CCS in the Baltic Sea region – Bastor 2

Final Summary Report
Elforsk report 14:50

A research project with support from

The Swedish Energy Agency
The Global Carbon Capture and Storage Institute
Carbon Capture and Storage Program (CCSP)
Svenska Petroleum Exploration
Jernkontoret
SMA Mineral
Vattenfall
Cementa
Nordkalk
Fortum
Preem
MinFo
SSAB

Per Arne Nilsson 30.09.2014

ELFORSK

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Preface

This report aims at providing a summary of the research undertaken in the project Bastor2 (Baltic Storage of CO_2), with the overriding objective to assess the opportunities and conditions for CO_2 transport and storage in the Baltic Sea Area. The project, which was in operation from June 2012 through September 2014, was financed by the Swedish Energy Agency, the Global CCS Institute and a number of Swedish industrial and energy companies.[1] Elforsk has commissioned the work in five separate work packages to universities, institutes and consultants in Sweden and internationally. The project follows an earlier screening study (Bastor1) in Sweden and research performed within the Finnish CCS programme, CCSP. In the Introduction more details are given of project participants, Project Board and references. This report is to a large extent based on direct quotes from the five work package reports, for which the respective authors have given their consent. There is no chapter summarizing project conclusions or recommendations, as this is done specifically in each chapter, but in the Executive Summary the very key conclusions are presented in a table format.

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[1] The companies were SSAB, Jernkontoret, Svenska Petroleum Exploration, Cementa, Nordkalk, SMA Mineral, MinFo, Vattenfall, Fortum and Preem.

Executive summary

The Baltic Sea CO_2 Storage (Bastor2) vision is the development of joint transport and storage infrastructure in the Baltic Sea region. The project's objective has therefore been set to investigate the potential and conditions for geological storage in the region. The principal task was to make as thorough as possible geological assessments, given the currently available geological information. Four additional work packages were organized, in support of the project objective, (i) environmental impact, (ii) communication and acceptance, (iii) legal aspects and (iv) transport infrastructure.

Following the final funding agreement and based on prior research within the Finnish Carbon Capture and Storage Program, CCSP, the geological assessment was initiated ahead of the other work, in order to provide input for the further studies. The set of geological information available from the outset was deemed insufficient and so agreements were made to procure additional data from Latvia, Russia and Poland. These initiatives were successful and new data was made available, to a large extent helping to enhance the confidence in the geological predictions from the project. A positive side effect is that channels have now been opened for expanded geological cooperation in the Baltic Sea region.

In the following, the key results from each work package are presented. However, given the complexity of the research, these are only highlights, for which reason the interested reader is kindly advised to consult the respective chapters of this report and/or the respective work package reports, referenced in Chapter 9.

Geological Assessment The study concludes that there is a theoretical regional capacity to store some 16 Gigatons (Gt) of CO_2 in the sandstone formations under the South Eastern parts of the Baltic Sea (see Figure 4). "Theoretical" capacity is the lowest level of confidence in site characterization model used to describe storage opportunities. The project suggests a number of further measures to be taken in the further geological characterization.

The southern Swedish sector has relatively poor permeability and porosity characteristics. The dynamic modelling suggests that with five injection wells, a total injection capacity of 2.5 Mt per year could be achieved. There may be reservoir intervals with better properties where higher injection rates could be safely achieved. Thus it is possible that this area could be suitable as a storage site for CO_2 captured from a limited number of industrial facilities. Other areas to the north east in the Dalders Monocline may have better qualities and allow a higher rate of injection. Therefore new well data covering this area, in particular offshore Latvia would help to identify more suitable sites. Also areas onshore and offshore Kaliningrad would appear to have better reservoir qualities.

The risk associated with seal failures is considered low, however the sealing integrity will require further investigation once new data becomes available and an injection site is selected.

The recommendations for further work include a study of the Cambrian sandstone interval to better understand the heterogeneity and distribution of good quality reservoir; a seismic attribute study to investigate the porosity trends in the Cambrian reservoir; a structural geology study to understand the influence of faulting on diagenesis and fracture porosity within the Cambrian; and a fracture gradient study of the Cambrian interval.

On the basis of the recommendations above, additional efforts to increase Baltic Sea regional cooperation should be undertaken to ensure that an effective strategy for CO_2 storage is developed.

Environmental Impact

There is high generic knowledge about the Baltic Sea ecological and environmental conditions. For industrial projects the respective Nordstream and OPAB Environmental Impact Assessments (EIA) have provided additional and valuable information. For a CCS pilot project with exploration drilling and test injection of CO_2, comprehensive and site specific investigations are required. The delivered catalogue of knowledge will be of use when an EIA team is planning the work and content, especially the identified knowledge gaps related to CO_2 injection activities and site development. The project has produced an outline work plan for a future EIA including a preliminary budget. Mandatory items are pinpointed in the plan, along with a number of recommended topics. The tentative work plan, proposed EIA content and time/cost estimate can serve as basis documents for a tender process for a field trial EIA.

Communication and Acceptance

The technical and commercial CCS development has in some cases been impeded by public opposition. This report describes social factors, which may influence the plans for a Baltic Sea storage project:

- The proximity of an operation to populated areas (including whether the operation is onshore or offshore)
- The environmental status of the Baltic Sea
- Differences between capture, transport and storage operations
- Climate change awareness
- Economic benefits from a storage project
- Possibility to deal with concerns through funds or investments
- Foreign interests in the project

These findings are in agreement with literature on CCS and experiences from EU CCS projects. A general conclusion is that the collected material is not consistent enough to draw robust conclusions about a firm communication plan. The report provides insights though, into which aspects should be considered and thus gives increased possibilities to identify and responsibly handle the social conditions associated with a Baltic Sea storage project.

Legal Aspects

This report provides an analysis of the current and suggested legal framework that would regulate CCS activities. It also identifies potential barriers to CCS implementation. The evolution of a well-functioning legal framework for regional CCS operations is expected to be time consuming for which reason the early identification of potential hurdles is critical to all stakeholders. Although taking a Swedish perspective the report has its main focus on the EU CCS Directive and related pieces of EU law.

A number of recommendations are given as input to the imminent (2015) revision of the CCS Directive. Among these are (i) a clearer definition of 'captured CO_2', (ii) the need to give more consideration to potential market failures and (iii) the role of competition authorities in the build-up of CCS infrastructure. Particularly the rules on third party access to pipelines and storage sites are found to be quite vague at the EU level and thereby create room for problematic discrepancies between the Member States. The responsibility for transboundary CCS installations or structures is also under-regulated, causing significant uncertainties that should be addressed. As to the potential for storing CO_2 captured in the EU, outside of the union, this is found to be impossible without significant amendments to applicable EU law. It is also concluded that further efforts should be made to enable transport of captured CO_2 by ship, as it is currently not recognized by the EU emissions trading system (EU ETS), and that the inclusion of biogenic emissions under the EU ETS may also benefit the deployment of CCS in the Baltic Sea region.

Infrastructure for Transport

Transport is considered the technically most mature part of the CCS supply chain why the main consideration has been cost estimation rather than technology. There are some technical issues related to the offshore discharge of ships, which need to be addressed.

The cost of CO_2 transport by pipeline has been compared to the corresponding cost by ship for volumes and transport distances relevant to the Baltic Sea region. The results show that ship transport could be the preferable short and the long term mode of transport with the lowest specific cost, for most of the CO_2 sources in Finland and Sweden.

One conclusion is that the total capital investment required for developing the transport infrastructure necessary to cope with the volumes in question, is so large that no single project operator will be able (or willing to) to carry all the risk. Therefore, for the build-up of CO_2 transport systems, public involvement will be required.

The presented cost estimates are in alignment with those of the two reference reports, the Zero Emission Platform, Cost of CO_2 transport and the CO_2 Europipe report, both from 2011. A marked difference though, is the higher absolute cost level, which is essentially due to the lower emission volumes per site and the longer transport distances in the region. The lowest specific cost for pipeline transport to the Dalders structure, is the one representing a large cluster concentrated around Oxelösund.

