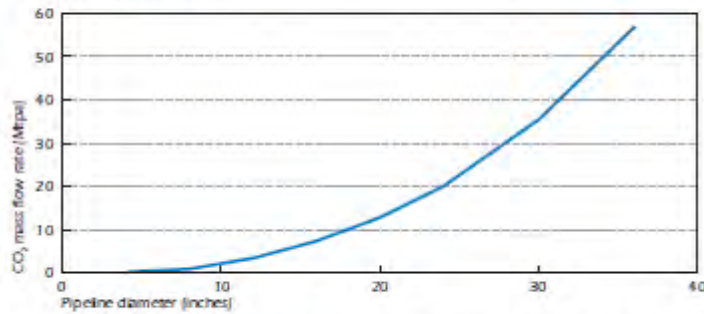
## Economics of scale

Pipeline transportation, both on- and offshore, is characterised by significant economics of scale. Pipe costs increase almost linear to pipeline diameter while annual volumes transported increase even more than the cross section of the pipe (a square function of diameter).

**Figure 4.1** Pipeline Diameter Relative to Flow Capacity

**Key point**

The most appropriate pipeline diameter for CO<sub>2</sub> transport depends on the volume transported and operating conditions.



Note: Such curves depend on the input-output pressure, here 80-120 bars. In offshore conditions, pressures may be higher.

Source: Williams, et al., 2007.

**Figure 29: Pipeline diameter and mass flow of CO<sub>2</sub> (vertical axis)**

Costs of ditching, reinforcements against landslides, bridging and tunnelling for different crossings are only weakly dependent on pipe size, a factor that also increases economics of scale in pipeline transportation.

Offshore pipelines are more stepwise in cost development since the technology for laying of pipelines changes with diameter.

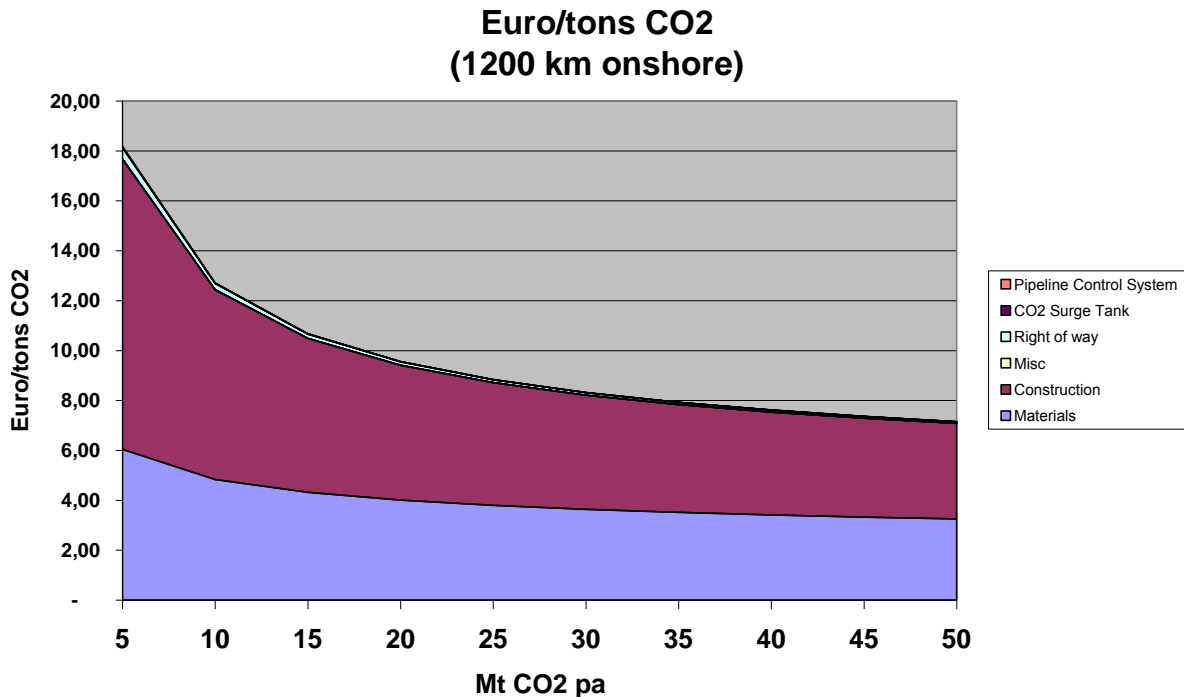


Figure 30: Pipeline mass flow (horizontal axis) and costs of CO<sub>2</sub> transportation in a 1200 km onshore pipeline. (Source:INSA)

The figures in the above charts are generated by a simplified and generic transport cost model constructed for this project. The figures fit well with the point estimates in the mentioned ZEP study.

### 9.1.2 Reuse of pipelines

Reuse of pipelines may be a feature that will benefit storage in the North Sea, but as explained in the One North Sea report:

*"it must be considered to what extent pipelines which are now used for transportation of oil or gas may be re-used for transportation of CO<sub>2</sub>. Although the economic benefits could be high, the challenges related to pipeline re-use are substantial:*

1. *Design pressure could be a limitation. Maximum allowable operating pressures are often reduced with age and may be particularly reduced for re-use with CO<sub>2</sub>. This effectively reduces transportation capacity compared to a purpose-built new line (with design pressure of typically 200 – 300 bar).*
2. *Remaining service life for CO<sub>2</sub> operation can only be assessed on a case-by-case basis, based on data on internal corrosion, historic use and maintenance records. Even when there appear to be no technical barriers to reuse, it is possible that owners/operators may not wish to take risks of committing pipelines that have been in long-term use for hydrocarbon transport.*
3. *Timing will be a major limitation. The date at which pipelines become available is inherently uncertain and is commercially sensitive information. Even if information can be shared, it may be very difficult to match decommissioning timelines with those for CCS demand and sink availability – mothballing may be necessary."*

### 9.1.3 Lead times

Lead times in transportation and storage planning and development will be of great significance for possible joint solutions for transportation and storage in the BASREC nations. Lack of political and regulatory clarity may cause serious delays in development of an efficient transportation and storage infrastructure. The following chart illustrates possible lead times for new CO<sub>2</sub> pipelines in the first period of CCS development. Due to lack of clarity regarding possible storage sites the initial planning phase may stretch out.

Construction planning can begin either before or after right of way is secured, but a decision to construct will not be made before a legal right to construct a pipeline is secured and all governmental regulations are met. High uncertainty relates to the consenting process which in fact could prove to be more time-consuming (and costly) onshore than offshore, especially since it includes issues surrounding right of way and local public opinion.

Onshore and underwater CO<sub>2</sub> pipelines are constructed in the same way as hydrocarbon pipelines, and for both, there is an established and well understood base of engineering experience.

The construction phases of a land pipeline are outlined below. Some of the operations can take place concurrently. Environmental and social factors may influence the season of the year in which construction takes place. The land is cleared and the trench excavated. The longest lead items come first: urban areas, river and road crossings. Pipe is received into the pipe yard and welded into double joints (24 m long); transported to staging areas for placement along the pipe route, welded, tested, coated and wrapped, and then lowered into the trench. A hydrostatic test is carried out, and the line is dried. The trench is then backfilled, and the land and the vegetation restored.

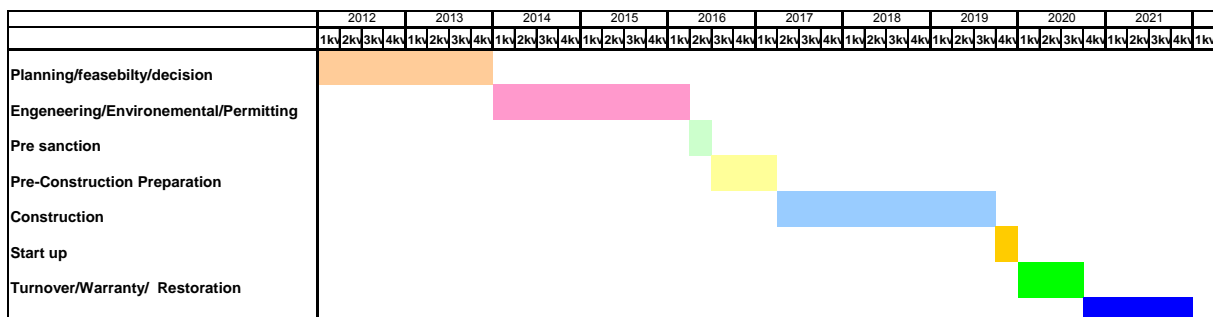


Figure 31: Project schedule plan for pipeline. (Source: INSA assessment on several sources)

Future planning and development may take place within shorter time spans. Lead times for uncontroversial pipelines are normally shorter.

## 9.2 Ship transportation

### 9.2.1 Overview

Shipping of CO<sub>2</sub> can be cost competitive with pipelines for smaller volumes (such as those corresponding to demonstration projects), or for very long distances (over 600-1000 km, depending on complexity of constructing the pipeline.) Shipping can also be the best solution when:

- No economic pipeline route can be identified, because distances or terrains are too challenging.
- The timescale and success of obtaining pipeline consents are difficult to predict or incompatible with demand.
- There is a high risk associated with the locations of sources or sinks or with the rate of growth in capacity, which challenges the business case for high capital investment in pipelines that are sized for future capacity.
- The ability to handle variations in capacity over time is essential. CO<sub>2</sub> ships and hubs can potentially handle throughputs of up to 20 Mtpa with high flexibility, relatively low capital costs, and reduced risks from planning delays or of stranded assets.

By use of ship transportation, capacity and utilisation can be matched more carefully than for use of pipelines. Scaling down the total ship transportation capacity is unlikely to be a problem as ships could be redeployed for CO<sub>2</sub> transport elsewhere in the world, or modified for use in the LPG trade. Ship transport was proposed for the Fortum/TVO project. In this project, it was intended that CO<sub>2</sub> from the Meri Pori coal-fired power plant in Finland should be transported to the North Sea by ship. This project has now been discontinued.

## 9.2.2 Breakdown of ship transportation costs

The main cost elements of ship transportation described below are as described in an earlier report from Mitsubishi. It is informed that the cost level for the different elements has risen considerably since the report was made.

### Liquefaction cost

Liquefaction of CO<sub>2</sub> to dense form seems to be the most cost effective ship transportation solution. The cost of liquefaction is about 1.5 USD/tonne CO<sub>2</sub> if CO<sub>2</sub> is supplied at 10 bar pressure. If CO<sub>2</sub> is supplied at a pressure of 1 bar, cost of liquefaction is increased to about 8.7 USD/tonne.

### Storage cost

Shipping requires intermediate storage of liquefied CO<sub>2</sub> in port. Average storage duration depend on the shipping schedule and will be optimised as part of the total system. Typical costs for intermediate storage are 4-5 USD/ton.

### Port fees

Port fees will depend on the loading and unloading time. Port fees are normally higher in congested ports but will typically be in the order of 2 USD/ton.

### Ship cost

Shipping cost is normally calculated on a daily rate basis. Ship cost are divided into time used for loading and unloading, and for freight time. Daily rates for a freight carrier with a capacity of 30 000 tons CO<sub>2</sub> are calculated to 30 000 USD/day provided 85% annual capacity utilisation.

Operating cost mainly consist of fuel costs, that increase with the oil prices.



## Cost structure shipping transport of CO<sub>2</sub>

30 000 tons vessel

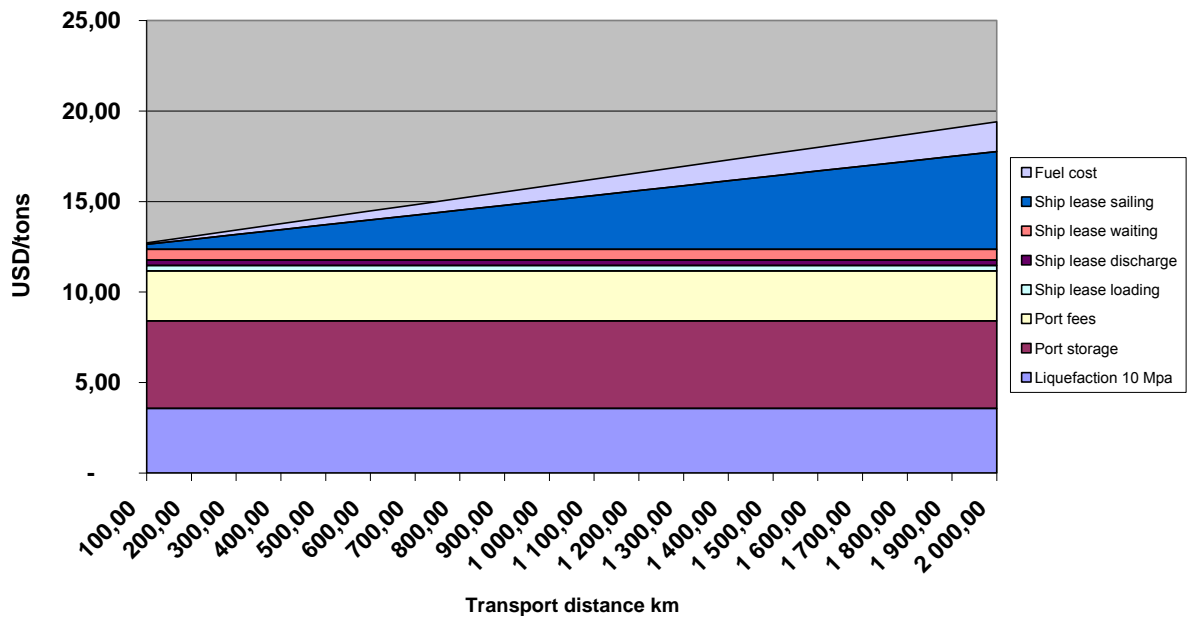


Figure 32: Cost structure ship transportation. (Source: INSA transportation model based on several papers and reports)

The high share of costs that do not vary with distance makes shipping costly for short distances compared to pipeline transportation.

## 9.3 Systems economics

### 9.3.1 Grid economics

It is evident from pipeline economics that it may be cheaper to collect CO<sub>2</sub> from several sources into a single pipeline than to transport smaller amounts separately. Hence early and smaller projects will face relatively high transport costs, and be highly sensitive to transport distance to storage sites. In a situation with large and wide-spread application, costs will decrease. CCS projects will hence benefit from a joint and well developed transportation system. Implementation of a "backbone" transport structure may facilitate access to large but remote low cost storage reservoirs. Restrictions on use of well characterised, low cost storage opportunities within low distance onshore may be particularly unfortunate for the economics of early stage commercial scale CCS projects.

The following table from the One North Sea report summarises the pros and cons of pipeline networks.

**Table 12:** Comparison of transport network topology options

Topology	Advantages	Disadvantages
<b>A</b> point-to-point	<ul style="list-style-type: none"> <li>• Low up-front capex</li> <li>• Does not require estimation of future demand</li> <li>• Does not require co-ordination between multiple stakeholders</li> <li>• Reduces risk of low pipeline utilisation</li> </ul>	<ul style="list-style-type: none"> <li>• Average cost per tonne across all networks is higher than with shared infrastructure.</li> <li>• Multiple pipelines across different routes means large planning hurdles and disruption to those affected.</li> <li>• No flexibility to accommodate additional sources at low cost.</li> <li>• Could be higher capex in long term.</li> </ul>
<b>B</b> Shared pipeline	<ul style="list-style-type: none"> <li>• Low transport cost when operating at full capacity.</li> <li>• Enables connection of marginal sources. Could attract new sources e.g. industry to the region.</li> <li>• Lower planning hurdles and disruption since multiple sources share one trunk pipeline.</li> </ul>	<ul style="list-style-type: none"> <li>• High initial cost. May require public sector funding initially.</li> <li>• Risk of low utilisation if demand is lower than forecast.</li> <li>• Requires common entry specification for CO<sub>2</sub>.</li> <li>• Complex business models.</li> <li>• Requires higher up-front confidence in storage availability</li> </ul>
<b>C</b> Shared rights of way	<ul style="list-style-type: none"> <li>• Robust and flexible</li> <li>• Lower planning hurdles as new pipelines are built on shared rights of way.</li> <li>• Capacity matched to demand.</li> </ul>	<ul style="list-style-type: none"> <li>• Transport costs are higher than for shared pipelines with same throughput.</li> <li>• Does not significantly reduce costs for smaller, marginal sources.</li> </ul>
<b>D</b> Shipping	<ul style="list-style-type: none"> <li>• Lower upfront costs than pipelines.</li> <li>• Flexible in the event of sink failure CO<sub>2</sub> can be routed to other storage sites.</li> <li>• Suitable for projects where multiple, small sinks may be required, or where project lifetimes are small.</li> <li>• Capacity matched to demand</li> </ul>	<ul style="list-style-type: none"> <li>• Very high transport costs compared to mature pipelines.</li> <li>• Large number of ships required to meet high demand.</li> </ul>

*Figure 33: Pros and cons of different transportation solutions. Source: (One North Sea report)*

### 9.3.2 Pipeline risk premium

There is a fundamental difference between pipeline and ships with regard to sensitivity to technical and commercial risk. This is because pipelines are highly capital intensive, with the annualised cost of capital counting for more than 90% of the total cost. Ships are less capital intensive, with capital cost well below 50% of the total cost. Pipelines are also generally considered "sunk cost" with no residual value, while CO<sub>2</sub> ships for one project are likely to have a residual value, either in other CCS schemes or in hydrocarbon transportation.