Shipping could simplify the CCS deployment decision making process, simply by offering a lower threshold for investment. In comparison with pipelines, ship transport requires lower capital expense, offers higher flexibility and near linear scalability. With the possibility of redeploying vessels into another product segment, should the CO_2 trade be reduced or aborted, it offers reduced capital risk than the pipeline business case.

As a final remark, continued geological assessment is required for both the Swedish territory and for the Dalders Monocline areas towards the Latvian sector, for which regional cooperation is an imperative. A Swedish demonstration project, for instance based on one of the SSAB blast furnaces in Oxelösund or the Cementa cement furnace in Slite on Gotland, could be facilitated by ship transport to the Dalders structure, thereby avoiding some of the current legal barriers.

Sammanfattning (Swedish summary)

Visionen för Bastor2 (Baltic Sea CO_2 Storage) är utvecklingen av gemensam, regional infrastruktur för transport och lagring av koldioxid. Projektets mål har varit att undersöka potentialen och villkoren för geologisk lagring i Östersjö-regionen. Huvuduppgiften var att (i) göra en så grundlig värdering, som möjligt av de geologiska förutsättningarna, med basis i den för projektet tillgängliga, geologiska grundinformationen. Bastor2 omfattade ytterligare fyra delprojekt, (ii) miljökonsekvenser, (iii) kommunikation och acceptans, (iv) legala förhållanden samt (v) infrastruktur för transport av koldioxid.

Baserat på forskning inom det finska programmet Carbon Capture and Storage Program, CCSP, så initierades geologiprojektet före de andra delprojekten, för att dessa därigenom delvis skulle kunna utnyttja resultaten av de geologiska analyserna. Den från början tillgängliga, geologiska informationen bedömdes vara otillräcklig, varför överenskommelser gjordes med institut i Lettland, Ryssland och Polen, vilka upplät ytterligare data för projektets arbete. Detta visade sig lyckosamt, eftersom den nya informationen i hög grad bidragit till att höja träffsäkerheten i projektets geologiska bedömningar. Samtidigt förde detta till att nya kanaler öppnades för ett utökat samarbete runt Östersjön.

Den följande sammanfattningen redovisar översiktligt resultaten från varje delprojekt, men givet komplexiteten, så hänvisas den intresserade läsaren till respektive kapitel samt till de specifika delprojektrapporterna, vilka anges, som referenser i kapitel 9.

Geologisk utvärdering

Studien landar i slutsatsen att det finns en teoretisk kapacitet att lagra upp till 16 Gigaton (16 Gt) koldioxid i sandstensformationerna under den sydöstra delen av Östersjön (se karta i Figur 4). ”Teoretisk” kapacitet innebär den lägsta nivån av noggrannhet i den modell för att utvärdera potentiella, geologiska formationer för koldioxidlagring, som normalt används i sådana bedömningar. Projektet föreslår ett flertal analyser, som bör göras i den fortsatta utvärderingen.

Den södra delen av den svenska ekonomiska zonen uppvisar relativt låg permeabilitet (genomsläpplighet) och porositet. Resultatet av den dynamiska modelleringen säger därför att med fem injektionsbrunnar, så skulle den årliga lagringskapaciteten kunna uppgå till cirka 2,5 miljoner ton per år. Men det kan även finnas lokala reservoarer med bättre lagringsegenskaper, varför lagring från svenskt territorium förväntas kunna ske i en omfattning, som motsvarar utsläppen från ett mindre antal industriella anläggningar. Vidare indikeras att områden med bättre lagringsegenskaper finns nordost om det undersökta området i riktning mot Lettlands kust, i en struktur, som kallas Dalders-monoklinalen. Därför är det av stor vikt att i det fortsatta arbetet kunna arbeta med nya data, från brunnar borrade i närtid, speciellt utanför Lettland, för att därigenom kunna identifiera mer lämpliga lagringsplatser med kapacitet att lagra regionala volymer. Även geologiska formationer under landmassan och i havet utanför ryska

Kaliningrad framstår som möjliga platser för koldioxidlagring.

Risken för läckage genom sprickor i täckbergarterna av koldioxid till markytan och därmed till atmosfären, bedöms, som låg, även om täckbergarternas integritet måste bli föremål för ytterligare undersökningar, när man får fram mer och nyare geologisk data samt att en injektionsplats har valts ut.

Rekommendationerna för fortsatta studier av den Kambriska sandstenen, innefattar (i) en studie för att bättre förstå dess heterogenitet och fördelningen av god reservoarkvalitet, (ii) seismisk attributtolkning för att kartlägga porositetstrender, (iii) en strukturgeologisk studie kring hur förkastningar påverkar den kambriska sandstenens diagenetiska egenskaper och sprickporositeten och (iv) en studie av uppspräckningsgradienten i det kambriska intervallet.

På basis av dessa rekommendationer bör därför ytterligare ansträngningar göras för att utöka samarbetet mellan Östersjöländerna, för att säkerställa utvecklingen av en effektiv och långsiktig strategi för geologisk lagring av koldioxid i regionen.

Miljö-konsekvens-beskrivning (MKB)

Det finns en stor allmän kunskap om de ekologiska och miljömässiga förhållandena i Östersjön. Studier av de respektive miljökonsekvensbeskrivningarna för de bägge industriella projekten Nordstream och OPABs föreslagna provborrning i Dalders, har därtill bidragit med mycket god specifik information för projektet. För ett CCS-projekt med provborrning och test-injektering av CO_2 krävs omfattande och platsspecifika undersökningar av möjliga miljökonsekvenser. Projektet har färdigställt en kunskapskatalog, vilken blir ett praktiskt verktyg för planeringen av en framtida MKB, både vad avser resursåtgång och innehåll. Speciellt användbara blir de här identifierade kunskapsluckorna kring utvecklingen av en injekteringsplats och kring CO_2-injektering. Projektet har även utvecklat en preliminär arbetsplan och budget för en MKB för nödvändiga fältförsök. Här redovisas såväl obligatoriska, som rekommenderade studier. Planen, det föreslagna MKB-innehållet och kostnadsuppskattningarna, kan fungera, som direkta underlag för upphandlingen av genomförandet av en MKB.

Kommunikation och acceptans

Den tekniska och kommersiella utvecklingen av CCS har i några sammanhang bromsats av ett motstånd hos den berörda lokalbefolkningen. Den här rapporten beskriver vilka sociala faktorer, som skulle kunna påverka planer och genomförande av ett projekt för lagring av koldioxid i Östersjö-området:

- Närheten till den planerade aktiviteten från befolkade områden (inklusive aspekten om den sker på land eller till havs)
- Östersjöns miljömässiga status

- Skillnader mellan olika aktiviteter, som koldioxidavskiljning, transport och lagring
- Medvetande om och attityd till klimatförändringar
- Ekonomiska fördelar med att genomföra ett lagringsprojekt
- Möjligheten att hantera viss oro genom att avsätta medel eller genom att göra vissa investeringar
- Utländska intressen i projektet

Resultaten stämmer väl överens med befintlig litteratur och med erfarenheter från faktiska CCS-projekt. Ett konstaterande är dock att den i projektet insamlade informationen inte är tillräckligt entydig för att tillåta långtgående slutsatser kring hur en effektiv kommunikationsplan ska utformas. Rapporten belyser dock vilka aspekter som måste beaktas och ger därför förbättrade möjligheter till att identifiera och på ett ansvarsfullt sätt hantera de sociala villkoren kring ett potentiellt projekt för lagring av koldioxid i Östersjö-området.