### 9.3.3 Ramp up solutions

The levelized transportation cost increases typically with 50% if volume build up to full capacity is linear (from 0 to 100%) over a 10 year period. Hence pipeline companies try to ramp up transported volumes as fast as possible. This may in particular be difficult in the current phase of CCS development, where only few and small projects are launched. Combinations where ship transport is utilised until sufficient volumes for a trunk line is developed will help reduce the overall transportation costs. This will only be possible if there are no or very low sunk costs connected with the shipping alternative. This will probably require that suitable harbours already exist and that storage and liquefaction plants can be built on mobile barges that can be used around the world after the ramp up period.

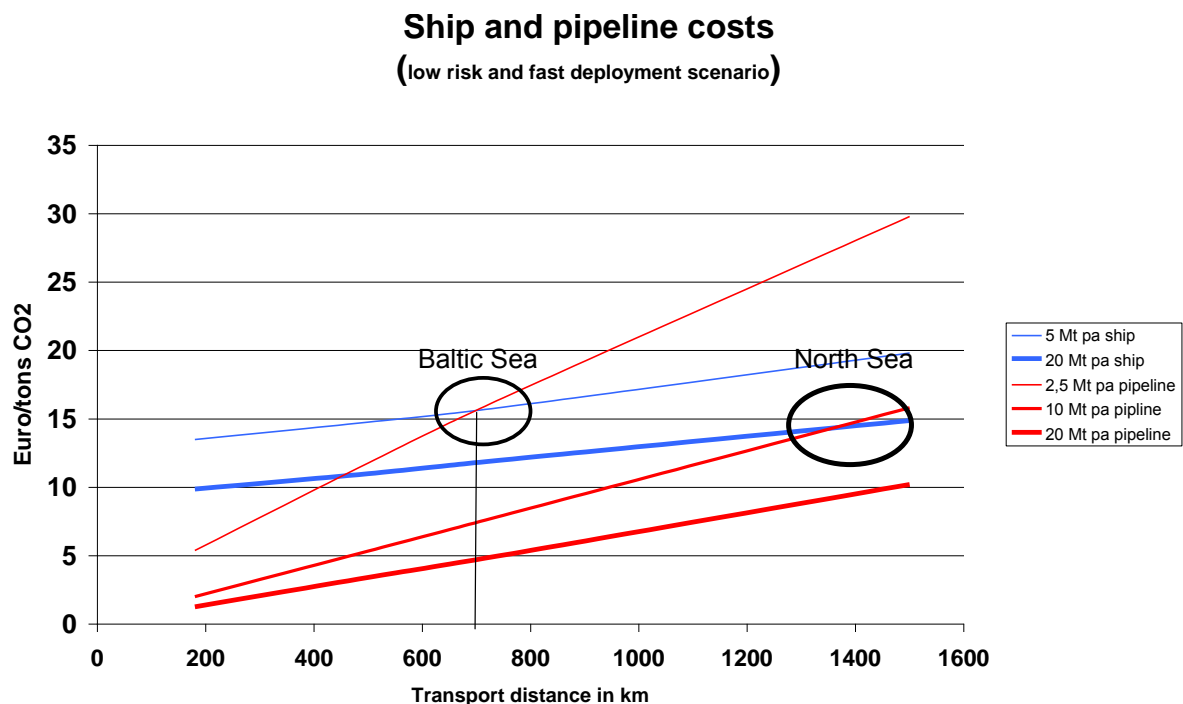


Figure 34: Unit costs of CO<sub>2</sub> pipeline and ship transportation according to distance and scale. (INSA-model based on input from ZEP-study and other papers and reports)

Most Baltic Sea nations will face the choice of ship or pipeline transport or a combination of these solutions. As summarized in the above figures, pipeline transport appears to be the most favourable transport solution at almost all distances provided high degree of certainty as regards volumes and sufficient storage capacity. Pipeline transportation becomes in particular favourable when sources are clustered both geographically and in time. For instance, pipeline transportation to North and Norwegian Sea destinations will be more cost effective than a shipping system for cluster volumes above 10 Mtpa. If sufficient storage capacity is found and allowed in the Baltic Sea, pipelines become the dominant solution at even smaller volumes if sufficient cooperation and coordination can be established between both nations and participants in potential clusters. In the below example negligible cost of transporting from the individual plants to the trunk line via feed in pipelines are assumed. The feed line costs may be very high if sources are dispersed.

### Ship and pipeline costs (high risk slow deployment scenario)

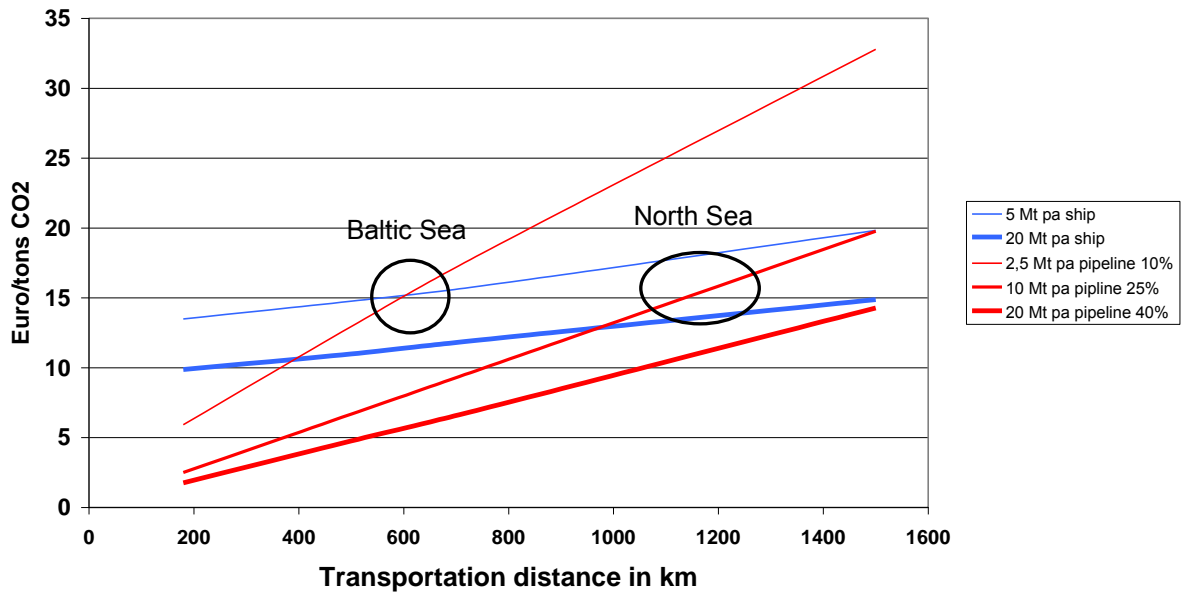


Figure 35: Risk and ramp up adjusted costs of pipeline and ship transportation for different volume assumptions and distances. (Source; INSA model)

Ship transport becomes relatively more favourable if we take the risk premiums and ramp up time for pipeline into account. In the above example it is assumed a 10% risk premium on levelized cost for the 2.5 Mtpa pipeline due to sunk cost and low flexibility compared to ship transport. The risk premium and ramp up disadvantage is assumed to increase by the size of the pipeline, hence the risk and ramp up adjusted costs increase by 25% for the 10 Mtpa pipeline and 40% for the 20 Mtpa pipeline. But as can be seen, pipelines may still be the preferred solution if sufficient storage capacity is found in the Baltic Sea area. This may even be the case for the North Sea area if clusters with 20 Mtpa can be established. In addition ship transportation routes to the Norwegian shelf will have longer distances than pipeline routes crossing Sweden and Norway.

#### 9.3.4 The value of flexibility and options

Ship transportation opens in theory up for more flexibility in choice of storage sites, which may give opportunities for skimming the cream of the market for enhanced oil recovery. This opportunity may be reduced by possible needs for permanent installations at the petroleum reservoir. This analysis should be further refined in a follow up project.

## **10 Preliminary evaluation of transportation and storage solutions in BASREC countries**

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### **10.1 Possible solutions in the 2020-2030-2050 scenarios**

The EU funded CO2Europe project has made a comprehensive study of possible transportation and storage scenarios in Europe based on the databases from GeoCapacity and the PRIMES model<sup>2</sup>. In the CO2Europe study, the captured CO<sub>2</sub> volumes from the source clusters are linked with the total storage capacity and the yearly injection capacity to store the yearly produced volumes. This creates a network of transport corridors, covering North-West and Central Europe. These scenarios may serve as a useful starting point for discussion of transportation and storage and joint transboundary solutions in BASREC countries.

In the CO2Europe report three different storage scenarios are used:

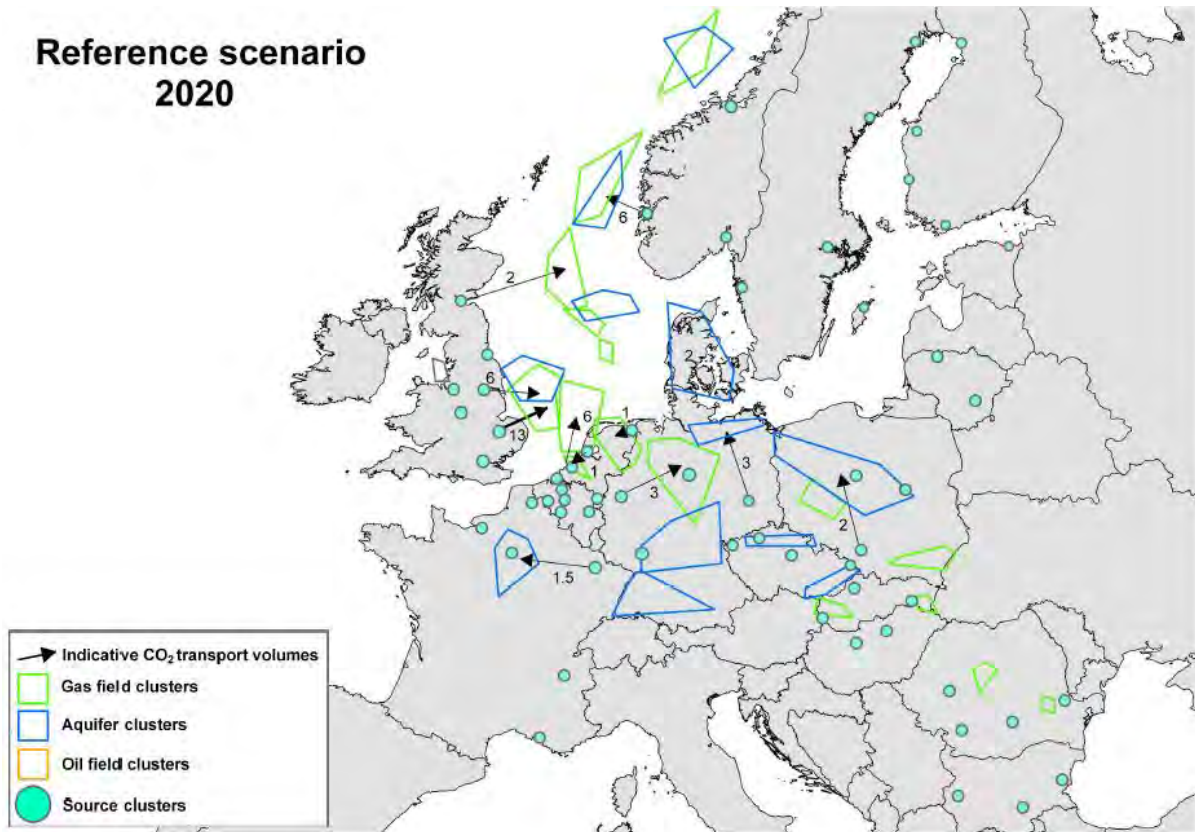
- Reference scenario: storage takes place both onshore and offshore. Matching of supply and demand was based on current models and projects for the development of CCS that exist in the Member States.
- Offshore-only scenario: onshore storage was excluded from the assessment to investigate the impact of current public concerns and stringent permitting issues that might result from these concerns;
- EOR scenario: in addition to the offshore-only scenario it is assumed that EOR is economically attractive and will therefore use part of the captured CO<sub>2</sub>.

The results from the study are summarised in the following figures taken from the report: "Development of a large-scale CO<sub>2</sub> transport infrastructure in Europe, Matching captured volumes and storage availability".

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<sup>2</sup> The study used the PRIMES model for picking possible CCS projects after the initial demonstration phase. For the demonstration phase up to 2020 the database in annex 17.2 was used as a reference. It is worth noting that several of the projects applied in the study have now been discontinued due to reasons discussed later in our report.

**Reference scenario  
2020**



*Figure D.4 Flow rates for the reference scenario in 2020.*

**Figure 36: Transportation solutions in the reference scenario without onshore storage restrictions. (Source: CO2Europe)**

In the 2020 reference scenario, only internal transport is expected to take place. Consequently there may be no need for transboundary solutions in the first phase up to 2020 unless planning for longer term scenarios is included. Only one project is assumed to be realized in the Scandinavian countries, namely the Mongstad project requiring transport and storage of 6 million tons CO<sub>2</sub>. (Assuming full scale CCS at the refinery). Within the other BASREC countries, transportation and storage is expected to take place within Poland and within Germany.

In the above figure, all assessed sink clusters are shown. As can be seen, the potential sink in the Baltic Sea underground has not been considered as a potential sink in this study.

**Reference scenario  
2030**

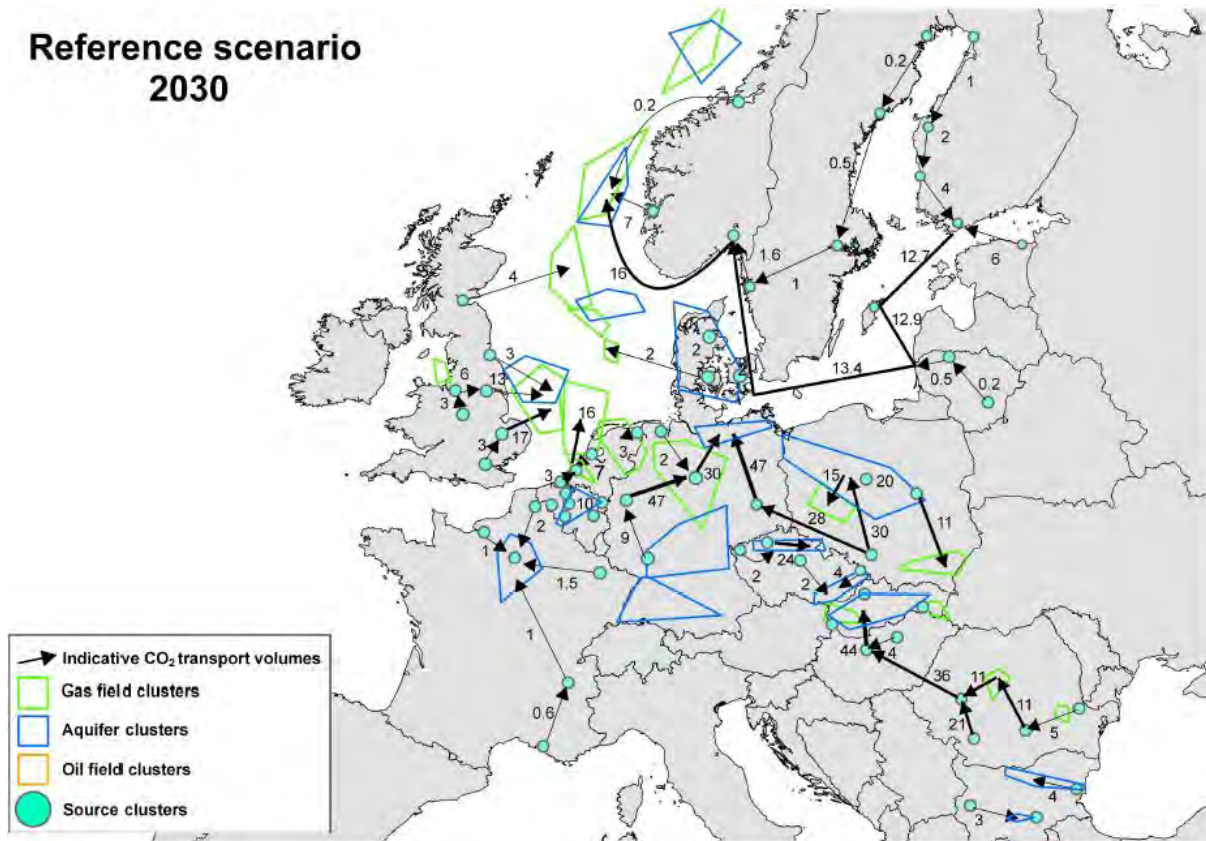
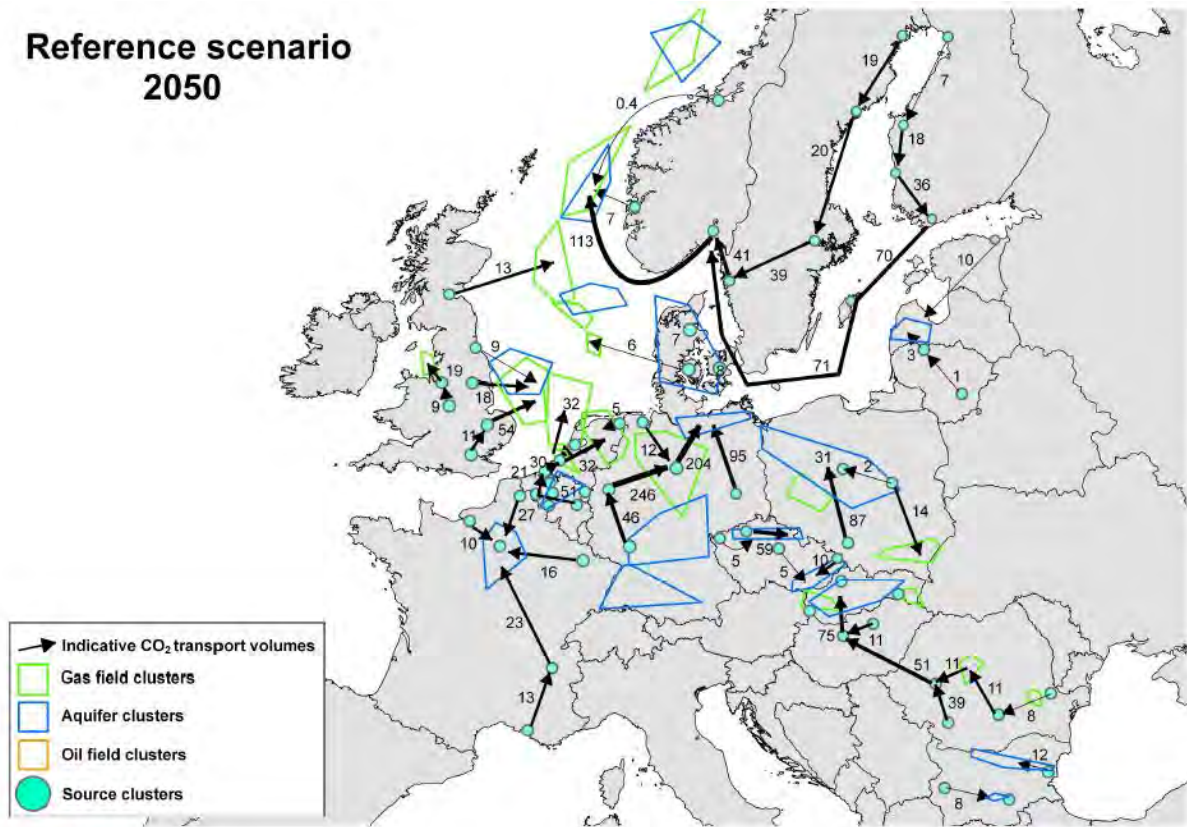


Figure D.5 Flow rates for the reference scenario in 2030.