Legala aspekter

Delprojektets rapport ger en ingående analys av det befintliga och föreslagna juridiska ramverket, avsett att reglera CCS-aktiviteter, speciellt för gränsöverskridande verksamhet. Samtidigt identifieras och beskrivs möjliga legala hinder för införandet av CCS. Den nödvändiga utvecklingen av ett välfungerande juridiskt ramverk förväntas ta lång tid, varför det är kritiskt för alla intressenter att tidigt klarlägga möjliga hinder. Även om rapporten har ett svenskt perspektiv, så ligger dess huvudfokus på EUs CCS-direktiv och andra delar av EU-lagstiftningen, som berör olika aspekter av CCS.

Projektet ger ett antal rekommendationer som input till den förestående (2015) revisionen av CCS-direktivet. Bland dess finns (i) en tydligare definition av begreppet ”avskild CO_2”, (ii) nödvändigheten att ta hänsyn till möjliga störningar i marknaden och (iii) den roll, som konkurrensmyndigheterna måste ta när infrastruktur för transport och lagring av koldioxid byggs upp och utvecklas. Speciellt de nuvarande EU-reglerna för tredjepartstillgång till rörledningar och lagring anges, som otydliga, vilket kan skapa utrymme för stora skillnader i tolkning och tillämpning mellan medlemsstaterna. Ansvaret för gränsöverskridande CCS-installationer är likaså inte entydigt reglerat, vilket ger en betydande osäkerhet, som behöver åtgärdas. Möjligheten att lagra koldioxid, fångad inom EU, i länder utanför unionen, beskrivs, som omöjligt utan väsentliga förändringar av den nu gällande lagstiftningen. Rapporten drar också slutsatsen att ytterligare ansträngningar behöver göras för att likställa fartygstransport med transport i rörledningar, eftersom den förra inte erkänns, som lagrad inom EUs system för handel med utsläppsrätter, EU ETS. Likaså föreslås att om koldioxid från biomassa skulle ingå i handelssystemet ETS, så skulle detta vara fördelaktigt för införandet av CCS i Östersjöregionen.

Infrastruktur för transport

Transport av koldioxid betraktas, som den tekniskt mest beprövade länken i CCS-kedjan. Därför behandlar delprojektet kostnadsestimat för transportsystem snarare än teknologiaspekter. Dock konstateras att vissa tekniska frågor kvarstår kring lossning av gastankers till havs.

Kostnaden för att transportera CO_2 i rörledning har jämförts med dito för fartygstransport, för de volymer och avstånd, som är aktuella i Östersjöregionen. Resultaten visar att fartygstransport ur kostnadssynpunkt är att föredra på både kort och lång sikt, för de allra flesta källorna i östra Sverige och Finland.

En betydande slutsats är att kapitalinsatsen för att utveckla infrastruktur för transport, är så stor att ingen enskild operatör eller projektutvecklare kommer att varken klara eller vilja bära den relaterade risken. Detta medför, menar författarna, att staten måste vara involverad i utvecklingen av transportsystem för koldioxid.

Kostnadsuppskattningarna har jämförts med och visat sig ligga i linje med motsvarande från två referensrapporter, ”The Zero Emission Platform, Cost of CO_2 transport” och slutrapporten från projektet ”CO_2 Europipe”, båda från 2011. Kostnaden i Östersjöregionen ligger dock väsentligt högre, vilket förklaras med de lägre volymerna och de längre avstånden i regionen. Den lägsta specifika kostnaden för rörledningstransport anges vara den från ett kluster med nära tolv miljoner ton CO_2 per år kring SSABs stålverk i Oxelösund, till den tänkta lagringsplatsen vid Dalders-strukturen, sydost om Gotland.

Transport i gas-tankers skulle kunna förenkla beslutsprocessen kring införandet av CCS, genom att tröskeln för investeringsbeslut blir lägre. I jämförelse med rörledningar, kräver fartygstransport lägre kapitalinsats och erbjuder större flexibilitet och nära nog linjär skalbarhet. Genom möjligheten att omplacera fartygsflottan i andra produktsegment, så minimeras risken för att CCS-verksamheten av någon anledning skulle upphöra eller drastiskt minska, vilket beskrivs, som attraktivt i jämförelse med rörledningssystem.

Till slut, fortsatt geologisk utvärdering behövs för både svenskt territorium och för Dalders-Monoklinalen mot Lettisk sockel, vilket i sig kräver ett regionalt samarbete. Ett tidigt svenskt demonstrationsprojekt, till exempel baserat på en av SSABs två masugnar i Oxelösund eller på Cementas fabrik i Slite på Gotland och byggt kring fartygstransport till Dalders-strukturen i den svenska, ekonomiska zonen, skulle kunna vidareutveckla inhemsk och regional kompetens och samtidigt undvika de nuvarande juridiska hindren för ett smidigt genomförande.

Table of Contents

1 Introduction

1.1 Background

IPCC’s 5th (Intergovernmental Panel on Climate Change) assessment report underlines the importance of both CCS and Bio CCS (BECCS) in order to limit the maximum global average temperature increase to 2 degrees Celsius above pre-industrial levels. The EU supports the 2 degrees target and is committed to reducing GHG emissions by 20% relative to 1990 by 2020, a target that they most likely will reach. The EU Commission has also suggested a 40% reduction by 2030 (EC 2014) and, in the longer term, by 80 to 95% in 2050, in both cases relative to 1990 (EC 2011). In its Energy Roadmap 2050, the EU states that CCS will have to contribute significantly in most scenarios designed to meet the long-term emission reduction target and that BECCS could deliver “carbon negative” emissions (EC 2011). Furthermore, in its communication on a proposed GHG emission reduction target for 2030, the commission states that CCS may be the only option available to large scale emission reductions from certain industrial processes such as steel and cement production (EC 2014).

Sweden is aiming to reduce net GHG emissions to zero in 2050. The Swedish Environmental Protection Agency (NVV 2012) has proposed two indicative scenarios aiming to reduce emissions to levels close to zero in 2050. In the scenario with the highest emission reductions, down to levels around 10 Mt CO_2eqv in 2050, both CCS and BECCS have a large role starting around 2040 and by 2050 some 20 Mt is suggested to be captured and stored annually as can be seen from Figure 1 taken from NVV (2012). The graph shows GHG emission reductions by technology as proposed by NVV in its “Målscenario 1”. The red area refers to CCS applied to fossil emissions from the industry while the grey area refers to BECCS on bio-refineries, pulp and paper and the mineral industries.

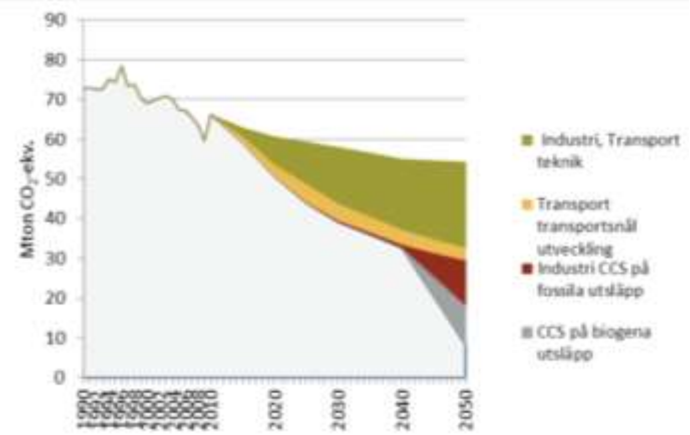

Figure 1 GHG emission reductions, Swedish Roadmap 2050 (NVV, 2012)

Also the International Energy Agency (IEA) identifies CCS as a key mitigation technology and in its Nordic Energy Technology Perspectives IEA suggests that 50% of the cement plants and at least 30 % of the iron and steel and chemical industries are equipped with

CCS if the Nordic countries are to reach near complete decarbonisation target in 2050. IEA states that Nordic governments must scale up policy actions if CCS is to realize its full potential and that co-operation in infrastructure development, RD&D and in strategies for transport and CCS would offer significant benefits (IEA 2013).

Thus, there should be little doubt that CCS (and BECCS) is considered as one out of several key technologies to achieve the GHG emission reductions required to reach the 2 degrees Celsius target.

Implementation of CCS will depend on sufficient incentivisation. The CO_2emission price in the European Emission Trading (ETS) scheme, anticipated to be the main policy instrument to drive CCS forward in the EU, has been fluctuating around € 5/ton for the last year, far below what will be required for deployment of CCS. The low ETS price is a consequence of a large surplus of emission allowances within the trading scheme and that the EU Commission appears, at least for now, unable to adjust the number of allowances, so that the CO_2 price could rise to the levels necessary for CCS to be deployed. Moreover, storage of biogenic CO_2-emissions is not incentivised at all since there is no CO_2-price on these emissions.

It can therefore be concluded that although there is convincing scientific evidence that climate change is happening, although there is considerable political consensus around commitment to the 2 degrees Celsius target and although most politicians and scientists agree that CCS is a key mitigation technology required to meet the 2 degrees target, there is, at least up to now, not enough political will to ensure large scale deployment of CCS in Europe.

1.2 Bastor2 objectives

The purpose of the Baltic Storage of CO_2 (‘Bastor 2’) project is to increase awareness of the potential for geological storage of CO_2 in the Baltic Sea and to identify barriers to CCS implementation. Thereby, the project will provide insight for both the authorities and the industry for strategic decisions about carbon capture and other measures to reduce greenhouse gas emissions in an environmentally responsible manner.

In the longer term, the project will also lay the groundwork for possible future commercial development of transport and storage of CO_2 as part of efforts to facilitate the deployment of CCS in the region in cooperation with other countries. The vision is the development of common cross border infrastructure for transport and storage of CO_2 in the Baltic Sea region. The evolution of a well-functioning legal framework for regional CCS operations is expected to be time consuming for which reason the early identification of potential hurdles is critical to all stakeholders.

1.3 Report structure

Each of the project’s five work packages has been a separate research assignment, with its scope defined in a project description, forming the basis for the research. These were all described to underpin the project’s vision but with only few other links between the work packages. The results from the geological assessment were used primarily in the study of the infrastructure for transport. Therefore each work package has been dedicated one chapter in this report, chapters two to six, each with its own summary.

In chapter seven the overall conclusions and possible implications of these are discussed as well as the Project Board's agreement and proposal for continued studies in the field.

There is no separate Chapter for Conclusions, as each work package has been summarized and the overall conclusions have been stated in the Executive Summary.

1.4 Work package reports

This current report is a summary of work that has been separately documented in scientific reports. These in turn, have undergone independent reviews and been modified as a consequence of comments and suggestions from reviewers. Therefore, the intent of this report is rather to provide an inside and easy-to-consume overview of the main research, methods and results but without the ambition to systematically provide evidence or references. For the interested reader it is instead proposed to download the complete work package reports. The reference list includes references to the five individual work package reports, where all external references and other source information will be found. All reports are open to the public and available at three websites:

The Swedish Energy Agency: [link]
The Global CCS Institute: [link]
Elforsk: [link]

1.5 Acknowledgements

The research activities in this project have been made possible through the financial support from the Swedish Energy Agency, the Global CCS Institute and a group of industrial companies and organisations. The companies and their representatives are listed below (Project Board) and their active participation in the fifteen Project Board Meetings also secured the industrial experience and aspects of the project.

The project was coordinated through the Project Board with

Kim Kärsrud	SSAB (Chairman)
Jan Bida	MinFo (Swedish Mineral Processing Research Association)
Lars B Johansson/Bengt Hanell	Elforsk
Torgny Berglund/Erik Palmlöv	Svenska Petroleum/OPAB
Angeline Kneppers/Andrew Purvis	Global CCS Institute
Christian Bernstone	Vattenfall
Kjell Dahlberg	Nordkalk
Sören Ericsson	Preem
Stefan Sandelin	Cementa
Leif Norlander	SMA Mineral
Eva-Katrin Lindman	Fortum
Matti Nieminen	VTT/CCSP
Helen Axelsson	Jernkontoret (Swedish Steel Producers' Association)

Project Manager was Per Arne Nilsson, *panaware ab*.

Valuable input and advice to the editing of this summary report were received from the Project Board and from Jan Kjærstad, Chalmers University of Technology.

Finally the insightful results from the Bastor2 project could be produced thanks to the dedicated efforts from the team of more than twenty researchers and consultants, who are listed in the References section. The list may be incomplete, if so apologies to the concerned.

2 Geological assessment

SLR Consulting was commissioned by Elforsk to identify and characterise the potential CO_2 storage sites in the southern Baltic Sea. The work was conducted jointly by SLR and Uppsala University, with the active support of Svenska Petroleum AB (OPAB).

2.1 Geological overview and the study area

The geology work package assessed the potential of geological formations in the Baltic Sea area to store 50 million tonnes of dense phase CO_2 per year for a minimum of 25 years. A storage site with this capacity would make sense in the light of the total potential for carbon capture in the Baltic Sea region. The study area was defined as previously mapped Palaeozoic sedimentary basins in the Baltic Sea area. The Baltic Sea Basin is a marginal platform depression, with an area of about 200,000km^2. The area of interest covers parts of onshore Latvia, Lithuania, Kaliningrad and northern Poland, as well as the respective economic interest zones of the Baltic Sea. Most of the oil and gas fields in the Baltic Basin are found in the following four sub-basins:

- Slupsk Border Zone (SBZ), located in the South-western Baltic Sea between Poland and Sweden, has an approximate surface area 2 500km^2
- Gdansk-Kura Depression (GKD), located in the south-eastern Baltic Sea, covers parts of Poland, Russia and Lithuania and has an approximate surface are of 8 000km^2
- Liepaja Saldus Ridge (LSR), located in the southern part of the Baltic Sea and extends southwest to northeast across the Baltic Sea into Latvia. The Liepaja Saldus Ridge has a surface area of 2 500 km^2
- Latvian, Estonian, Lithuanian Border Zone (LEL), is located in the mid Baltic Sea and extends southeast to northwest covering parts of Estonia, Latvia and the Swedish Gotland Island. The border zone has an approximate surface area of 2 500 km^2