**Figure 37: Joint onshore and offshore transportation routes in 2030. (Source CO2 Europe)**

By 2030 it is foreseen a pipeline solution where CO<sub>2</sub> is collected from sources in Finland, Estonia, Gotland and Lithuania. A trunk line is constructed, and CO<sub>2</sub> from the areas mentioned are fed in to the trunk line. In Gothenburg, CO<sub>2</sub> from several sources in Sweden is fed into the trunk line, and a total of 16 Mtpa CO<sub>2</sub> is transported out to the Utsira saline aquifer in the North Sea. Internal transportation in Germany and Poland and transboundary transportation of considerable amounts between Poland and Germany takes place. Furthermore, transportation from Denmark for injection in gas field clusters in the North Sea also takes place. As analysed in the next subsection, it is doubtful whether these concepts are economically viable even with very strict emissions limitations and high prices on CO<sub>2</sub> emissions.

**Reference scenario  
2050**



*Figure 38: Joint transportation solutions in 2050 (Source: CO2Europipe)*

In the 2050 perspective the study foresees a large trunk line along the Finnish coast, through the Baltic Sea, Skagerrak to Oslo, connecting with a Swedish collection and trunk line system. The combined quantity transported by these trunk lines to the Utsira formation is estimated to 113 Mtpa. This CO<sub>2</sub> system will consist of several parallel 40" pipelines. In this scenario, very large amounts of CO<sub>2</sub> are transported and stored within Germany and Poland but no volumes are transported to the Baltic Sea or to the North Sea from these countries.



## Offshore-only scenario 2030

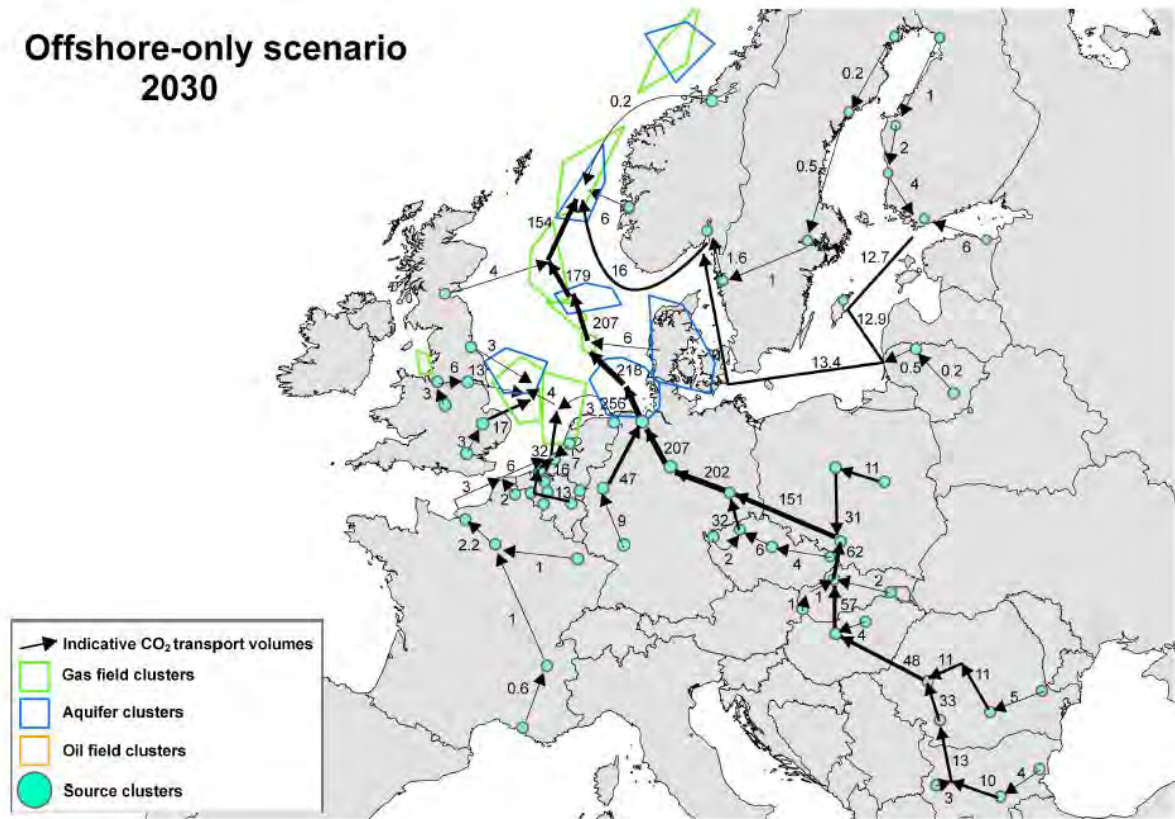


Figure D.8 Flow rates for the offshore-only scenario in 2030.

Figure 39: Joint pipeline transportation routes in the offshore only scenario. (Source: CO2 Europe)

The current opposition to onshore storage in several countries may result in a need for construction of several very large trunklines through Eastern and Central Europe to offshore saline aquifers and depleted hydrocarbon reservoirs already by 2030. This will be very challenging both economically and politically.

## EOR scenario 2030

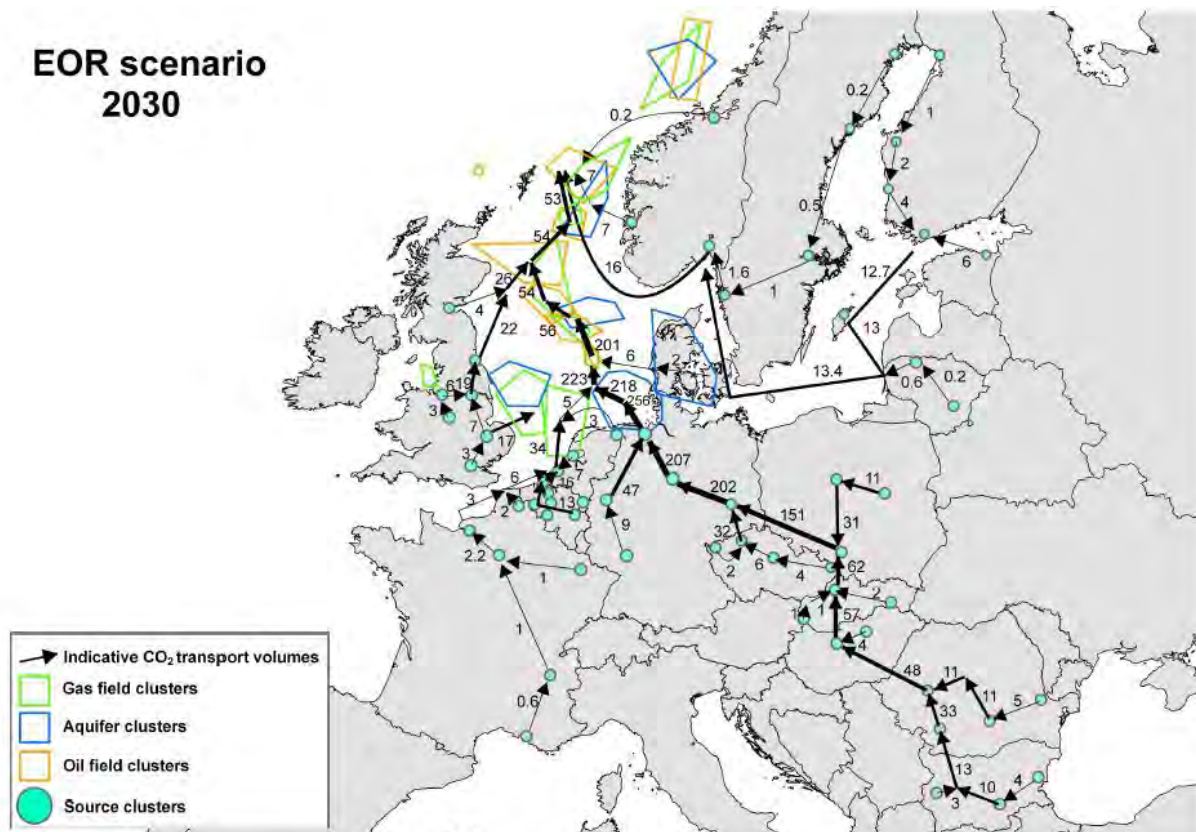


Figure D.11 Flow rates for the EOR scenario in 2030.

Figure 40: Joint pipeline transportation routes in 2030 in the EOR scenario (Source: CO2Europipe)

The EOR scenarios for 2020, 2030 and 2050 give the same transportation pattern as the offshore only scenario.

## 10.2 Possible joint solutions in BASREC countries

Despite the possible presence of sufficient onshore storage capacity to meet storage requirements from national CCS projects, transboundary solutions may be necessary even before 2020. The main reason is opposition to onshore storage in several countries.

In the longer term major deployment of CCS projects will by necessity involve both joint and transboundary solutions. The reasons for this are as follows:

- Finland and possibly Sweden need to transport and store CO<sub>2</sub> either in saline aquifers in South Baltic Sea, in onshore or offshore storages in Denmark, in the North Sea, or in Russia. In the short to medium term, transportation by ship may be a solution. Transportation in the longer term will involve construction of both trunklines and feeding lines.
- Restriction on the use of storage in Germany and Denmark may result in joint solutions for storage in the North Sea.
- Estonia and Lithuania must find storage solutions in cooperation with Latvia and Russia in joint Baltic Sea storages or in joint pipelines from Finland via Sweden to the North Sea.
- The Norwegian continental shelf and the rest of the North Sea offers opportunities for large scale safe storage of CO<sub>2</sub> in depleted oil and gas reservoirs, in connection with EOR/EGR projects and in saline aquifers. This will in particular be

relevant for transboundary solutions in Northern Europe. The opportunities will be further explored following a bilateral agreement between Norway and Germany on ministerial level signed by Minister of oil- and energy Borten-Moe and his German counterpart Rösler last summer. A working group, dealing inter alia with long term secure storage development and regulations as well as public perceptions and communication issues, has been established. The working group will further explore options for carbon capture in the particular in the field of energy-intensive industrial sectors and CO<sub>2</sub> intensive fossil fuel power plants such as lignite and hard coal.

The following subsections offer a more detailed analysis of these issues.

### **10.3 Solutions until 2020**

Only a few CCS projects will probably be in operation in continental Europe before 2020. In the BASREC countries only Jänschwalde Power Plant in Germany and Belchatów Power Plant in Poland applied for and were granted the EEPR support. Jänschwalde has received exploration allowances for possible areas (Birkholz-Beeskow and Neutrebbin). But Vattenfall officially abandoned its demonstration project in Jänschwalde on Dec. 5th, 2011. Opportunities and costs for transportation and storage seem to be one of the issues.

The significance of the cost effective transportation and storage solution is highlighted in this section by some theoretical examples chosen by the authors of this report for the sake of illustration.

Jänschwalde Power Plant is located near inexpensive brown coal sources close to the Polish border and the project need to store about 1.7 Mtpa. Transportation to and storage in an onshore saline aquifer 200 km north of the plant is estimated to cost 8 -10 Euro/ton. With prohibition on onshore storage the costs of alternative solutions may be as in the following examples:

1. A single purpose pipeline to German North Sea sector and storage in a saline aquifer could cost 18 Euro/ton for transport and 14 Euro/ton for storage, all together 32 Euro/ton.
2. A single purpose line from Jänschwalde to a possible Baltic Sea saline aquifer storage site may cost about 20 Euro/ton + 14 Euro/ton for storage, all together 34 Euro/ton.
3. The Belchatów Power Plant in Poland could connect with the pipeline from Jänschwalde at the coast of Poland or Germany. Economics of scale for the offshore pipeline could then contribute to about 4 Euro/ton in cost reduction. The indicative cost increase resulting from not allowing onshore storage would still be in the order of 20 to 22 Euro/ton. This may be a significant obstacle for one of the few planned CCS projects in the pre commercial phase.
4. The Belchatów Power Plant is situated approx. 500 km south of the Baltic Sea, and faces about the same cost increases as Jänschwalde if the situation should arise that onshore storage is not allowed. Poland and Germany could theoretically find joint solutions for storage in saline aquifers in the German North Sea sector. A solution may then be to transport 2 Mtpa from Belchatów Power Plant in Poland to Jänschwalde in Germany, connect to a joint pipeline from Jänschwalde to Bremerhafen where a pipeline from Essen is connected before finally transporting 7 Mtpa to a saline aquifer in the German sector of the North Sea. If pipeline costs and storage costs are shared equally, the transportation cost from Belchatów

Power Plant to the North Sea aquifers can be estimated to 27 Euro/ton and storage cost 14 Euro/ton, 41 Euro/ton all together.

Possible restrictions on pipeline routing, the increased cost of crossing congested and populated areas, roads and other infrastructure are not taken into account.

Storage of CO<sub>2</sub> from Aalborg in an offshore oil and gas field may cost 16 Euro/ton, while storage at for instance Hanstholm may cost 4 Euro/ton for transport and 14 Euro/ton for storage, all together 18 Euro/ton.

The cost for transport and storage in this range may prove to constitute serious barriers for early stage commercial projects. The above figures are based on the INSA generic calculation tool which corresponds well with the results from the ZEP CCS cost study. The above calculations are assumed to capture the core of the economic problem. Detailed planning, engineering and final project implementation will result in deviating figures but probably not in a way essential for the discussions in this report.

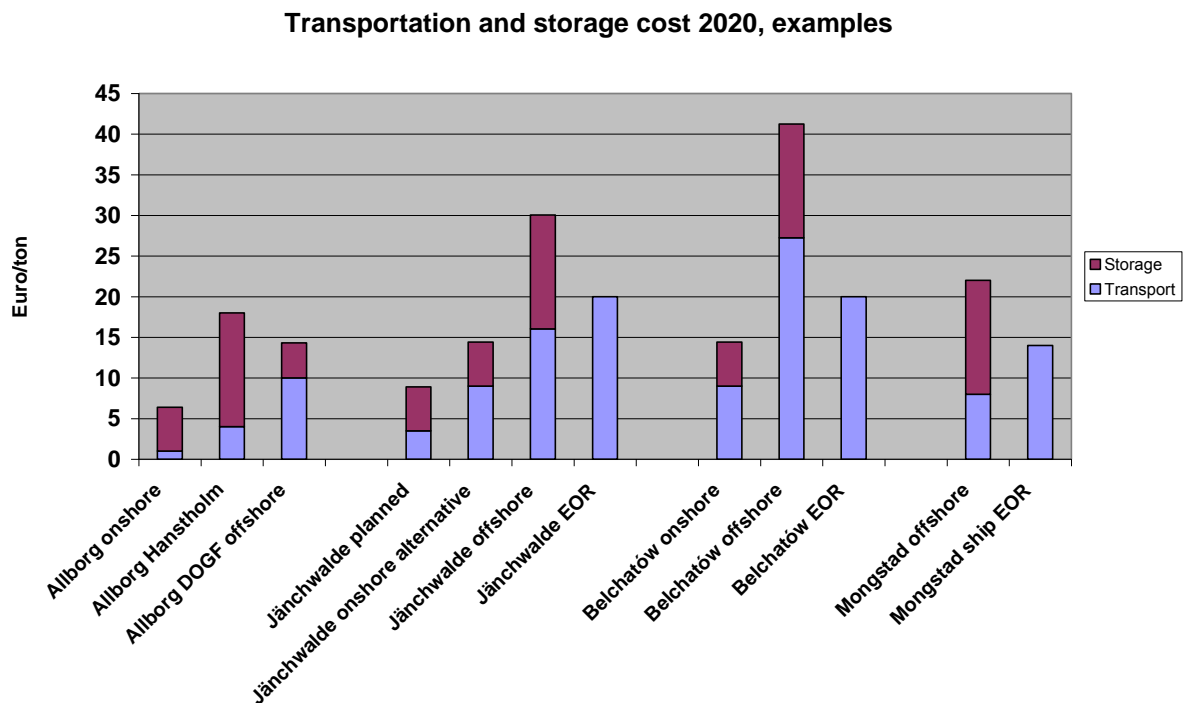


Figure 41: Examples of transportation and storage cost for single purpose solutions in 2020. (Source: INSA calculations)

Enhanced Oil Recovery (EOR) may offer opportunities for free or even paid storage and may therefore offer possibilities for early phase CCS projects. The CO<sub>2</sub> sources for such projects should preferably be located close to harbours. Cost of a single purpose pipeline to ports in the Baltic Sea plus shipping cost to an EOR project could be about 20 Euro/ton for Janschwalde and Belchatow.

## 10.4 Baltic Sea solutions

### 10.4.1 Latvian solution

As outlined in section 7 on storage opportunities, Latvia is the only nation with significant identified onshore and offshore economically viable storage capacity in the Baltic Sea region, and Latvia could contribute to cost effective joint solutions if storage is allowed. The storage sites may have a shorter timeline for clarification than other identified saline aquifers. Indicative costs of storage in the onshore aquifers are 4-5 Euro/ton if the information from the ZEP cost study is applied.

A possible joint project between Estonia and Latvia has previously been evaluated in connection with the GeoCapacity project.

In this project the expected 400 MW and 300 MW new and capture ready power blocks at Eesti and Balti Power plants were selected, capturing about 10 Mtpa. The plan was to transport CO<sub>2</sub> by pipeline co-routed with the gas pipeline from Russia to two storage sites in Latvia. Conservative estimates of storage capacity in these fields are 84 Mt, enough for 8 years of storage. The following table gives the estimated parameters of the project:

	Geocapacity	Indicativ	
Captured volume	10,7		Mt pa
Transportation distance	800		km
Cost of CO <sub>2</sub> avoided	37		Euro/tons
Transportation cost	5,3	8,5	Euro/tons
Storage cost	3	5,4	Euro/tons

Source: Alla Shegenova et al., INSA, ZEP

Transportation cost seems at first sight underestimated in the project calculations, but co-routing with existing gas pipelines may give significant savings on CO<sub>2</sub> transportation<sup>3</sup>. Storage cost estimates may also be on the low side. The difference is equivalent to the cost of site exploration and characterisation in the ZEP estimates.

The project will need new storage after 8 years and will use a large part of the onshore storage capacity if the conservative estimates prove to be right. Latvia may have significantly additional storage capacity offshore. Hence a pipeline should be prepared for offshore extensions. In this respect the project could nucleate a future transportation network in the region connecting to potential storage sites in the South Baltic Sea.

Due to the comparatively low estimated transportation and storage cost the project could be a good candidate for a joint BASREC cross border testing ground project for the whole CCS chain.

#### 10.4.2 Finnish and Swedish solution

An example based on the situation in Finland, both with regard to potential sources and sinks, can be used to illustrate some principle issues regarding transportation and storage of CO<sub>2</sub> in the BASREC region.

<sup>3</sup> But such co-routing may represent a hazard risk for the gas pipeline.

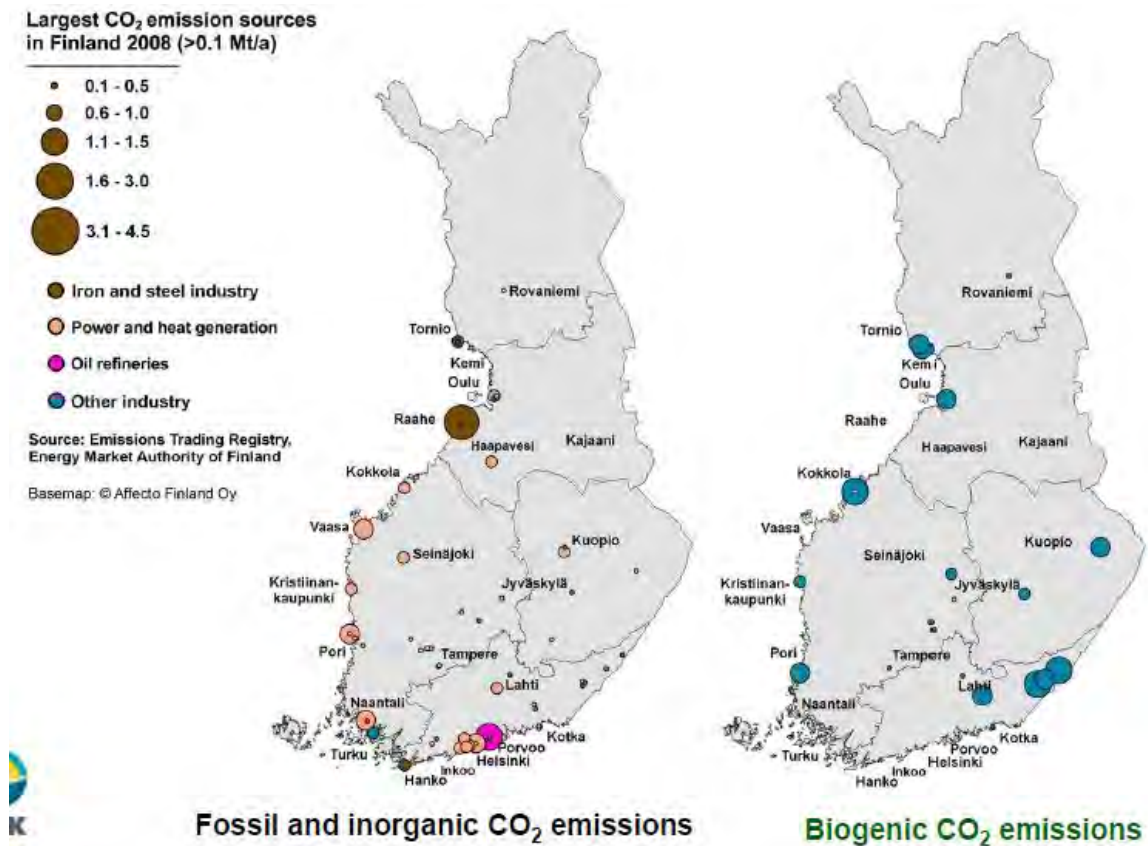


Figure 42: CO<sub>2</sub> sources in Finland. (Source: VTT research centre of Finland).

As can be seen from the above chart taken from a presentation of the research program FINNCAP, Finland has several large scale industrial and energy sources as well as refineries suitable for CCS along the coastline. Some large scale biogenic sources are located inland.

Main sources of CO<sub>2</sub> emissions in Finland are typically dispersed along the coast line. Finland has no suitable storage sites and must consequently transport and store CO<sub>2</sub> abroad. Options for storage of CO<sub>2</sub> from Finland may be saline aquifers in the South part of the Baltic Sea, offshore Denmark, in the underground under the Norwegian Sea or the North Sea, or even in the underground under the Barents Sea. Transportation can take place either by ship or pipelines.

We will now use transportation from Finland to illustrate how dispersed sources may affect the cost of transportation alternatives.

			Euro/tons CO <sub>2</sub>	
Pipeline distance to Hanko	Volum Mt pa	Distance to trunk line	Pipeline cost	Ship cost**
Kemi	0,2	856	34	19
Oulu	0,6	766	28	19
Raahe	4,6	706	24	19
Kalajoki	0,3	646	22	19
Kokkola	0,3	586	21	18
Pietarsaari	0,4	556	20	18
Vaasa	0,9	474	18	18
Pori	5,0	294	15	17
Rauma	2,0	252	14	17
Turku	1,0	165	13	17
Hanko to storage	-	1330	12	
Helsinki	3,0	117	14	17
Porvo	2,6	167	15	17
Kotka	3,0	227	17	17

\*shared section basis      \*\* assuming local collection system

(Source: INSA –model calculations)

The above table illustrates hypothetical capture volumes, the distance to a possible joint trunkline for transport to for instance the North Sea with the hypothetical departure from Hanko at the south coast of Finland. The last two columns show the transportation cost pr. ton of CO<sub>2</sub> if a) each source has to pay the shared cost of transportation on each segment of the pipeline used, or b) uses ship transport.

### Marginal cost for marginal volumes

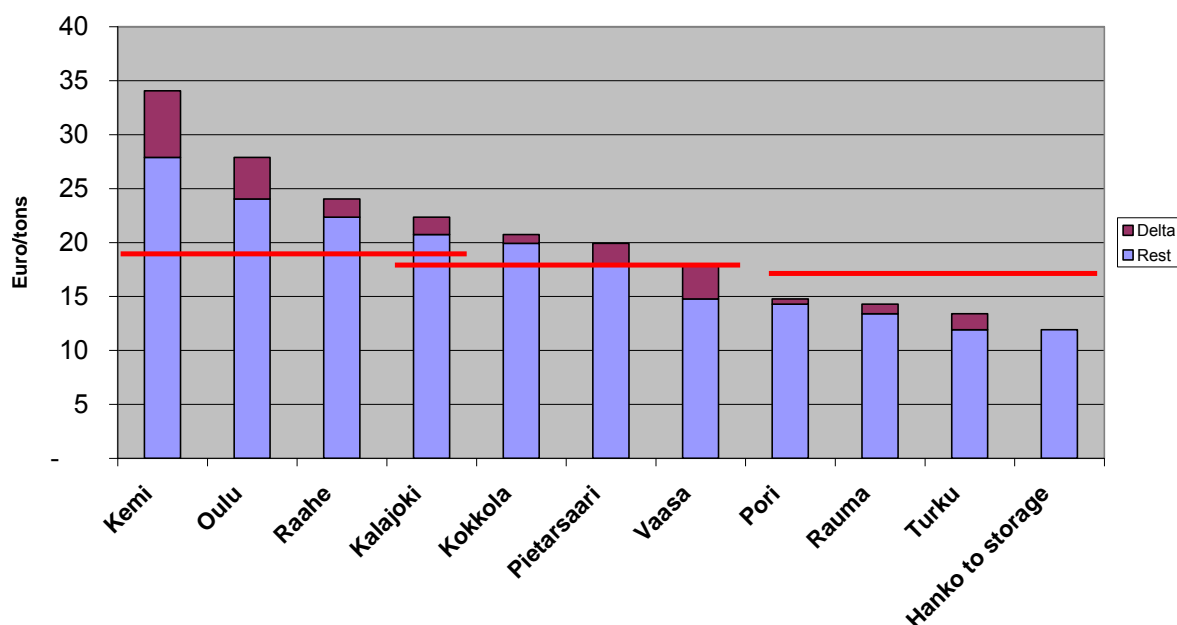


Figure 43: Cost of pipeline transport from Finland to North Sea storage sites on a shared cost basis for utilised pipelines. The bar to the right show unit cost for transportation in the 20 Mtpa CO<sub>2</sub> pipeline from the south end of Finland to the North Sea, while bars leftwards present increasing cost for more distant volumes. (Source: INSA-calculations)

With dispersed sources the feed line cost can become very high, and a combination of ships transportation for marginal volumes and pipeline transportation for the most dense source clusters may be a better solution. Such combinations require careful

consideration, coordination and planning as well as a large organisation to plan and implement.

ZEP CO<sub>2</sub> shipping transportation costs are considerably higher than assessed in earlier studies on the subject. This is probably due to the surge in construction costs from 2003 to 2007. Since all costs depend on when cost figures are gathered, it is difficult to draw conclusions about preferred transportation and storage solutions without detailed project knowledge.

Ramp up time and risk premiums will add to the cost of pipeline transportation. Hence transportation by ship may turn out to be the most cost effective solution for Finland, in particular if storage sites in the Baltic Sea prove difficult and costly to develop and joint solutions become too challenging to develop. Probably only CO<sub>2</sub> capture projects located close to the coast will be viable, since transportation costs from inland plants to shipment harbours will be high. The issue should be challenged and refined in a possible follow up project in collaboration with industrial and research partners. In Sweden, the potential capture sources on the east of Sweden also are located near the coastline. Hence the Finnish evaluation is also relevant for the east coast of Sweden. Sweden has substantial CO<sub>2</sub> emission at their west coast. The CCS solutions for this area will most likely include storage in the North Sea.

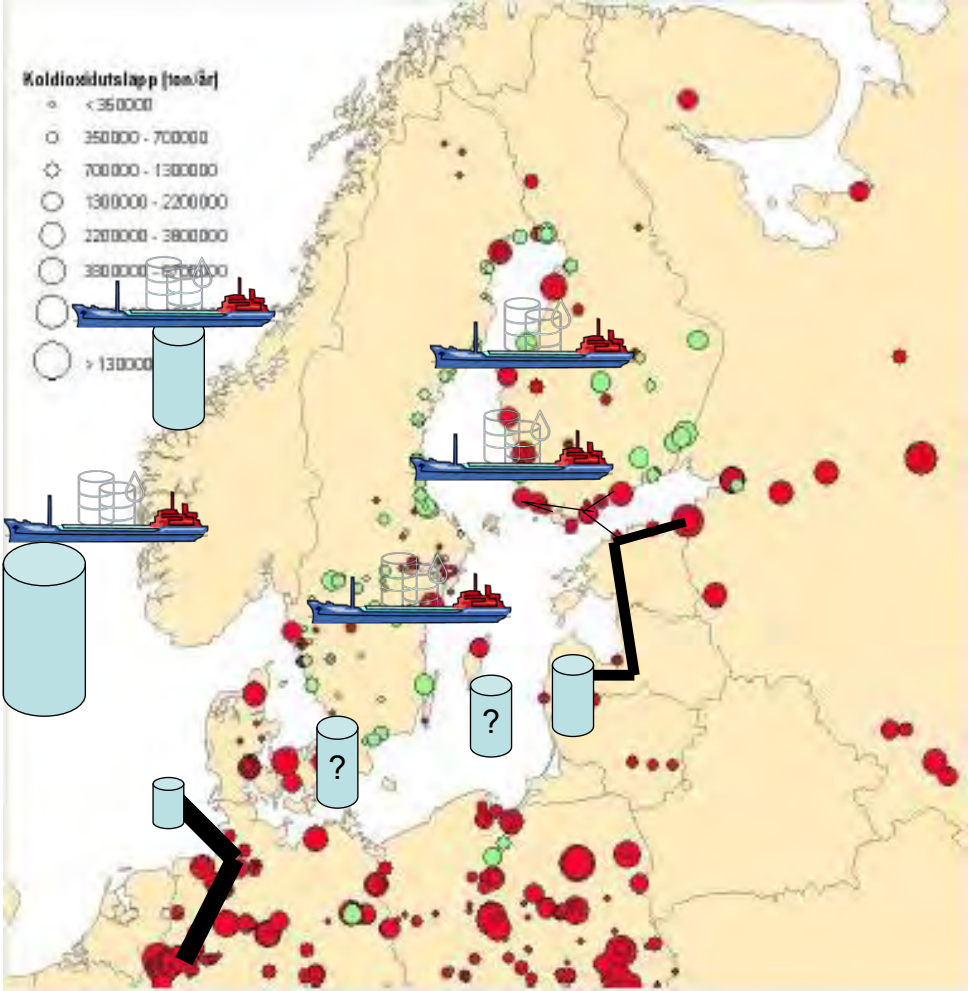


Figure 44: Possible joint transportation and storage solutions in BASREC countries in the early phase of system development. Red spots represent fossil emissions from power plants and industry. Green spots represent biogenic sources. Cylinders represent storage opportunities, and lines represent pipelines. Thickness of lines indicates transported volumes. (Source:INSA, Kjärstad-Chalmers, (Background map))



Even though ship transport may be the most cost effective solution for transport of CO<sub>2</sub> in the ramp up period for Sweden and Finland, the solution is relatively costly. The calculations indicate a cost of about 12 Euro/ton in shipping cost from a plant close to harbour along the coast to a storage site in the Baltic Sea and in the order of 15 Euro/ton to the North Sea. Once a shipping solution is chosen, cost differences between a Baltic Sea destination and North Sea are relatively small and availability of cost effective storage opportunities will be decisive for the choice of the actual storage solution. EOR/EGR with possible negative costs and/or depleted oil and gas fields within the storage cost range of 4-5 Euro/ton may be a preferred solution in a ramp up period towards 2030. Total cost may be in the order of 16 to 20 Euro/ton if suitable EOR project are not found.

A pipeline solution may be established if suitable storage opportunities are found in the southern part of the Baltic Sea. A variant of the solution calculated earlier in this report could be a pipeline from Estonia to the Helsinki area which connects to a trunk-line from the coast of Finland to a storage site in the Baltic Sea region. A feed line system from plants in southern Finland could collect about 10 Mtpa and a combined pipeline carrying 20 Mtpa to the storage sites in the Baltic Sea could be established. The collection system would on average cost about 4 Euro/ton and the trunk line about 5 Euro/ton. Development of storage in the saline aquifers in the Baltic Sea could cost in the order of 14 Euro/ton, hence total cost could be in the order of 18 to 25 Euro/ton.

Such a network could form the nucleus of a grand scheme for CO<sub>2</sub> transportation in the longer term in the BASREC nations.