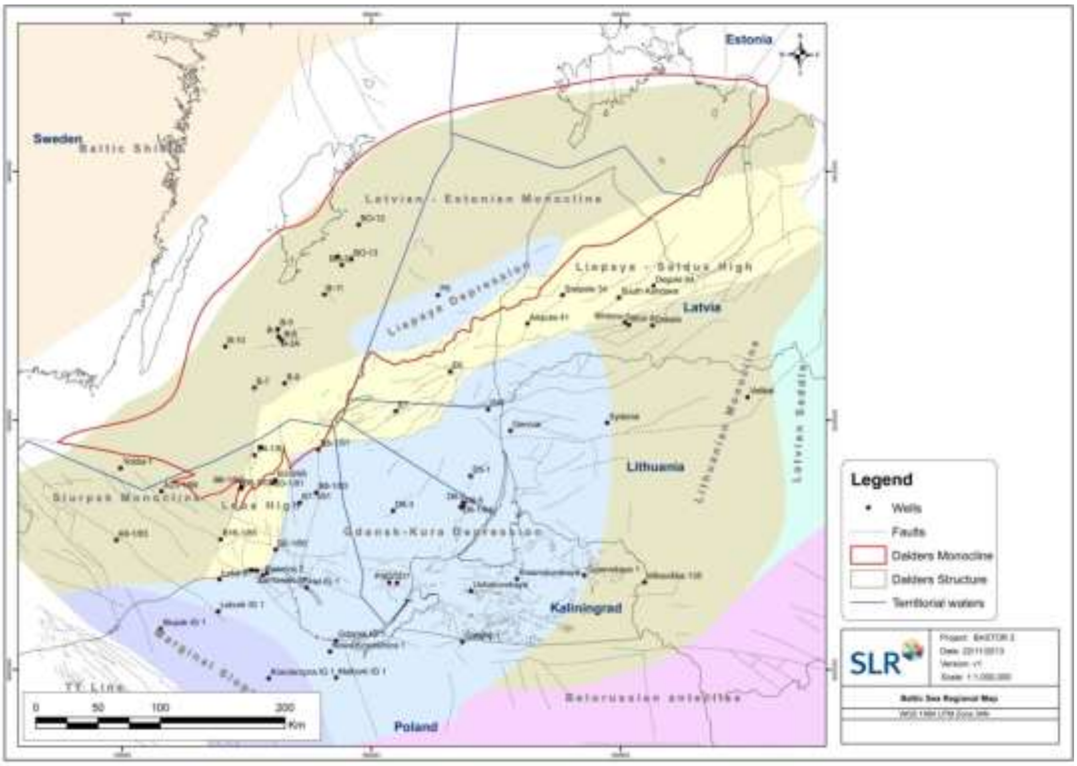

Figure 2 The Baltic Sea Map

The report assesses the potential for geological storage of CO_2 in sedimentary basins in these four zones. Storage potential may exist in depleted oil and gas fields or saline aquifer formations at depths greater than 800m, the minimum depth for CO_2 stability. The principal stage of basin development was during the Middle Cambrian-Lower Devonian (Caledonian) sequence. This sequence contains sandstone and limestone aquifers sealed by shale and claystone aquifers (see Figure 3).

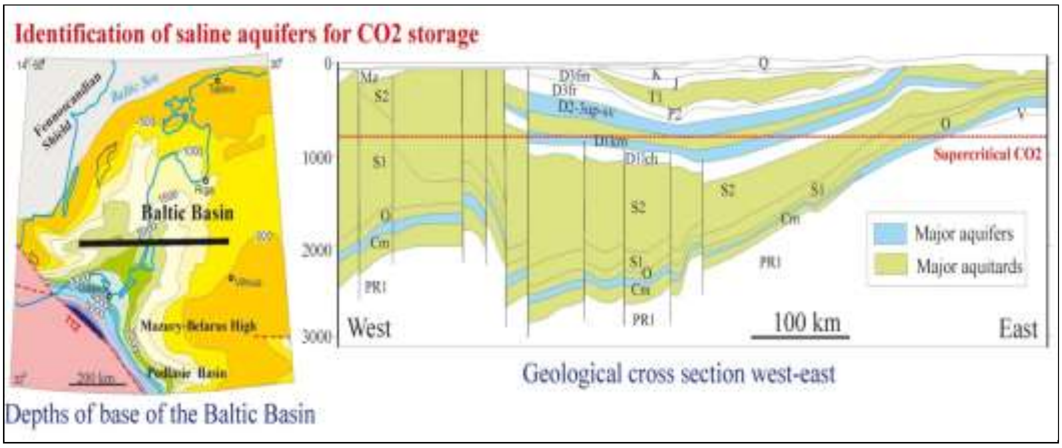

Figure 3 The Caledonian Baltic Sea Basin, with aquifers that could store CO_2

The main targets for CO_2 storage are faulted anticlines, step and nose features associated with the monoclines that occur on the northwest margin of the Baltic Basin. These structures contain the Lower to Middle Cambrian sandstone (Deimena Formation in

Latvia, Faludden Sandstone in Sweden) that is the main hydrocarbon bearing reservoir of the Baltic region. There is also the possibility of stratigraphic traps, particularly in the Ordovician shelf carbonate rocks that are porous but not very permeable. There are indications on seismic sections offshore Latvia of possible Ordovician shelf carbonates but poor reservoir quality and small size make them inappropriate for CO_2 storage.

The offshore Dalders Prospect Structure (Figure 4), which straddles Swedish, Lithuanian and Latvian territory, has been identified as a potential site for storage. Associated with the Dalders structure is the Dalders Monocline that extends NW to Gotland in Sweden. While CO_2 storage is preferred in confined aquifers and closed structures, it would significantly increase the potential of aquifers offshore Sweden if it could be shown theoretically and by demonstration projects that CO_2 can be trapped in monoclinal structures.

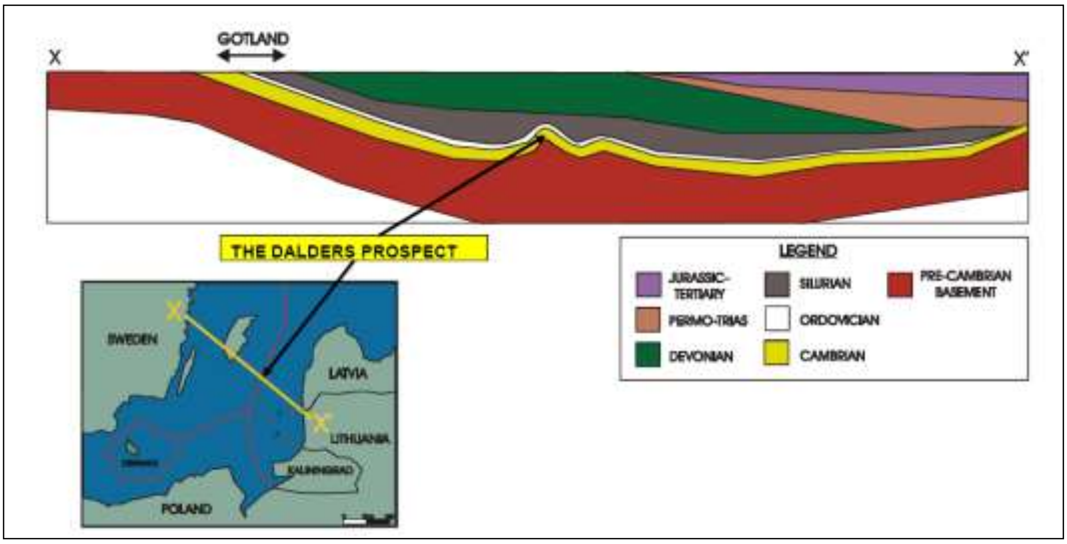

Figure 4 Location of the Dalders Structure and the Dalders Monocline

From OPAB and from the Swedish Geological Survey, the project had access to detailed information from the Dalders area, which allowed in depth analysis.

The report gives a detailed account of the Baltic Sea Basin sedimentary sequence. The conclusion of the geological overview is that the only workable reservoir seal pair for CO_2 storage is the Cambrian sandstones sealed by the Ordovician Silurian argillaceous carbonates and shales.

2.2 Basin screening and ranking

To ensure that the most relevant reservoirs are analysed, the project applies a quantitative evaluation of a basin's suitability for CO_2 storage, as developed by Bachu (2003). This includes the use of fifteen parameters, for each of which, the four areas screened were attached numerical values. Sedimentary basins were assessed by applying the minimum criteria, secondary qualifiers and weightings as defined in Table 1 and
Table 2.