## **10.5 Longer term system solutions**

A common Estonian/South Finnish system could as mentioned be connected with pipelines in the Stockholm area with feed in from Swedish sources along the east coast of Sweden, starting with CCS projects in the Stockholm area. This would imply an extra distance of about 100 km and extra costs of about 1 Euro/ton due to distance, but economics of scale will reduce the shared cost of transportation to the storage sites in the Baltic Sea by about 2 Euro/ton creating a possible net benefit of 1 Euro/ton. A connection via Sweden adds value for the real option to transport volumes through a future pipeline system in Sweden through Skagerrak to storage locations in Denmark and/or the North Sea. The Estonian, Finnish and Swedish trunk line also forms the nucleus of a transportation system to Russia and to the Norwegian Sea. Hence this trunk line illustrates the value of flexibility when options for future transportation and storage are taken into account. The alternative of storing CO<sub>2</sub> in Denmark instead of the Baltic Sea will increase the cost of trunk line transporting from 5 to 8 Euro/ton. Transportation to the North Sea will add additional 4 Euro/ton, resulting in a total trunk line transportation cost of 12 Euro/ton.

Due to the exploitation of economics of scale and scope, the cost differences for transportation may become less significant, while availability of cost effective storage capacity becomes relatively more important in a future when CCS becomes normal for fossil fuel and biomass power plants and process industries.

As illustrated in the figure below, uncertainty regarding acceptable storage sites is one of the main risk factors in development of future cost effective transportation and storage systems in the BASREC countries. This underscores the needs for clarifications. Uncertainty blurs the possibilities for efficient system planning. Regulatory risk is one of the main risk factors in this system. Only governments and parliaments can remove this risk factor.

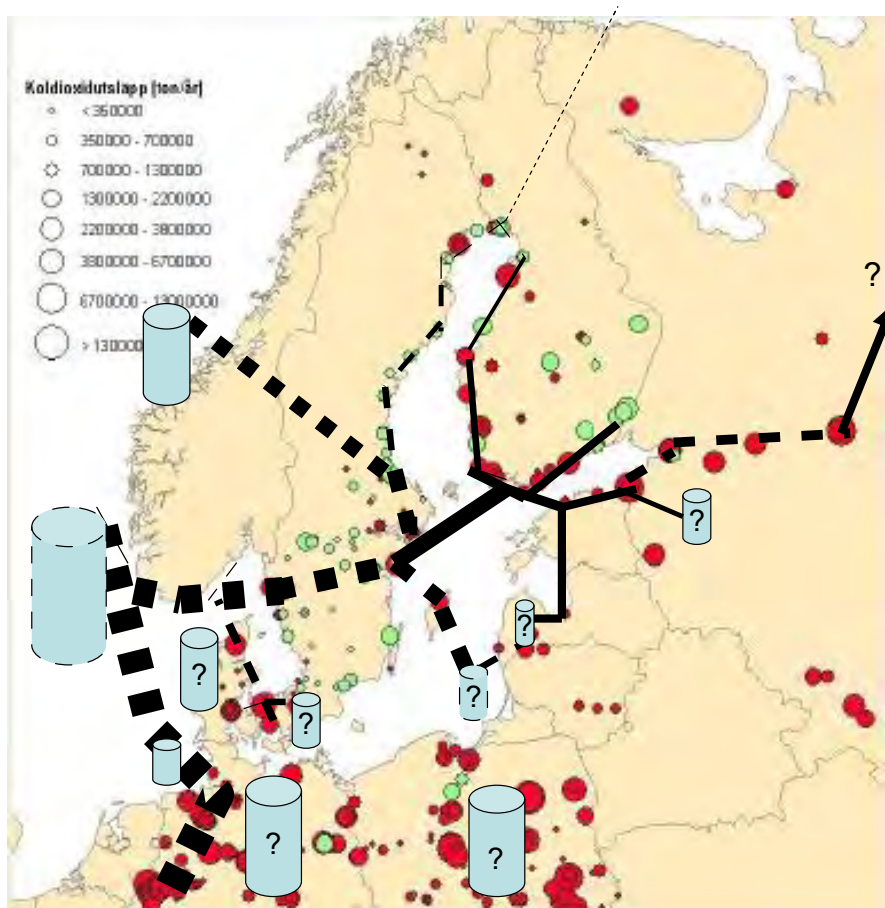


Figure 45: Possible future CO<sub>2</sub> pipeline system in the BASREC region.

## 11 Legal and regulatory requirements for CCS in the BASREC countries

### 11.1 Introduction

There has been performed extensive work on legal issues relating to implementation of CCS both in international organizations and on national level in several states. In this pre-study, we present an overview of status of work with regulations related to CCS, and point out the areas of work which, based on our analysis, are the most important to pursue further in BASREC countries in the short run.

Focus should be on the most relevant challenges. This means that if it is considered that storage possibilities first and foremost exist in a few identified areas and countries, then legal framework for storage should be developed in these countries, not all. Likewise, location of storage and sources will decide which national borders will be crossed, and consequently which states must cooperate to solve cross-border issues.

## **11.2 Overview, status legal framework**

### **11.2.1 Introduction**

In this pre-study, we give a short summary of work performed on legal issues regarding CCS within EU, IEA and on behalf of the North Sea Basin Task Force. While valuable work has been carried out also by several other organizations and states, we find that the regulations adopted and reports issued by the abovementioned organizations give a useful overview of central issues to be addressed by the BASREC countries.

The BASREC countries have to a varying degree implemented laws and regulations to govern CCS activities. We have issued inquiries to all BASREC countries, and replies have been received from a number of countries. Status for the work in the other countries is reported based on publicly available sources.

### **11.2.2 EU legal framework**

As described previously, there are three main elements in the CCS chain – capture, transportation and storage. Within EU, it is considered that only activities related to storage are in need of new regulation. With respect to capture and transportation, it is assumed that existing legal framework can be used, with some amendments to regulate these activities.

#### **11.2.2.1 The Carbon Dioxide Storage Directive and corresponding guidance documents**

The carbon dioxide storage directive (Directive 2009/31/EC) was adopted 23 April 2009. The directive covers all underground storage of CO<sub>2</sub> in EU, and contains requirements covering the entire lifetime of a storage site, from identification of a site as a potential storage location, until monitoring the site after injection has stopped and the storage is closed.

The member states are obliged to bring into force the laws, regulations and administrative provisions necessary to comply with the Directive by 25 June 2011. By that date, 12 of the 27 EU member states had actually adopted a law regulating underground storage of CO<sub>2</sub>. Four of the BASREC countries, Denmark, Latvia, Lithuania and Finland, met the 25 June deadline.

In order to aid the member states in their implementation of the Directive, four guidance documents were issued:

1. CO<sub>2</sub> Storage Life Cycle Risk Management Framework
2. Characterisation of the Storage Complex, CO<sub>2</sub> Stream Composition, Monitoring and Corrective Measures
3. Criteria for Transfer of Responsibility to the Competent Authority
4. Financial Security (Art. 19) and Financial Mechanism (Art. 20)

In these guidance documents, both the Competent Authorities and other stake holders, such as potential operators of storage sites, will find explanation of the background for, and elaborated comments on, the provisions of the Directive.

The main objective of the Directive, and of the guidance documents, is to ensure that potential storage sites are developed, managed, monitored and sealed off so as to minimize the risk of negative effects of CO<sub>2</sub> storages.

Article 1.2: The purpose of environmentally safe geological storage of CO<sub>2</sub> is permanent containment of CO<sub>2</sub> in such a way as to prevent and, where this is not possible, eliminate as far as possible negative effects and any risk to the environment and human health.

In Article 4, it is laid down that the right to determine the areas from which storage sites may be selected shall remain with the Member States. If a Member State intends to allow geological storage within its territory, an assessment of the storage capacity shall be undertaken. The suitability of a geological formation for use as storage site shall be determined through a characterization and assessment of the storage complex pursuant to specific criteria. Such criteria are specified in Annex 1 to the Directive, and are further described in Guidance Document 2. In order for a geological site to be selected as a storage site, there must be no significant risk of leakage, and no significant environmental or health risk.

In order to obtain the necessary information for selection of storage sites, Member States may determine that exploration is required. In such case, it is decided in Article 5 that a system with exploration permits must be implemented. No exploration shall take place without an exploration permit.

A system with storage permits is introduced in Chapter 3 (Articles 6 to 11). No storage site shall be operated without a storage permit. Pursuant to Article 7, the applications for storage permits must, in addition to characterization of the storage site and assessment of the expected security of the site, also include information regarding the total quantity of CO<sub>2</sub> to be stored and of possible sources, transportation methods and composition of CO<sub>2</sub> streams. Furthermore, the application must include a description of methods to prevent significant irregularities, a proposed monitoring plan, a proposed corrective measures plan and a proposed provisional post-closure plan. Finally, the application must also include information required under Article 5 of the environmental assessment Directive (85/337/EC), and proof that necessary financial security will be valid and effective before commencement of the injection.

The conditions for storage permits are stated in Article 8. Storage permits cannot be issued unless the competent authority is satisfied that all relevant requirements of the Directive and other relevant Community legislation are met, and that the operator is financially sound and technically competent. The competent authority shall, before issuing a storage permit, issue a draft permit, for the possible opinion of the Commission. The competent authority cannot issue a permit without considering the opinion of the Commission (if such opinion is rendered.)

The contents of storage permits are regulated in Article 9. The storage permits shall, i.a., contain the requirements for storage operation, the total quantity of CO<sub>2</sub> authorised to be geologically stored, the reservoir pressure limits, and the maximum injection rates and pressures. Furthermore, requirements for composition of the CO<sub>2</sub> stream must be stated. In addition, requirements regarding monitoring plans, notifying obligation and corrective measures plans, as well as conditions for closure and the approved provisional post-closure plan must be included. Finally, the permit shall contain the requirement to establish and maintain the financial security.

The Commission shall receive all draft permits, and have the opportunity to issue a non-binding opinion on the draft permits.

If the operation of the storage does not comply with the permit conditions, or if scientific development renders it necessary, the competent authority shall have the right to update or even withdraw the storage permit. (Article 11).

The requirements with regard to operation, closure and post-closure obligations are stated in Chapter 4 (Articles 12 to 20).

The acceptance criteria for the CO<sub>2</sub> stream are stated in Article 12. It is not allowed to add waste or other matter to the stream; it shall consist "overwhelmingly" of CO<sub>2</sub>. Other substances than CO<sub>2</sub> may be contained, but the amounts of such other substances must be small enough to avoid damage to the integrity of the storage site or the transportation infrastructure, and to avoid significant risks to the environment or human health.

In Article 13, the requirements for monitoring are stated. The Member States shall ensure that the operator of the storage site carries out monitoring necessary to verify both the actual behavior of the CO<sub>2</sub> in the storage site (as compared to the modeled behavior), and to detect any CO<sub>2</sub> migration or leakage. Monitoring is also required in order to detect any adverse effects on the environment, to assess effects of any corrective measures, and to update assessments of the long term safety and integrity of the storage site.

The operator is required to carry out extensive reporting. (Article 14). Reports on issues such as results of monitoring, the quantities and properties of CO<sub>2</sub> injected, and proof of financial security shall be submitted to the competent authority at a frequency decided by the competent authority.

The Member States are obliged to ensure that the competent authorities establish a system with routine and non-routine inspections (Art 15).

The Member States shall ensure that in the event of leakages or significant irregularities, the operator of the storage site shall immediately notify the competent authority, and take the necessary corrective measures. (Article 16). The competent authority may also take corrective measures, and if the operator fails to take corrective measures, the competent authority shall take corrective measures. The costs for corrective measures taken by the competent authorities shall be covered by the operator. The financial security can be drawn on for this purpose.

After a storage site has been closed, the operator has obligations with regard to monitoring, reporting and corrective measures, and also with respect to surrendering of allowances in case of leakages (Article 17). The obligations shall be fulfilled on the basis of a post-closure plan. If, however, the storage site has been closed by the competent authority after a storage permit has been withdrawn, the post-closure obligations rest with the competent authority. In such case, the competent authority shall recover the costs for fulfilling the post-closure obligations from the operator.

After a minimum period of 20 years after the storage site has been closed, and provided that certain conditions have been met, the responsibility for all legal obligations in the post-closure period shall be transferred to the competent authority (Article 18). Before such transfer can take place, the operator shall prepare a report documenting that all available evidence indicates that the stored CO<sub>2</sub> will be completely and permanently contained.

The Member States must ensure that the potential operator must provide proof that adequate provisions can be established, by way or for instance financial security (Article 19).

The operator must make a financial contribution available to the competent authority before transfer of responsibility (pursuant to Article 18) takes place (Article 20).

As for natural gas transportation systems, third party access shall be given to both CO<sub>2</sub> transportation network and storage sites. In chapter 5, the requirements for such third

party access and requirements regarding dispute settlement arrangements are stated. With regard to dispute settlements, special challenges emerge in the event of cross-border disputes. If more than one Member State has jurisdiction over the transport network or storage site to which the dispute relates, the "Member States shall consult with a view to ensuring that this Directive is applied consistently" (Article 22).

The issue of transboundary cooperation is also addressed in Article 24, where it is stated that the competent authorities shall jointly meet the requirements of the Directive and other relevant Community legislation in cases of transboundary transport of CO<sub>2</sub>.

In Chapter 7 of the directive, amendments to several other EU directives are decided. These amendments are i.a. related to directives regulating waste management. By amending these directives, a number of uncertainties regarding transportation of CO<sub>2</sub> are removed. The most important of these amendments are contained in Article 35, whereby CO<sub>2</sub> captured for geological storage is excluded from the definition of "waste" in the Waste Framework Directive.

### **11.2.2.2 Other amendments to existing EU regulations**

In addition to the amendments to other Directives contained in the storage Directive, a separate Directive 2009/29/EC was adopted amending directive 2003/87/EC with the aim to improve and extend the greenhouse gas emission allowance trading scheme (ETS) of the Community to ensure that allowances must be surrendered for any emissions resulting from leakage of CO<sub>2</sub> from transportation or storages. By amending the greenhouse gas ETS directive, leakages of CO<sub>2</sub> from transportation or storages are dealt with as other emissions of CO<sub>2</sub>. The amendment also ensures that CO<sub>2</sub> emissions which are captured, transported and stored according to the Storage Directive will be considered as not emitted.

### **11.2.2.3 Relevant regulations at Member State level**

Liability for damage to health and property is not regulated at Community level, but is left for regulation at Member State level. When Member States develop amended regulations in order to regulate such liability for damage to health and property, this is at the same time an opportunity to increase information, knowledge and awareness amongst the population with regard to potentially controversial issues.

## **11.2.3 IEA Legal and Regulatory Review and Model Regulatory Framework**

IEA has performed extensive work to identify and address regulatory issues that must be solved in order to provide basis for deployment of CCS projects. The second edition of the IEA Legal and Regulatory review regarding Carbon Capture and Storage was issued in May 2011. In this review, status for CCS regulatory measures is presented for individual nations, the EU, and international organizations.

IEA has also issued an information paper: Carbon Capture and Storage, Model Regulatory Framework, in November 2010.

In the November 2010 information paper, 29 key issues relating to CCS regulatory frameworks are presented. Of these 29 issues, 14 are characterized as CCS-specific regulatory issues:

1. CO<sub>2</sub> capture
2. CO<sub>2</sub> transportation
3. Scope of framework and prohibitions
4. Definitions and terminology applicable to CO<sub>2</sub> storage regulations
5. Authorisation of storage site exploration activities
6. Regulating site selection and characterization activities
7. Authorisation of storage activities
8. Project inspections
9. Monitoring, reporting and verification requirements
10. Corrective measures and remediation measures
11. Liability during the project period
12. Authorisation for storage site closure
13. Liability during the post-closure period
14. Financial contributions to post-closure stewardship

As can be seen, the information paper lists the same main issues as regulated in the EU storage directive (apart from the two first issues, CO<sub>2</sub> capture and CO<sub>2</sub> transportation).

It is clear that understanding of what issues must be solved is quite the same in different international forums, the challenge is not to identify what issues must be solved, but rather to ensure that activities are actually performed to implement the necessary regulations. The issuance of the Model Framework will aid the implementation of necessary regulations in countries outside EU.

With regard to CO<sub>2</sub> capture and CO<sub>2</sub> transportation, it is also stated in the IEA information paper that many of the issues related to these activities may be regulated through appropriate amendments to existing regulations.

## **11.2.4 Report for The North Sea Basin Task Force**

In the report "One North Sea", prepared by Element Energy for the Norwegian Ministry of Petroleum and Energy and The UK Foreign and Commonwealth Office, on behalf of The North Sea Basin Task Force (member states UK, Germany, the Netherlands and Norway), several issues, including legal and regulatory issues, relating to the potential cross-border transportation and storage of CO<sub>2</sub> in the North Sea are addressed.

One of the important findings of the report is that depending on how they are implemented, some of the elements of the CCS Directive may actually make economic deployment of CCS less likely. It is therefore stated that it is important to engage industry and, where possible, implement the Directive coherently. Although the report addresses issues related to the North Sea, it is no reason to disregard the risk that different implementation of the Directive in different countries may impose barriers to the roll-out of CCS projects also in the BASREC countries.

## **11.2.5 Status within the BASREC countries**

### **11.2.5.1 Introduction**

Several of the BASREC countries have already adopted, or are very close to adopting, laws to transpose the Storage Directive into national legislation. In the following subsections, status in each of the BASREC countries is addressed, as basis for assessments of necessary actions.

### **11.2.5.2 Denmark**

The Parliament in May 2011 adopted a law to implement the Storage Directive. The implementation of the Storage Directive is obtained by amending the law on exploitation of the Danish underground. The amendment provides the regulatory framework for underground storage of CO<sub>2</sub>. Also, more detailed regulations are provided for the technical criteria to be fulfilled when applying for storage permissions.

Even though the regulatory framework is provided, there has not been any political decision to open up for storage of CO<sub>2</sub> into the Danish underground. There is political agreement in the Parliament that before storage of CO<sub>2</sub> is permitted; the issue must be subject to a principle political assessment in the Parliament. In connection with adoption of the regulatory framework, it was hence clearly stated by the climate and energy minister that storage of CO<sub>2</sub> will not be permitted until more experience is gathered from storage projects in other countries. It is believed that this may happen around 2020.

The opposition against onshore storage of CO<sub>2</sub> has been particularly strong, and for the time being it is considered very unlikely that onshore storage of CO<sub>2</sub> will be permitted.

Amongst several political parties, there is strong principle resistance against storage of CO<sub>2</sub> from petroleum production. This resistance is based on the notion that allowing storage of CO<sub>2</sub> from oil and gas production will hamper the transition to renewable energy.

However, using CO<sub>2</sub> for the purpose of enhanced oil recovery is considered more positive by several of the political parties, and it is assumed that if storage of CO<sub>2</sub> is at all allowed, use of CO<sub>2</sub> for enhanced oil recovery will be amongst the first projects.

Also, the possibility of storing CO<sub>2</sub> from bioenergy is viewed as more positive than storing CO<sub>2</sub> from oil and gas production.

### **11.2.5.3 Estonia**

Estonia has assessed that there are no suitable geological storage sites within their territory. Estonia is in the process of adopting a CCS law whereby storage of CO<sub>2</sub> will be prohibited within the Estonian territory.

### **11.2.5.4 Finland**

There are no areas considered suitable for storage of CO<sub>2</sub> in Finland, and therefore, transposition of the CCS Directive has not caused many problems, as it is not necessary to regulate any storage activity. Finland has transposed the CCS Directive into Finnish law.

### **11.2.5.5 Germany**

On July 7<sup>th</sup> 2011, the German Parliament (Bundestag) approved a bill for a CCS Act that was intended to implement the storage Directive. However, the Federal Assembly (Bundesrat) rejected the draft CCS Act on September 23<sup>rd</sup> 2011. Currently the Bundestag and the Bundesrat are trying to reach a compromise within a conciliation committee.

A first Draft Law in 2009 was intended to open up for full scale commercial deployment of CCS. The legislative process coincided in time with the first exploration activities in Schleswig-Holstein by RWE. This exploration activity triggered unexpected public



resistance. The public was concerned about risks of leakage, pollution of drinking water and long term safety, and the land owners were concerned about infringement of property rights. The lack of public acceptance resulted in postponement of the legislative process, and also in significant amendments to the proposed law. As a consequence, the draft law adopted by the Bundestag only regulated demonstration projects by restricting the amount of CO<sub>2</sub> per storage site and nationwide (thus allowing a max of three medium sized demo projects).

Despite this restriction, several German states, among these Schleswig-Holstein and Niedersachsen, demanded a right for the states to exclude demonstration of CCS from their territory. In the draft law adopted by the Bundestag, it was included a so called states' clause, pursuant to which the States shall be allowed to exclude parts of their territory from the storage of CO<sub>2</sub>, if based on reasonable grounds. The state of Brandenburg opposed to this clause, as this might imply that Brandenburg became the storage site for CO<sub>2</sub> for whole Germany. Pursuant to the draft law, application for demonstration projects must be made before the end of 2016. Annual storage capacities of an individual site must not exceed 3 million ton of CO<sub>2</sub>, and total annual capacity must not exceed 8 million ton.

#### **11.2.5.6 Iceland**

Iceland has, to our knowledge, not started a legislative process yet. Iceland has only limited suitable storage locations (no deep sedimentary rocks), but this limited potential storage capacity will still be sufficient to store CO<sub>2</sub> from Iceland sources for about 200 years. See chapter 7.2.6 on the alternative storage technology project at Iceland.

#### **11.2.5.7 Latvia**

Latvia has recently adopted a law whereby CO<sub>2</sub> storage is prohibited within Latvian territory until 2013. The question will then be subject to renewed considerations. Possible conflict with natural gas resources and storage, environmental issues etc will be taken into account. There is currently no interest for storage by Latvian companies, as Latvian power production and industry only use coal to a very small degree. Possible storage of CO<sub>2</sub> in Latvia will consequently be a result of agreements with neighboring countries wanting to utilize Latvian storage capacity. This will require bilateral or multilateral agreements between the nations involved.

#### **11.2.5.8 Lithuania**

Based on the answer to our inquiry, the following can be stated for the implementation process in Lithuania:

Currently there are no CCS facilities deployed in Lithuania, nor are there CCS projects developed or planned.

Lithuania is implementing the Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the Geological Storage of Carbon Dioxide via the Law on Geological Storage of Carbon Dioxide of the Republic of Lithuania of 2011, as well as via the Lithuania's Law on Waste Management, Lithuania's Law on Environmental Protection, Lithuania's Law on Environmental Impact Assessment of Planned Economic Activities, and via numerous other legislation (up to 30 laws and other type of acts).

The Ministry of Environment of the Republic of Lithuania, together with the Lithuanian Geological Survey under the Lithuanian Ministry of Environment, in 2011 have prepared a number of legislative act projects connected with CCS, such as the following Lithuanian Governmental decision projects needed for the Law on Geological Storage of Carbon Dioxide of the Republic of Lithuania to be implemented:

- "On the Approval of the Exploration Methodology Description on Geological Storage Facilities for Carbon Dioxide and Usage and Closure of such Storages";
- "On the Amendment of the Approval of the Bowel's Register Guidelines";
- "On the Supplementation of the Regulations on the Exact National Fee Amounts and their Payment and Refunds"

The Lithuania's National Program of Geological Exploration for the period of 2011-2015, named "Explorations of bowel's spatial, renewable and unconventional resources (Geological resources)", encompasses a target to gather data on geological characteristics of a possible carbon dioxide storage facility and its surroundings. The other target is to assess the suitability of a potential CCS facility for Lithuania's environment. In 2011, the Lithuanian Geological Survey has started a project aimed at summarising and analysing the geophysical data from the Lithuania's western region, as well as seismic exploration data and data gathered from geophysical exploration wells.

In 2008, a feasibility study "Carbon dioxide capture, transportation and storage in geological structures according to the guidelines of the Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the Geological Storage of Carbon Dioxide" was prepared.

#### **11.2.5.9 Norway**

The Storage Directive has not been included in the EEA-agreement, but the directive is considered to be EEA-relevant, and Norway has taken steps towards implementing the Directive into Norwegian legislation.

Offshore storage of CO<sub>2</sub> takes place in two areas offshore Norway, and Norwegian authorities have invited the industry to nominate areas for exploration activities.

Norway will implement a system for exploration and production licenses for CO<sub>2</sub> storages, in line with the system for exploration and production licenses for the petroleum activities. A regulation under the governing the law for exploitation of resources on the Norwegian continental shelf was adopted in 2009. By this regulation, a concession system for future CO<sub>2</sub> storage is envisaged.

The responsibility to implement the Directive in Norwegian law is delegated to three ministries; the Ministry of Petroleum and Energy, the Ministry of Labour, and the Ministry of the Environment.

#### **11.2.5.10 Poland**

Poland is in the process of transposing the CCS Directive into Polish Law. However, during the transitional phase, until 2026, only demonstration projects will be allowed. The transposition will take place first and foremost by amending the existing laws rather than by creating new laws.

### **11.2.5.11 Russia**

Russia has not yet, to our knowledge, established policies or regulations to provide incentives for development or implementation of CCS technologies.

In Strategic Analysis of the Global Status of Carbon Capture and Storage, report 3, it is stated that for the time being, new CCS specific legislation is not being developed.

CCS projects are expected to be governed by Russian legislation already regulating environment protection, oil and gas activities and climate change. This legislation is characterised as a combination of rules and procedures, and not as a solid framework. One of the laws which will govern potential CCS activities is the law for protection of the environment and the atmosphere. The law obligates private parties to acquire environmental permits and follow emissions standards. Payment for exceeding such standards is the main regulatory mechanism used to enforce the scheme.

Russia has started to consider the spheres in which the CCS may be implemented effectively and is trying to create legislation closer to European standards.

### **11.2.5.12 Sweden**

For the time being, storage of CO<sub>2</sub> in Swedish territory is prohibited. This is only a temporary solution in order to be in compliance with the time limit to implement the CCS directive. A law proposal was sent for comments from the Environment Department 23 November 2010, and comments were received within 17 January 2011. Originally, it was planned that the law should be adopted before 23 June, but this has now been postponed. Currently, it is expected that new regulation will not be adopted before end of 2011.

The proposed law implementing the Storage Directive only opens up for offshore storage; the storage possibility in the southern part of Skåne is for the time being excluded from use as CO<sub>2</sub> storage. It is however assumed that the situation may be altered when Sweden has developed legislation regarding underground property rights and regarding possible conflicts with geothermal, groundwater and petroleum interests.

One big obstacle to offshore storage in Sweden is that the most prospective storage possibilities seem to stretch out to Russian territory. According to the CCS directive (Article 2.3), storage of CO<sub>2</sub> in storages which stretch out to territories outside EU may not be permitted. This implies that potential storage in storages which stretch beyond EU territories require special cooperation between the nations involved, and special treatment within EU.

## **11.3 Conclusion**

Based on the perusal of the legislative processes on international and national levels, it can be concluded that even though solid work has been carried out in international organisations and in EU, the problems with establishing national frameworks for CCS activities may constitute a very substantial obstacle for realizing CCS projects. Several of the BASREC countries have identified locations which may be suitable for geological storage of CO<sub>2</sub>, but instead of opening up for qualification of such storages, they have decided to wait for experience from other countries. If this continues to be the case, it will not be possible to realize CCS projects with the speed necessary to achieve the goals set in the IEA CCS roadmap.

## **12 Public acceptance and perceptions**

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### **12.1 Introduction**

Public objections have already resulted in serious difficulties and cost increases for development of CCS pilot and demonstration projects. In the longer run objections to onshore storage will reduce long term storage capacity and increase the costs and risks of CO<sub>2</sub> transportation and storage services. The average cost difference between the reference scenario and the "offshore only" could be in the order of 14 Euro/ton in 2030 and 25 Euro/ton in 2050, reflecting the increased transportation length and use of more costly offshore storage.

The opposition to onshore storage may be transitory but uncertainty creates significant risks for planning of transportation and storage. The awareness that a change in public opinion may at a later stage reduce the need for the costly parts of the transportation system, causes the investors to try to delay investments in order to get more information before investments are committed.

Public engagement and acceptance is critical. A variety of issues require public support including:

- political support for government incentives, research funding, long-term liability, and the use of CCS as a component of a strategy to combat climate change;
- property owners' co-operation to obtain necessary permits and approvals for CO<sub>2</sub> transport right-of-way and CO<sub>2</sub> storage sites and
- local residents' informed approval of proposed CCS projects in their communities.

Public awareness about CCS is currently low, which has in part led to low public support for government programmes and for funding which promotes CCS.

The public generally has not yet formed a firm opinion of CCS and its role in mitigating climate change. The response from environmental NGOs has until now been mixed, ranging from opposition (groups like Greenpeace) to acceptance (Bellona and others), with other organisations such as the WWF in the middle. To help inform the debate, it is vital that government and industry actors significantly expand their efforts to educate and include key stakeholders.

### **12.2 Public concerns**

Three classes of concerns are particularly relevant to public acceptance of geological storage of CO<sub>2</sub>.

The first relates to human health, safety and groundwater supply and pertains mainly to storage on land.

The second relates to consequences for terrestrial or marine ecosystems due to the risk of leakage.

The third concerns the energy and climate policy aspects of a CCS strategy.

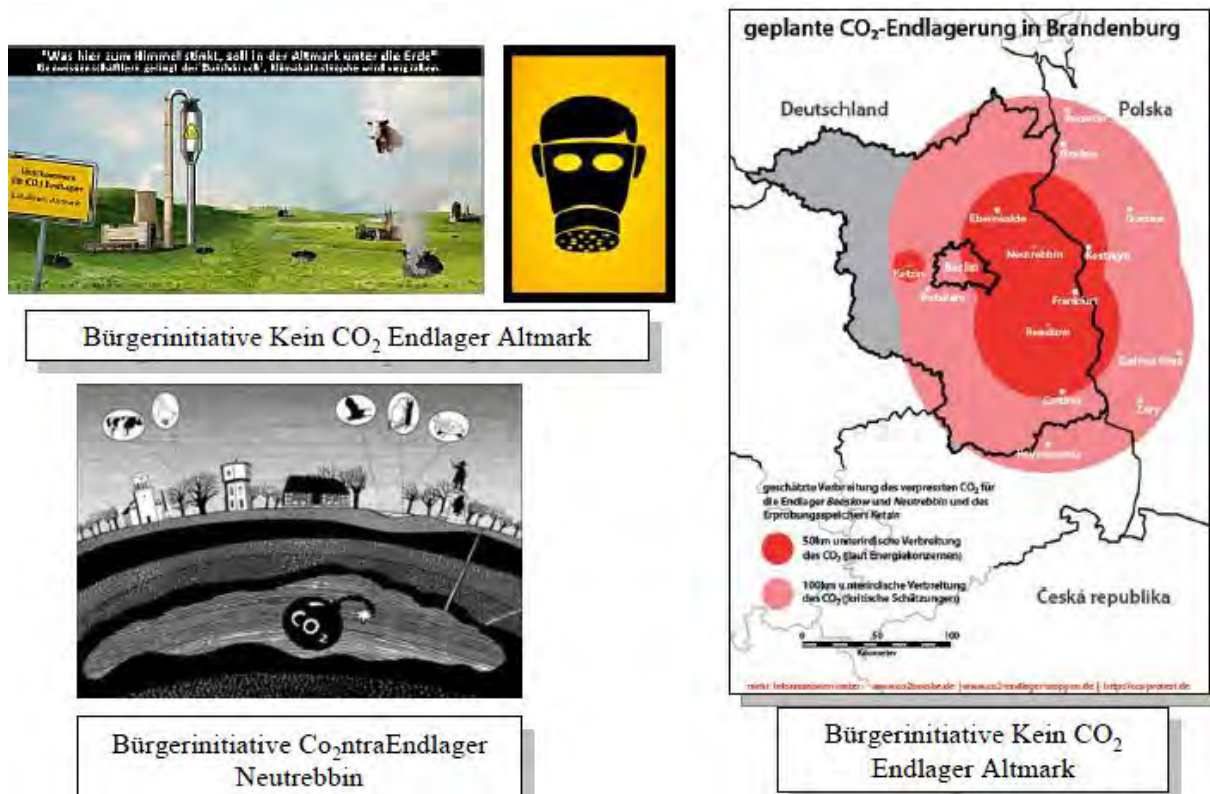


Figure 46: Posters against CO<sub>2</sub> storage. Opponents often use strong measures in their campaign against CO<sub>2</sub> underground storage.

As a general observation, the public is likely to be a lot more worried about storage in geological formations under inhabited land areas than about storage under the seabed. This is because on land, health and safety concerns for people are added to the list of potential problems, along with contamination of freshwater aquifer resources. In case of accidental and abrupt release of large amounts of CO<sub>2</sub>, people in the close vicinity fear that they may suffocate.

Depending on local geological conditions, contamination of groundwater and induced seismic activity (small earthquakes) is possible in a worse case scenario, but is still a less dramatic consequence of CO<sub>2</sub> storage (IPCC 2005). Experience with natural gas storage in geological structures suggests that these issues may be manageable, but likely to cause "NIMBY" (Not In My Back Yard) reactions.

In Denmark, there has been strong opposition against geological storage of CO<sub>2</sub> on land, and the Parliament recently decided to postpone any CO<sub>2</sub> storage until more experience is gained.

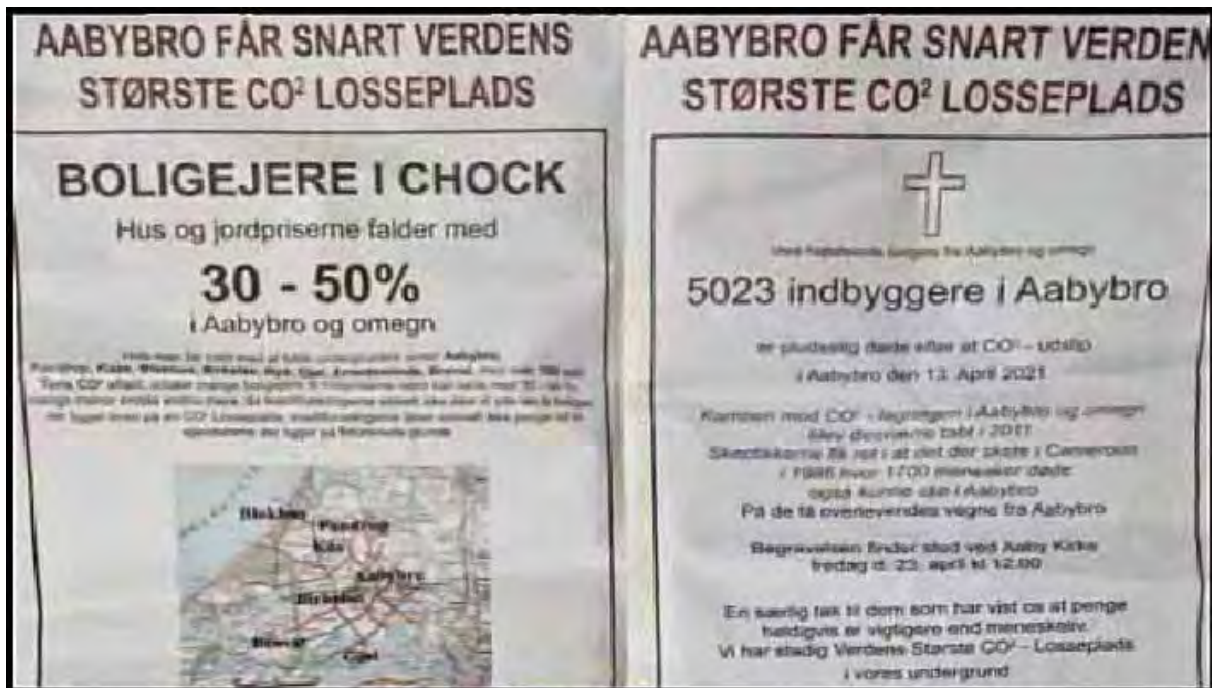


Figure 47: Campaign against CO<sub>2</sub> storage

Indication of worries about local effects is also found in an inquiry about CO<sub>2</sub> storage among 112 residents in a part of the Netherlands subject to small earthquakes induced by underground natural gas storage.