Table 1 Minimum criteria for consideration of sedimentary basins for CO_2 storage

	Suitability Criterion	Suitability threshold	Weight
1	Depth	>800 m	0.07
2	Size at surface	>2500 km^2	0.06
3	Seismicity	<High (i.e., not in subduction zones)	0.06
4	Reservoir/Seal	At least one major extensive and competent seal	0.08
5	Faulting and/or fracturing	Low to moderate	0.07
6	Pressure regime	Not overpressured	0.05
7	Regulatory status	Accessible	0.03
		TOTAL	**0.42**

Table 2 Proposed secondary qualifiers for assessing the potential of sedimentary basins for CO_2 storage

	Potential Criterion	Poor Potential	Good Potential	Weight
1	CO_2 sources	At >500 km distance	At <500 km distance	0.08
2	Physical accessibility	Difficult	Good	0.03
3	Infrastructure	None or poor	Developed	0.05
4	Hydrogeology Flow systems	Shallow, short	Deep and/or long	0.08
5	Geothermal regime[1]	Warm	Cold	0.10
6	Hydrocarbon potential and industry maturity	None, poor	Large, mature	0.08
7	Coal	Too shallow or too deep	Between 400 and 1000 m depth	0.04
8	Coal value[2]	Economic	Uneconomic	0.04
9	Climate	Arctic and sub-arctic	Temperate	0.08
			TOTAL	**0.58**

The Baltic Sea Basin is considered to be a potentially good candidate for CO_2 storage because it is a stable basin with limited faulting and extensive sealing shale. It has regional long range flow systems. The cold climate and geothermal gradient increase CO_2 storage capacity and decrease CO_2 buoyancy. There is a proven hydrocarbon system with oil and gas production. However the monoclines around the margins are relatively shallow. In the relatively shallow monocline structures where the target saline aquifer reservoirs are less than 800m deep, CO_2 storage is inefficient (low CO_2 density) and unsafe because of very high CO_2 buoyancy. The Baltic Sea sub-basins are all of suitable size but the structures within them are not. The monoclines that form the boundary to the basin may be candidates for CO_2 storage in saline aquifers but further reservoir engineering studies are required to establish the integrity of CO_2 trapping in monoclines where no structural closure exists. This applies also to the Dalders Monocline in Sweden.

The results of the screening exercise for sedimentary basins of the Baltic Sea are shown in Table 3 with additional weightings applied by SLR.

Table 3 Ranking of Baltic Sea sub-basins in terms of suitability for geological CO_2 storage

Rank	*Basin*	*Characteristics*	*Score*
1	Slupsk Border Zone	Proven reservoir/seal pair, moderate size structures, offshore, large saline aquifer, limited faulting, good accessibility, <500kms to strategic CO_2 sources	0.76
2	Gdansk-Kura Depression	Existing oil and gas production infrastructure, moderate sized structures, offshore, fair accessibility, >500kms to some strategic CO_2 sources	0.75
3	Liepaja Saldus Ridge	Proven reservoir/seal pair, moderate size structures, offshore, fair accessibility, <500kms to strategic CO_2 sources	0.75
4	Latvian Estonian Lithuanian Border Zone	Proven reservoir/seal pairs, small structures, potential saline aquifer, only small area sufficiently deep for CO_2 storage, accessible, 250kms to strategic CO_2 sources	0.71

In this initial ranking the Slupsk Border Zone has the highest priority because it contains the Dalders Monocline which is a probable CO_2 storage structure that is accessible to Swedish CO_2 point sources. The Gdansk-Kura Depression is geologically suitable for CO_2 storage and has existing oil production infrastructure at PetroBaltic's B3 field and Lukoil's Kratsovskoye field. However access may be restricted depending on when the depleted oil and gas reservoirs become available. There are existing plans to use the offshore facilities in Poland to store CO_2 from the Lotos refinery in Gdansk. The Liepaja Saldus Ridge is closer to CO_2 sources in Finland and has potential CO_2 storage in saline aquifers offshore Latvia. The LEL Border Zone has the lowest rank because only a small area is sufficiently deep for CO_2 storage.

2.3 Storage capacity

The respective reservoirs' capability to receive and store carbon dioxide depends on two key parameters, the total storage volume capacity (pore space) and the injectivity, as measured in tons per year and on the number of wells. The modelling and estimation of storage capacity is quite complex and therefore the interested reader is kindly advised to read the complete work package report. This section deals with the static storage volume capacity. Following the ranking of the sub-basins, storage capacity calculations were completed, using the GeoCapacity (2009) methodology. Hydrocarbon exploration and production data obtained in the initial phases of the project was integrated into a GIS database and used to estimate the potential theoretical storage capacity for the basins. The calculations were undertaken as regional estimates for both hydrocarbon fields and saline aquifers.

Based on the available data for specific hydrocarbon fields, two separate calculation methodologies were used. Where limited data is available the Generic Hydrocarbon Fields method is used and where detailed reservoir and formation data are available calculations of CO_2 storage capacity have been undertaken based on Bachu. For saline aquifers, a storage capacity calculation for the Cambrian sandstone below 900m and for the Dalders Monocline was performed using the modified formula by Bachu. The outline of the Cambrian below 900m was digitised into GIS and an area of 193 192km^2 was calculated. The Dalders Monocline as mapped below 900m was calculated as 19 634km^2. An average height of the reservoir of 70m and average porosity of 13% were used based on data in Skirius, 1996 (Amoco report) and data for the Faludden sandstone from the B-9 and P6 wells. A trap specific theoretical storage capacity calculation was carried out for 8 offshore Latvia closures and for the Dalders Structure as presented in the 1996 Amoco report. The calculation was undertaken assuming the structures are open or semi-closed and assuming the Middle Cambrian Faludden sandstone is an unconfined aquifer. This conceptual model assumes that storage space is generated by displacing existing fluids and distributing the pressure increase in the surrounding and connected aquifer.

Table 4 shows the theoretical storage capacity calculation results for the Baltic Sea region based on the methodologies described above. The best prospects are the Dalders Monocline and the Cambrian across the Baltic Sea region below 900m depth. The Cambrian has an estimated theoretical storage potential of 16 222Mt of which 1 924Mt is in the Dalders Monocline and 128Mt in the Dalders Structure, located in the central part of the Baltic Sea Area. The total individual field storage capacity is estimated to be 943Mt of which the individual hydrocarbon fields are estimated to have storage potential of 210Mt.

Table 4 Theoretical Storage Capacity Summary

	Estimated CO_2 Storage Capacity (10^6 tonnes)
Regional Cambrian Below 900m	16 222
of which Dalders Monocline	1 924
Individual Baltic Sea Field Total	743
Dalders Structure	128

2.4 Modelling

2.4.1 Static modelling

Static modelling determines the key physical characteristics of the targeted structures. These relate to volumetric data, such as depth (top and bottom), thickness and extension, length and width. This enables the geologists to define the boundaries of the structures in question. Figure 5 is an example that illustrates the boundaries of the Dalders Monocline, showing the Monocline (red polygon) and the area covered by the Alum Shale within the Dalders Monocline (grey Polygon)

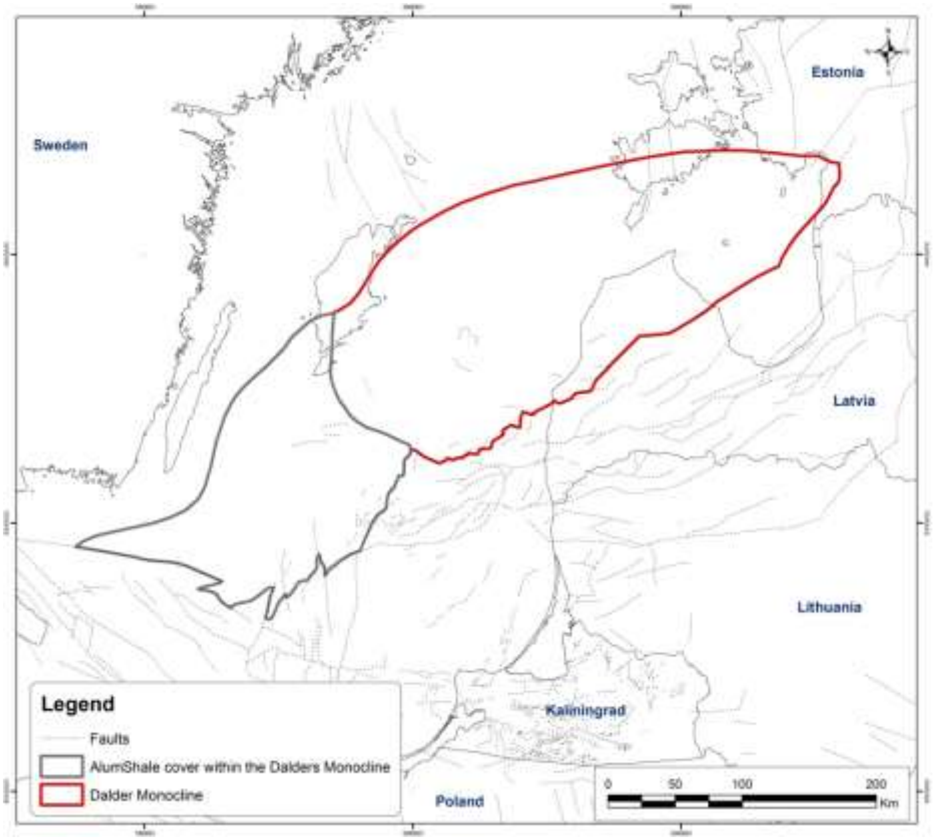

Figure 5 Boundaries of the Dalders Monocline

In addition and key to assessing the storage capacity, is the possibility to establish the permeability and porosity of the structures. The porosity of the Middle Cambrian in the Dalders Monocline was interpolated using effective porosity values measured in core samples from offshore wells. A general trend as low as 3% offshore Poland, increasing up to 20% in Latvia is observed. A low anomalous value of 12% is noticeable in the well P6 located in the central part of the Dalders Monocline, which could be due to the local depositional environment.

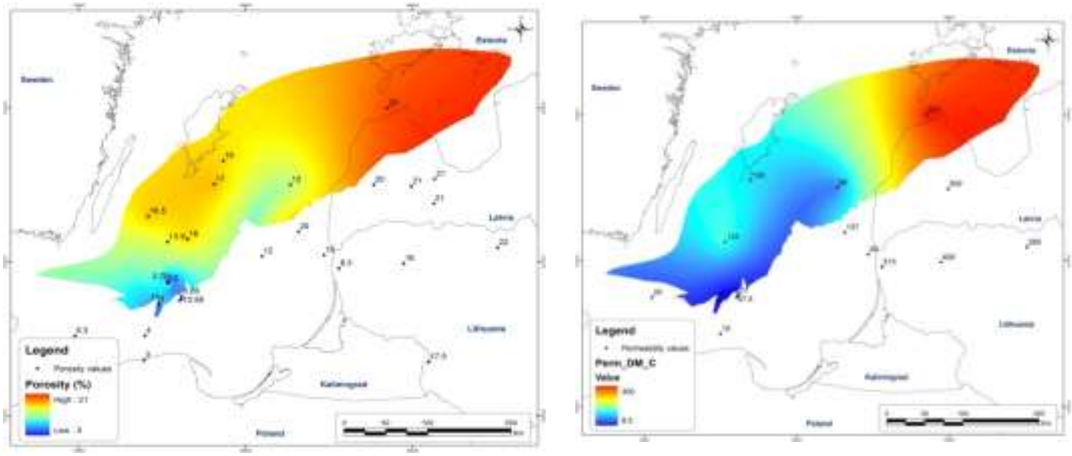

Figure 6 Porosity (left) and Permeability (right) of the Dalders Monocline

The permeability of the Middle Cambrian in the Dalders Monocline has been defined using permeability values from measurements in wells and core samples. The trend is similar to that observed for the porosity with low values in the southwest and higher values in the northeast. The lowest value is 10mD in the B16 well (offshore Poland) and a maximum of 400mD in the Syderiai structure (onshore Lithuania).

The static model for the Dalders structure was developed based on the lithofacies distributions of the Middle Cambrian sandstone unit observed in the B3 field in the Polish offshore sector. This was considered to be the best analogue to use for reservoir heterogeneity in the Dalders Structure and was used to map individual lithological sub-layers within the Middle Cambrian reservoir section.

Based on the result of the static modelling the Dalders Monocline and the Dalders Structure were selected for dynamic modelling. Both structures are large enough for industrial scale CO_2 storage. The Dalders Structure is also potentially a target for hydrocarbon exploration.

2.4.2 Dynamic modelling

The data compiled for the static modelling for both structures comprised existing exploration well data, including core and petrophysical analysis as well as analogous reservoir production data. The dynamic modelling was applied to the static models for both candidate structures.

The University of Uppsala Earth Sciences Department undertook the dynamic modelling of both structures, with a view to assessing the potential of the Middle Cambrian sandstone reservoir and adjacent formations to store CO_2 and to provide a semi-quantitative analysis of the behaviours of the reservoir and CO_2 plume during the course of injection and post-injection periods.

The specific objectives of the modelling included:

- Define the reservoir pressure behaviour with respect to seal integrity for different injection scenarios based on the existing petrophysical reservoir properties and hydrogeological aquifer parameters;
- Calculate the CO_2 plume migration tip speed and distance and the potential for dissolution trapping;
- Identify suitable multi-well injection scenarios in the Dalders Monocline to meet the estimated industrial CO_2 storage requirements identified around the Baltic Sea.

The modelling was undertaken with a view to characterising different injection scenarios for the Dalders Monocline and Dalders Structure. Three separate modelling approaches were used, the benefit of which was increased confidence and reliability of the predictions:

- Preliminary determination of the injection rates by means of analytical modelling
- Numerical modelling of CO_2 plume spreading with TOUGH2 model
- Vertical Equilibrium Model

Several boundary conditions were chosen for the two structures. These include a o reservoir pressure, hydrostatic pressure, porosity, permeability, injection rates, period of injection, reservoir thickness, fault structure and number of injection wells.

A number of scenarios of dynamic modelling, with the above variables, were developed. The requirement for CO_2 storage based on calculated emissions from the industrial sector in the Baltic Sea region suggests that the injection of 50Mt of CO_2 per annum over 25 years is needed. The initial analytical modelling demonstrates that in order to preserve cap integrity and avoid fault reactivation, injection rates should not exceed 0.5Mt per well and year. The report summarises and discusses the results for the modelled scenarios of CO_2 injection by focussing on:

- Pressure regime and overpressure ratio calculated
- CO_2 saturation within the reservoir
- CO_2 dissolution
- CO_2 plume migration
- Mobile CO_2 Plume Thickness

The dynamic modelling parameters used to estimate rates of injection of CO_2 in the Dalders Monocline are based on limited well data and reservoir properties, mostly confined to the southern part of the Monocline region within the Swedish offshore sector.

The preliminary simulations indicate for the southern part of the Dalders Monocline a maximum total injection rate of the order of 2.5 Mt/yr if five injection wells are used and assuming a maximum sustainable pressure increase of 50% from the hydrostatic condition. The 50% cut off value was used as site-specific mechanical data is not available. Increasing the number of wells would allow a larger total injection rate (e.g. 7 wells would allow an injection rate of about 3 Mt/yr) as would reducing the total injection time from 50 years to e.g. 25 years. The maximum injection rate is sensitive to parameters such as formation thickness and permeability, and analysing the effect of their local variability fully does require more detailed modelling than was possible in this preliminary study. In these simulations impermeable sealing units (cap-rocks) were also assumed and it should be noted that the injection-induced pressure increase could be dissipated by brine displacement through cap-rock if the permeability of the cap-rock is not extremely low and the compressibility of the cap-rock is large. In addition, pore pressure could be further relieved through brine production wells, thus allowing higher injection rates. The role of using horizontal, rather than vertical injection wells should also be investigated. Further modelling studies should address these issues in more detail. Such analyses should optimally be accompanied by additional site-specific data and/or further parameter sensitivity studies where data acquisition is not possible.

The Cambrian reservoir in the southern section of the Monocline has relatively low porosity and permeability values (of the order of 8% to 11 % porosity and 9mD to 70mD permeability respectively) with an improvement of these values towards the north east where permeability values of up 300mD for the Middle Cambrian sandstones have been documented in exploration wells. The example injection rate of 0.5Mt/yr from 5 wells is conservative and in areas of higher reservoir quality in the northern part it can be expected that higher CO_2 injection rates can be used without the risk of seal failure or fault reactivation. However, based on the currently limited well data in the northern part of the Monocline, this can only be considered speculative until additional data is obtained. The dynamic modelling results have assumed a threshold pressure of 50% above the hydrostatic pressure. This assumption was used as lack of formation leak off test data for the monocline area did not allow a more accurate estimate of this threshold. This could have implications for improved injection rates. The leak off test data would also provide thresholds for cap rock integrity and the risk for reactivation of existing fault structures.