Whether ecosystem effects will be a major concern for public opinion is perhaps less predictable, and will to a large degree depend on the positions adopted by experts and organized interests such as ENGOs. The discussion in OSPAR of the geological storage issue has not generated a lot of public attention this far.

It is safe to assume that both climate and energy policy consequences of any CCS strategy will certainly generate public debate. Relevant aspects of these discussions are mentioned in connection with the positions of ENGOs above.

### 12.3 Building Public Acceptance - Lessons Learned

From previous experience, there are several lessons to be learned

- Public perception may be heavily influenced by early CCS demonstration projects.
- Governments must take a leading role, establishing clear regulatory responsibility for CCS project evaluation, approval and monitoring. It is expected that public acceptance will increase if governments take a clear responsibility for addressing the different risk elements in CO<sub>2</sub> transportation and storage.
- Governments (and project developers) must use effective communication techniques to engage and educate different audiences including the public, the NGO community, local environmental groups and media, with special attention paid to developing guidelines for local community consultation for proposed CCS projects.

- The public acceptance will be influenced by climate change perceptions. CCS should be clearly communicated as an essential long-term climate change mitigation technology that is being deployed along with other important technologies, including renewable energy, energy efficiency, etc.
- Experience from other public engagement issues shows that confidence in the information given will be important. Hence approval by independent institutions is important. The integrity of the institutions giving information is essential, and information from players with economic stakes in the issue will be of less value.

A recent study by Carbon Sequestration Partnership (RCSP) in the USA shows that public understanding of technical issues seems to be less important than commonly believed by industry and governments. The most important factors seem to be the trust people have in the developer, the regulator and government with regard to their perceived ability to

- deliver truthful information and safe projects
- operate a transparent and fair decision-making process addressing adequately legitimate concerns
- be accountable should things go wrong and
- treat local public fairly with respect to distribution of economic benefits and hazard

Common questions to be answered are

- Where can the CO<sub>2</sub> be stored?
- How will CO<sub>2</sub> storage be conducted?
- What impacts could storage have on environment and human health?
- Will the CO<sub>2</sub> stay underground?
- What happens when CO<sub>2</sub> leaks?
- How will storage be monitored?
- How can leakage be detected?
- How can leaks be fixed?
- Under which circumstances can concentration of CO<sub>2</sub> be hazardous?
- What has happened, and how often, what were the consequences?

These issues should be carefully dealt with in licensing and permitting processes.

Since evidence from different countries suggests that very few are familiar with CCS it is easy to create misperceptions about the danger of CO<sub>2</sub> transportation and storage. Several studies show that while people are often enthusiastic about various climate policy measures such as energy efficiency, renewable energy sources and terrestrial sequestration (forests), they are much more sceptical about CCS.

It is further important to understand that the local public is one of the key stakeholders in CO<sub>2</sub> storage and transportation. Those are the ones directly affected and who must be convinced in order to accept the safety of the storage and transportation project. Both local public and politicians ask the question: What is in it for us?

The local council objected to the Shell plan to store CO<sub>2</sub> in the depleted gas field under the town of Barendrecht, near Rotterdam. This was despite a successful environmental impact assessment and the enthusiastic backing of the Dutch government.

The oil company Total made a great effort to engage the local community when it launched its CCS pilot project in Lacq, southern France, and was successful.

## **12.4 Environmental movements**

The environmental movement plays a key role in shaping public opinion on CCS, mobilising the public for or against CCS projects and influencing the positions of governments. Such a role is facilitated by the largely unformed public opinion on this issue, and the high level of trust enjoyed by ENGOs.

Many ENGOs point to the risk that storage sites might leak and release large amounts of greenhouse gases to the atmosphere. Furthermore, they are concerned that public funding for research, development and demonstration (RD&D) of CCS technologies as well as incentives for their deployment might replace support for renewable energy and energy conservation. Some argue that if CO<sub>2</sub> is used for enhanced oil or gas recovery, the increased supply of fossil fuels will cancel out the climate effect of CCS.

The major international groups, Greenpeace, WWF and Friends of the Earth International (FoEI) have expressed strong scepticism towards a CCS strategy. Greenpeace holds the strongest negative views. There are, however, some indications that important ENGOs which are active in countries where CCS is seriously considered as a policy option are warming to the idea.

## **12.5 The relativity of public acceptance**

The alternative to CCS in reaching the long term targets will be enormous roll out of wind power and bio power. Such enormous roll out may create increased public oppositions, thus making CCS relatively more acceptable.

# **13 Organising and incentivising the CCS chain**

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## **13.1 Introduction**

In the current environment, commercial fossil-fuel power and industrial plants are unlikely to capture and store their CO<sub>2</sub> emissions, as CCS reduces efficiency, adds costs, and lowers energy output. Current costs of emissions permits is much lower than the expected CCS chain cost for a coal fired power plant.

CCS chain development is driven inter alia by pre-investments and perceived value of business options if and when CCS becomes profitable. The current outlook for international cooperation and agreements reduces such incentives. CCS activities will furthermore be influenced by possible longer term distortions in competitions between different solutions. Even within the EU, which has carbon constraints in place, the benefits of reducing carbon emissions are in most cases not yet sufficient to outweigh the costs of CCS.

These barriers can be partially overcome by government support in the form of tax incentives. Even then, new technology and the lack of sufficient business incentives to bear the cost of CCS, imply that there must be significant government and industrial financial support to facilitate CCS.

A wide penetration of CCS will require such support at all stages of project development, including near-term demonstration project financing.



For investors, regulatory risks contribute significantly to over all projects costs and reduce expected project values. Development of coherent transparent and efficient regulations will foster CCS chain development.

This section describes the options available to governments and industry to finance CCS.

## **13.2 Possible schemes**

For CCS to achieve its full potential, power plant and industrial plant investors must be able to justify the additional cost of CCS when they are selecting new technologies and constructing new plants. For this to happen, the cost of eliminating any fossil-fuel related CO<sub>2</sub> emissions must become an inherent part of all projects in the power and industrial sectors. A number of different policy tools have been suggested to achieve this, including:

- a GreenHouse Gas (GHG) cap-and-trade system (ETS);
- a CCS energy support scheme like feed in tariffs and green certificate systems
- mandating CCS for new (and/or retrofit of existing) fossil fuel plants;
- creating a dedicated CCS Trust Fund to manage CCS investments.

### **Application of the ETS**

The ETS (emissions trading system) is considered by the European Commission (EC) to be a principal policy instrument for encouraging future CCS activities within the EU. The first EU Emission Trading Directive (Directive 2003/87/EC) was amended in 2009, by Directive 2009/29/EC. Pursuant to the revised ETS directive, CO<sub>2</sub> emissions captured in qualifying CCS operations are recognised and counted as CO<sub>2</sub> that is not emitted. Consequently CO<sub>2</sub> certificates will not have to be purchased by CCS power plants, giving CCS plants a comparative advantage over power plants not using CCS. For the third phase (2013-2020), full auctioning of CO<sub>2</sub> certificates is proposed for the electricity sector. This will provide better incentives for investing in CCS and other low or non carbon technologies than a system allowing free allocations.

The directive also includes the provisions for the NER 300 mechanism, where 300 million allowances are set aside and sold on the market. The income will be used to subsidise installations of innovative renewable energy technology and CCS. It is required that eligible projects are sufficient in scale, are sufficiently innovative in nature, that they are significantly co-financed by the operator and that an agreement on knowledge sharing is in place.

### **Other mechanisms**

As outlined in this report the current regulations and incentive systems does no seem to provide sufficient dynamics in the CCS chain development. Additional mechanisms could be to include CCS projects in a feed in tariff system or in the green certificate systems in the period up to 2025-30. This may in particular be relevant if such a system is extended to new countries in the BASREC area.

An introduction of a mandatory system for new and/or existing CO<sub>2</sub>-emitting sources can in theory regulate the CO<sub>2</sub>-emission. However, the Commission's January 2008 proposal does not propose that CCS be explicitly mandated in any form or for any processes. Rather, it allows the market to drive the uptake of CCS.

The NER 300 functions as a dedicated CCS trust fund in order to help the start up of the CCS chains. Additional funding could be considered for the first CCS chain in the BASREC area. The object of such funding is to reduce the risk for private entities involved in establishing the first CCS chain. Such additional trust Fund must be governed by the financing countries.

Additional mechanisms as those mentioned above could help bridge the gap in the CCS technology development period when costs and risks are high and emission prices too low.

In the longer run, a cap and trade system with caps in conformity with the 2°C target should result in sufficiently high prices on CO<sub>2</sub> emissions to make CCS projects profitable without further support, insofar as CCS projects are competitive with other mitigation measures.

### **13.3 Development of transportation companies**

The development of shared CO<sub>2</sub> transport networks will generate efficiency benefits on a system level, but the costs and benefits of such networks will go well beyond the interests and budgets of individual CCS projects. Consequently infrastructure companies able to execute long term system planning, like in the natural gas and electricity business, should be developed.

Governments may need to play a role in fostering such companies by taking ownership and subsidise in an early phase. In the longer term governments may substitute ownership with transmission company regulations. Operational guideline for such a company could be to maximise societal benefits from pipeline transportation. BASREC countries may agree to establish various degrees of multinational companies. Current natural gas transportation companies will, due to their expertise, experience and ownership of right of way for natural gas infrastructure, be obvious potential stakeholders in such companies.

In the European Union, a partnership for CO<sub>2</sub> transport pipelines could be modelled on the existing Trans-European Energy Networks. Under this programme, the EU finances electricity and gas transmission infrastructure feasibility studies that are of European interest. Eligible projects will typically cross national boundaries and have an impact on several member states. More detailed analysis is needed to identify the best ways forward for financing CO<sub>2</sub> transport networks in BASREC countries.

### **13.4 Development of a storage concessionary system**

Storage development may be best achieved by establishing property rights based on licensing systems like the concessionary systems for petroleum exploration and development. The governments retain the ownership to the underground resources while companies are given the licenses to explore, develop and operate petroleum reservoirs. Companies keep the income, less taxes and royalties. A similar system may be developed for storage of CO<sub>2</sub>. This is already a core element of the EU CCS Directive which should be developed and coherently implemented in the member states.

Within the petroleum sector, a concession system is often combined with a bidding process, where bidders offer a certain program for exploration and development of the concession area. In US and Australia the bidding process includes a money element (a positive or negative price).

As of now, profitability of investments in developing storage projects is assumed to be low. Hence, in order to make the industry interested in qualifying and developing storage opportunities, it may be necessary to give extra incentives for storage development in the initial phase. A suitable bidding process for support could be established where the bidder also request direct economic support in order to apply for a concession. The amount of the support sought will ideally reflect expectations of the bidder for the storage prospect, the cost and capacity for storage and injection, and the expected demand and willingness to pay for the services from the actual storage facility. Calculations will take into account the expectations regarding development of CCS projects in the different areas, their competitiveness, costs and possibilities and opportunities for transportation from source to sink etc. The purpose of such processes is to mobilize in house competence in the different companies and expertise from consultancy and research industries serving these companies. This may create an efficient and dynamic development of storage services.

Nations initiating bidding processes must secure the necessary legal framework and approvals for storage projects. This also implies securing the necessary public and political acceptance for transportation and storage. If these regulations are in place, the companies will not be exposed to this part of the CCS chain development risks. Authorities are best positioned to take such risks, and should therefore take them.

Norway has recently invited the industry to nominate areas in the North Sea and Norwegian Sea that might be suited for exploration of reservoirs for storage of CO<sub>2</sub>. This provides a preliminary screening of suitable storage sites that creates the formal basis for a licensing round for exploration and development of storage sites on the Norwegian Shelf.

The goal of an incentive system should be to develop the most cost effective project with the highest learning potential.

Technology development regarding capture and storage is currently the most important aspect of CCS chain development. There is also need for development of ship transport solutions, while pipeline transportation is a rather mature technology. From a technology development point of view, projects with the best potential for low future cost should be chosen. However, some of the EU programs seem not coordinated with national regulations to develop suitable low cost storage sites. Current projects could indeed fail due to prohibitively high transportation and storage cost. Hence BASREC nations should in cooperation with EU discuss the possibilities for extending support to overcome the difficulties in establishing storage sites.

An incentive program should aim for development of the most cost effective CCS *chains*, i.e. the chains with lowest total capture, transportation and storage cost. By organizing the chain with the capture project-owner in front and with sufficient incentives, the capture project owner will search for the lowest cost transportation and storage options. In turn this will stimulate supplies of least cost storage options close to the capture site, if such storages exist and are allowed. This solution however, is only preferable if the lead time for storage development is in line with the lead time for capture.

Since supply of storage services is one of the serious barriers for CCS development, it is our assessment that incentive programs for *storage* development should be established.

Incentives should stimulate mapping and collection of seismic data for characterisation in order to create competition and improved storage supplies when demand evolves. Together with political clarification such policies will better secure supply of reasonably priced storage options sufficiently close to the potential projects.

Storage development without firm demand must be based on speculation about demand, and may seem risky under the current circumstances if substantial costs are involved. Still, low cost storage sites close to large sources may be developed on speculation. But most probably development will take place as a result of negotiation between the capture project owner and a potential storage owner due to the need of intensive coordination and the risks involved on both sides. On the Norwegian Shelf the Mongstad project may create firm demand for storage that will stimulate storage development.

See additional considerations in the recommendation section.

## **14 Transboundary issues**

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In Europe, there are a large amount of transboundary arrangements for oil, gas and electricity transportation and transmission. The experience from these transboundary arrangements is valuable when establishing the regulatory framework for transboundary CO<sub>2</sub> transportation. However, additional needs arise in particular in relation to the liability for CO<sub>2</sub> emissions.

In the Baltic Sea region transnational agreements will in particular be needed since storage sites may cover several national sectors and Baltic Sea nations will need a treaty to deal inter alia with monitoring, leakage liability and remediation measures. In addition it will be necessary to agree on sharing of storage capacity, transfer of CO<sub>2</sub> liability in the transport system etc.

Such issues are now addressed in the CCS directive but may be developed in detail in concrete joint projects and agreements.

There are long lead times for development of international legal agreements and major infrastructures. International agreements often take several years to negotiate, and it can take more than ten years from early design to the eventual operation of a large pipeline that crosses international borders.

The "One North Sea report" and other reports mention the following main issues that need to be covered in agreements for transboundary solutions:

- Satisfactory regulations for exploration and storage licenses, particularly liabilities, within national laws. This will be achieved by implementation of the CCS Directive in national law.
- Clarifying jurisdictional responsibilities between the actual nations as regards the major elements of CCS Directive – including handover of stewardship of hydrocarbon sites for CO<sub>2</sub> storage, risk management, site qualification, monitoring, verification, accounting, reporting, decommissioning, and monitoring.
- Establishment of the legal rights to transport captured CO<sub>2</sub> across borders, which require ratification of the recent amendments to the OSPAR Protocol and London Convention.
- Clarifying emissions accounting rules for integrated CCS networks spanning multiple countries, with diverse sources, sinks and transport solutions.
- The permitting, construction, operation, decommissioning and liability issues for physical CCS infrastructure such as pipelines and injection facilities that span borders. Liabilities for fugitive CO<sub>2</sub> emissions from cross-border CCS networks should be limited and clear.

- For sinks that span national borders, agreements on the management of potential impacts from a project developed in one country on a second country are necessary. This may include impacts on storage capacity in hydrocarbon and geothermal reservoirs. Transboundary agreements may also cover joint exploration, leasing and licensing of pore spaces, short and long-term monitoring and liabilities. Liabilities in respect of storage complexes that span national borders should be limited and clear either on a case by case basis or generally.
- Transboundary agreements may also cover sharing of exploration data, as well as updated assessments of the economic potentials, timing, organisation and implementation of capture, transport, storage, enhanced oil recovery, and infrastructure re-use.

## **15 Recommendations for BASREC cooperation**

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The main recommendations are summarised in section 3 above and are only partly restated here. In this section additional issues worth further consideration and discussions in a follow up workshop are briefly mentioned and discussed.

### **Finance:**

- Demonstration projects are currently funded inter alia via the EU NER 300 scheme. The BASREC nations should consider an increased project support in order to overcome the current hurdles regarding development of storage and transport. Refinement of optimal support schemes could be an issue for a separate follow up project.
- Financial support for early phase CO<sub>2</sub> transport infrastructure. Economics of scale may imply marginal costs to be lower than average costs and could justify governmental support, in particular in the early phase when regulatory risks are high and network externalities can be particularly relevant. The issues should be further discussed in a possible follow up to this project.
- Evaluate the societal costs and benefits of extra CCS commercialisation incentives in the bridging period up to 2025-2030 via for instance bonus allowances in cap and trade schemes, feed in tariffs, participation in green certificate systems or a combination of these approaches.

### **Environment:**

- Consider permits for early demonstration storage projects if general permits currently are not allowed. Identify which issues should be clarified before general permits that fulfil EU requirements will be issued.
- Refine a comprehensive CO<sub>2</sub> transport and storage permit framework, including environmental impact assessments, risk assessments and remediation processes, as well as public engagement and communication protocols. BASREC countries should assign relevant regulatory bodies for such development which essentially would be the practical implementation of the CCS Directive.
- Cooperate to develop and harmonise CO<sub>2</sub> storage monitoring and verification (M&V) methods.
- Create public engagement processes with high levels of integrity by inviting stakeholder with the aim to identify and discuss legitimate concerns.

## **Local governance and engagements**

- Local governments should be engaged in regional cooperation for CO<sub>2</sub> transport and storage planning.
- Local emergency response officials have relevant competence and should have an adequate role in public engagement and communication processes.

## **Concession systems**

- Establish CO<sub>2</sub> transportation- and storage concessions that incentivise exploration and development of storage sites.
- Establish pre-competitive regional storage exploration programmes, and policies to encourage storage exploration.
- Develop national CO<sub>2</sub> storage capacity estimates using approved methodologies and share this information widely. This is urgent in order to clarify where to transport and store CO<sub>2</sub> at lowest costs possible and to facilitate development of common infrastructure.

## **Training dissemination**

- Identify CCS educational development/training needs for important areas like geologic assessment; develop training plans/grants for universities.
- Expand the number of geologists and reservoir engineers who are trained in CO<sub>2</sub> storage site assessment. This will probably be an automatic consequence of demand for such knowledge. The geologists reservoir engineers working within the petroleum sector are probably suitable for such analysis but they are today a highly scarce resource which will be increasingly required for future petroleum development.
- Ensure the provision of regular, transparent data from early projects.

## **Transport regulations**

- Establish health and safety regulations.
- Develop educations/outreach programmes on CO<sub>2</sub> pipeline transport safety issues.
- Develop long-term regional CO<sub>2</sub> pipeline infrastructure plans. It is important to discuss the role that governments should have in pipeline planning and development. As illustrated in this report, development of a cost efficient transportation and storage system requires detailed knowledge of possible storage sites, their capacity and costs of injection, possible routing between capture and storage, details about routing geography, ground, geology, costs, obstacles and regulatory restrictions. The task could rather be to develop national CO<sub>2</sub> transportation companies, regulated in the same way as the natural gas and electricity companies. Their core competence will be planning and development of optimal transportation systems.

## **Storage specific actions**

- Storage-specific exploration is required to locate and characterize suitable, deep saline formations. (Depleted oil and gas fields are already rather well characterized, but will also need extensive work to assess effects of storage of CO<sub>2</sub>). To date there has been very little site-specific storage exploration undertaken, and there is a clear need for both regional and site-specific

exploration to establish viable storage resources. Additional needs include: improved CO<sub>2</sub> seismic modeling and monitoring techniques to enhance the ability to predict the fate of CO<sub>2</sub> in the subsurface and verify its location; greater knowledge about understanding of leakage, including detection, rectifying and accounting; a better understanding of the impacts of CO<sub>2</sub> storage on the subsurface, including on brine displacement; and more information about the effect of CO<sub>2</sub> impurities on the storage formation. In addition, best practice guidelines are also needed for well construction and completion, remediation, and risk assessment. These practices must be implemented via safety regulations for CO<sub>2</sub> storage. Finally, publicly funded, regional, precompetitive exploration and evaluation programmes should be implemented to fill the priority gaps.

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## 17 Annexes

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### 17.1 Basic elements in pipeline transportation

A system for pipeline transportation of CO<sub>2</sub> consists of the following elements:

#### **Purification plant**

Impurities influence the pressure and temperature necessary to keep CO<sub>2</sub> in the dense and supercritical state in the pipeline system. These phases are considered most economical for pipeline transportation. Operators of CO<sub>2</sub> transportation systems will require deliveries within certain ranges of impurity tolerances. Impurities may as well influence corrosion of pipelines, cause pollution and environmental damages, and influence negatively both on injectivity in reservoirs, and the possibilities for EOR operations.

#### **Dehydration plant**

Free water makes CO<sub>2</sub> transportation highly corrosive, requiring special and costly steel. Transporters will require that CO<sub>2</sub> deliveries are kept within certain H<sub>2</sub>O limitations.

#### **Compressor station**

Friction between pipewalls and elevation will reduce pressure and velocity of the CO<sub>2</sub> stream. Hence compressor stations are needed to maintain pressure and velocity. Friction and energy needs pr. distance unit decreases with pipeline diameter (area) and velocity.

#### **Metering station**

A metering station is necessary both for economic and operational control purposes.

#### **Monitoring system**

Monitoring is required for operational and leakage control.

#### **Booster stations for maintaining necessary pressures and velocity**

Compressors and decompressor stations may be needed to keep the CO<sub>2</sub> stream in the dense and supercritical phase.

#### **Right of way**

In order to establish a pipeline system, right of using land for pipeline routes and ditches must be acquired. The costs will depend on the alternative value of land. The alternative value of land will normally be low in rural areas, where pipelines can be buried and surface land used for original purposes. Costs related to right of way will normally be much higher in urban areas.

#### **Ditching, trenching**

Costs of ditching do not vary significantly with the diameter of the pipeline. Hence there are considerable economics of scale in ditching costs.

## **Reinforcements against landslides**

Reinforcements against landslides are almost independent of pipeline size.

## **Crossings**

- **Rivers (tunnels, bridges)**
- **Urban (tunnels)**
- **Infrastructure (tunnels)**

## **Pipes (dimensions, steel quality)**

Cost of pipes depends on steel quality and dimensions. Costs normally vary linearly with diameter, which tends to create considerable economics of scale in pipeline construction.

## **Transportation of pipes**

### **Welding**

### **Covering padding**

### **Fracture halters**

### **Valves**

### **Inspection and pig stations**

### **Detection systems**

It is preferred to pipe CO<sub>2</sub> under very high pressure, up to 150 bar. At this pressure, the gas is in a physical state called super-critical, which means that it is as dense as if it were in the liquid phase but flows as easily as a gas. This makes this supercritical phase ideal for pipeline transport since energy for compensation friction loss is minimized. Typical density is like water.

The above system description gives insight into the economics of pipeline transportation. The cost structure can further be divided into

- Projecting costs
  - design,
  - project management,
  - regulatory filing fees,
  - insurances costs,
  - right-of-way costs,
  - contingencies
  - allowances)
- Construction costs
  - Material/equipment costs
    - o pipe, pipe coating, cathodic protection,
    - o telecommunication equipment;
    - o possible booster stations)
    - o purification
    - o dehydration

- Installation costs, trenching, drilling, stabilisation, crossing
  - o labour
  - o machine hours

- **Operation and maintenance costs**

- Monitoring costs
- Maintenance costs
- (Possible) energy costs

Projecting costs including costs related to right of way normally constitute 5-10% of total pipeline costs. (Operation and maintenance costs, including energy cost for booster stations, normally constitute 5% of total investment costs. Energy costs vary linearly with friction losses and average elevation in the system.)

Costs for right of way normally constitute a minor element in the total cost, since pipelines are buried in ditches allowing alternative use of land.

The cost of purification and dehydration will not vary with transport mode or distance, and can be attributed to the sources of CO<sub>2</sub>, capture and initial compression process. The cost of purification and dehydration may even be completely avoided if CO<sub>2</sub> is directly injected from the capture site, or short transportation distances allow for special steel or inner tubing. Metering, surveillance, and system control systems can be considered as fixed costs independent of volume and distance.

Investments are higher when compressor station(s) are required to compensate for pressure loss along the pipeline, or for longer pipelines or for hilly terrain. The need for compressor stations may be reduced by increasing the pipeline diameter and reducing the flow velocity. Reported transport velocity varies from 1 to 5 m/ s.

Cost of tubes and other construction materials constitute about 45% of total pipeline construction costs for a pipeline with 10 Mtpa CO<sub>2</sub> capacity while construction costs constitute typically 47%, right of way 5%, planning and engineering about 3%.

The cost of tubes are normally considered linear to the diameter while capacity increases more than linear to the area of pipeline cross section. This creates the basis for strong economics of scale in pipeline transportation.

## **17.2 Possible projects up to 2020**

This list of projects has been copied from the publication "Towards a transport infrastructure for large-scale CCS in Europe". (The list should be updated for the BASREC region. Several of the projects have been discontinued.)

Table 2-1 CO<sub>2</sub> capture demonstrations until 2020. Captured volumes in italics represent estimates/corrections by ECN (original list of projects based but adapted from CSLF, 2009). Bold faced projects have been assumed to be deployed in 2020 (see also Table 2-4). The totals have been placed between brackets for each country.

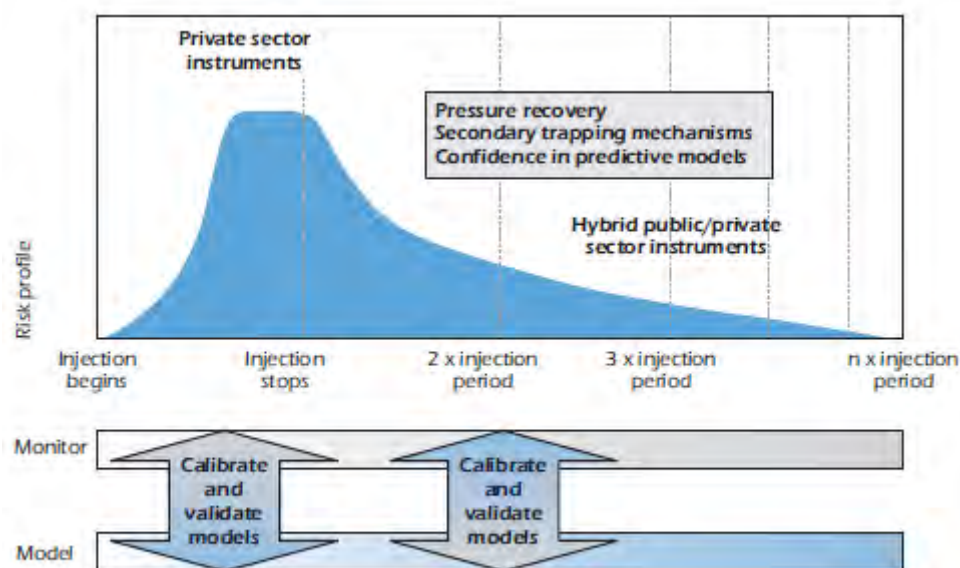
Developer(s)	Location	EEPR (€million)	Technology	Start	Capacity [MWe]	Volume CO <sub>2</sub> captured [Mt/yr]*
<b>United Kingdom (total 20.6)</b>						
Progressive Energy	Teesside		IGCC <sup>3</sup>	2012	800	4.2
RWE	Blyth		PC <sup>4</sup>	2014	2400	3
RWE	Aberthaw		PC	2015	25	Small
<b>Scottish Power</b>	<b>Longannet</b>	<b>?</b>	<b>PC</b>	<b>2014</b>	<b>300</b>	<b>2</b>
Scottish Power	Cockenzie		PC	2014	300	2
Eon	Killinghome		IGCC	2013	450	2.5
SSE	Ferrybridge		PC	2015	500	1.7
<b>RWE</b>	<b>Tilbury</b>		<b>PC</b>	<b>2016</b>	<b>1600</b>	<b>10.6</b>
<b>Powerfuel</b>	<b>Hatfield</b>	<b>180</b>	<b>IGCC</b>	<b>2010</b>	<b>900</b>	<b>6</b>
<b>Eon</b>	<b>Kingsnorth</b>		<b>PC</b>	<b>2016</b>	<b>300</b>	<b>2</b>
Progressive Energy	Onllwyn (Drym)		IGCC	2015	450	2.4
<b>Norway (total 6)</b>						
Haugesund Haugalandkraft	Haugesund		PC	2014	400-800	2
<b>Government</b>	<b>Kårstø</b>		<b>NGCC<sup>5</sup></b>	<b>2012</b>	<b>400</b>	<b>1.1</b>
<b>Tinfos AS. Sor-Norge Aluminium AS. Eramet Norway AS. Sargas AS</b>	<b>Sargas Hunes</b>		<b>PC</b>	<b>unknown</b>	<b>420</b>	<b>2.6</b>
StatoilHydro / gov	Snøhvit		Natural Gas Processing	2008	-	0.7
StatoilHydro	Sleipner		Natural Gas Processing	1996	-	1
StatoilHydro / Gassnova	Mongstad		CHP <sup>6</sup>	2014	280MWe/ 380MWh	1.3
StatoilHydro / Gassnova	Mongstad		Natural Gas Processing	unknown		1.2
Eramet. Sargas. Sor Norge Aluminum. Tinfos	Hordaland		Coal	unknown	380	2.4
Skagerak Kraft	Grenland		Gas	unknown	1000	1.6
Industrikraft Møre	Elnesvågen		Gas	unknown	450	1.2
<b>Finland (total 0)</b>						
Fortum/TVO	Meri Pori		IGCC	2015	565	2.5
<b>Poland (total 1.8)</b>						
ZAK. PSA.Shell. GE	Kędzierzyn-Koźle		Coal / biomass	2014	250	2.4
<b>Alstom/PGE</b>	<b>Belchatov</b>	<b>180</b>	<b>PC</b>	<b>2015</b>	<b>858</b>	<b>1.8</b>
Vattenfall	Siekierki		PC	2015	480	3.2

## EEPR CCS PROJECTS

Project name and short description	Applicant name (country)	Maximum Community contribution according to EC decision (in M EUR)
<p><b>Jaenschwalde</b></p> <p>Demonstration of the Oxyfuel and the post combustion technology on an existing power plant site. Two storage and transport options are analysed.</p>	<p>Vattenfall (Germany)</p>	<p>180</p>
<p><b>Porto-Tolle</b></p> <p>Installation of CCS technology on a new 660MW coal power plant. The capture part will treat flue gases corresponding to 250 MW electrical output. Storage in an offshore saline aquifer nearby.</p>	<p>Enel Ingegneria e Innovazione S.p.A. (Italy)</p>	<p>100</p>
<p><b>Rotterdam</b></p> <p>Demonstration of the full chain of CCS on a capacity of 250MW equivalent using post-combustion technology. Storage of CO<sub>2</sub> in a depleted offshore gas field near the plant. The project is part of the Rotterdam Climate initiative that aims at developing a CO<sub>2</sub> transport and storage infrastructure for the region.</p>	<p>Maasvlakte J.V. / E.ON Benelux and Electrabel (Netherlands)</p>	<p>180</p>
<p><b>Belchatow</b></p> <p>Demonstration of the entire CCS chain on flue gases corresponding to 250MW electrical output in a new supercritical unit of largest lignite-fired plant in Europe. Three different saline aquifer storage sites will be explored nearby.</p>	<p>PGE EBSA (Poland)</p>	<p>180</p>
<p><b>Compostilla</b></p> <p>Demonstration of the full CCS chain using Oxyfuel and fluidised bed technology on a 30MW pilot plant which to be upscaled by December 2015 to a demonstration plant of more than 320 MW. Storage in a saline aquifer nearby.</p>	<p>ENDESA Generacion S.A. (Spain)</p>	<p>180</p>
<p><b>Hatfield</b></p> <p>Demonstration of CCS on a new, 900 MW IGCC power plant. Storage in an offshore gas field nearby. The project is part of the Yorkshire Forward initiative that aims at developing a CO<sub>2</sub> transport and storage infrastructure for the region.</p>	<p>Powerfuel Power Ltd. (UK)</p>	<p>180</p>

## 17.3 Long term liability

The level of risk evolves along the life time of a CO<sub>2</sub> storage project; the area of most concern is the long-term "tail".



Source: WRI, 2007.

In general, the third-party and self-insurance instruments are best suited to the injection, closure, and post-closure periods. The risk profile of the project is clear while the site is active and the developer, owner or operator is best able at this stage to leverage the funds necessary to finance the instruments. In addition, during these phases, the estimated costs associated with closure and post-closure activities (e.g. monitoring and measuring CO<sub>2</sub> transport) are reasonably quantifiable (WRI, 2007).

Conversely, the activities associated with corrective (remedial) care over the long-term, i.e. after the site developer, owner or operator has completed any prescribed closure and post-closure activities, are more difficult to estimate. Specifically, the long-tailed risk profiles of CO<sub>2</sub> storage sites result in an uncertain probability of risk exposure, which will make it difficult to define the degree (and cost) of any necessary remedial activities. It is also difficult to identify (and monetise) the damages that could result from the long-term leakage of CO<sub>2</sub>.

It is difficult to assign the upper limits of financial liability that underpin the more traditional third-party and self-insurance financial instruments. In these circumstances, a public-private pooling structure, either in the form of an insurance pooling model, or a compensation (trust) fund model, is likely to be most suitable to provide the necessary financial assurances over the long-term. Both these models involve a blend of financial instruments designed to pool potential risk. However, careful consideration in the design of a public-private pooling structure is needed to assure against moral hazard, i.e. the risk that project developers, owners or operators can ignore (or avoid activities that will prevent or mitigate) future losses, including injury to public welfare and the environment, because the burden to pay for such losses rests with another party. For this reason, the financial limits of liability for either model must align with the evolution of the long-term risk profile of the relevant CO<sub>2</sub> storage sites.