The effects on overpressure modelled for higher injection rates suggest that these may be possible for single injection wells in better reservoir quality areas. However the use of CO_2 injection rates higher than 0.5Mt/yr in multiple well injections in the lower quality reservoir is not recommended. Should a grouped well injection methodology using several deviated wells from a central platform be adopted, the overpressure and CO_2 plume sizes are likely to be different to the single injection point methodology adopted in this model.

The modelling scenarios considered in this study are, for the most part, based on an injection period of 50 years. This may exceed the infrastructure lifetime and possible timescale of operational CO_2 storage projects.

2.5 Sealing integrity – risk for leakage

The seal integrity study investigates basic overburden properties above the Middle Cambrian reservoir including stratigraphy, lithology and thickness as well as the nature of any faulting and fracturing observed in the two candidate structures for CO_2 storage. Favourable overburden properties may include the presence of shallow aquifers that could, through monitoring, give early warning of upward CO_2 migration.

There is a significant thickness of overburden composed of low permeability layers that exceed 800m, overlying the two target storage sites. These cap rocks are sufficient to contain CO_2 within the underlying Middle Cambrian aquifer. Where the cap rocks lack faulting and have low structural dips (which means that most of the cap rock succession is in direct contact with the seabed), the overburden will form a satisfactory regional seal.

The seal integrity study also assesses the leakage risk from pathways other than faults such as high permeability sediment stringers in the immediate overburden by examining shallow gas occurrence as indicators of previous or ongoing gas leakage.

In addition to physical trapping and structural traps, CO_2 can be trapped by dissolution in the aquifer or trapped as residual gas. A longer migration distance towards a potential leak point would imply a greater degree of CO_2 trapping by dissolution and residual gas trapping. Before CO_2 can make its way out of the aquifer to surface, the residual gas trapping and dissolution alone may secure all of the CO_2 to be stored.

With respect to cap rock integrity, one would not expect major pathways for CO_2 migration along fault planes unless the complete cap rock is penetrated by a single fault. This can be identified from the existing seismic data. Due to high confining stresses at depths greater than 1,000m it can be expected that faults are closed and that shear zones would be filled with sealing debris of the sheared wall rock. Fault analysis using 3D seismic mapping should be used to fully evaluate the sealing potential of faults including clay smear and fault gauge ratio determinations.

The Dalders Monocline and the Dalders structure, contain Middle Cambrian reservoir formations covered by a thick sealing overburden of Upper Cambrian to Lower Ordovician shales, Ordovician marls, claystones and mudstone and most importantly, a thick complex of Silurian shales. The effectiveness of the sealing properties of these formations and their relationships to faults structures were examined with respect to the potential of leakage and migration of CO_2. Based on the analysis of the sealing formation at both sites, the following conclusions have been reached:

- Three possible modes of seal failure have been identified for the Dalders Structure, these include top seal failure, migration up the bounding fault planes and leakage across fault plane, with the former two considered to be the lowest risk.
- The potential for top seal failure across the Baltic Basin has been considered in detail as part of this study. Whilst a relatively thin cover of Alum Shale directly overlies the reservoir in both the Dalders Structure and the Dalders Monocline, a significant thickness of between 500m and 1,000m of combined Ordovician and Silurian deposits, comprising mainly shales and claystones, act as the ultimate seal. The potential for top seal failure is therefore considered low.
- Seal failure resulting in leakage across fault planes is more likely, however the risk of this is still low when the thickness of the reservoir and large throws along the fault planes are considered.
- The potential for migration of CO_2 along fault planes has been considered in the context of the different structural events recorded in the Baltic Basin, the trends of the faults structures and their relationships with the reservoir and seals identified in the Dalders Structure and Monocline. The main boundaries of both structures are considered to be sealed, leaving little or no risk of upward leakage or migration of CO_2 along fault planes.
- Evidence from analogous fields in the offshore Polish sector demonstrates that smaller scale cross cutting fault structures with particular E-W and NW-SE orientations) are likely to be open. These are associated with the development of gas chimneys and the upward migration of hydrocarbons from the Cambrian reservoir to overlying Ordovician limestones. However there is no current evidence for smaller scale cross cutting faults on the Dalders Structure.

Further activities for risk assessment of the Dalders Structure should include:

- A detailed structural study of the Dalders prospect, to clarify the probable migration pathways. One risk associated with anticlinal traps is the possibility of the build-up of a large, vertical column of CO_2, exerting buoyancy forces on the caprock. Although a large thickness of caprock with limited faulting has been identified, its structural integrity would need assessing. Long term hydraulic and gas transport testing on existing caprock samples from onshore Poland should be undertaken.

- Further seismic interpretation and where necessary, the acquisition of new data will be required in the vicinity of any proposed test injection site to be selected in the Dalders Monocline to map in detail any faults, structures and seismic attributes that remain poorly identified in the Swedish offshore sector.
- A detailed sensitivity analysis, with respect to different injection scenarios, resulting reservoir pressures and their potential impact on the preservation of the seal integrity around fault structures where the cap rock is thinnest. The results of these sensitivity analyses will have to be integrated with the results of the long term hydraulic and gas transport testing of caprock samples.
- A multibeam seabed survey and sub-bottom profiling above any potential CO_2 storage or injection test location.
- Detailed analyses of cored Silurian and Ordovician-upper Cambrian sealing formation from newly drilled exploration wells in the proximity of the Dalders Structure and Monocline.

2.6 Conclusions and recommendations

The principal conclusion from this study is that there is large theoretical storage capacity in the Baltic Sea basin beneath a 900 metre thick impermeable caprock. Ranking of Baltic Sea sub-basins in terms of suitability for CO_2 geological sequestration identified the Slupsk Border Zone as the highest ranked basin. Theoretical storage capacity calculations for the sub-basins indicated more than 100Mt of CO_2 storage capacity in the Dalders Structure within the Dalders Monocline. Preliminary dynamic simulations have been carried out focussing on the southern part of the Dalders monocline offshore Sweden, suggesting that maintaining the reservoir pressure at 50% above the hydrostatic pressure would limit the injection rate to 0.5Mt per well per annum over a 50 year period if five injection wells are used. Increasing the number of wells, would increase the total annual rate as would reducing the injection time to e.g. 25 years. The maximum injection rate is sensitive to parameters such as formation thickness and permeability, and analysing the effect of their local variability fully, does require more detailed modelling. Impermeable sealing units (cap-rocks) were also assumed and it should be noted that the injection-induced pressure increase could be dissipated by brine displacement through cap-rock if cap-rock properties are suitable. In addition, pore pressure could be further relieved through brine production wells (“water producers”), thus allowing higher injection rates. The role of using horizontal, rather than vertical injection wells should also be investigated. Such analyses should optimally be accompanied with additional site-specific data and/or further parameter sensitivity studies where data acquisition is not possible. Keeping these reservations in mind, the numerical values given above can be considered only indicative.

The results from the data analysis and the preliminary dynamic modelling do, however, indicate that the reservoir quality in the presently modelled area is not suitable for high injection rates and therefore not sufficient for CO_2 storage at the scale of projected, regional emissions around the Baltic Sea. Other areas to the north east of the Monocline, such as offshore Latvia could include areas with better reservoir quality, where a higher rate of injection could be achieved. The regional storage capacity assessment demonstrated that there are sweet spots in the Cambrian reservoir such as onshore Latvia and both onshore and offshore Kaliningrad.

The potential to store significant quantities of CO_2 in the Swedish part of the Dalders Monocline appears to be limited based on current data and assumptions of the reservoir and top seal properties used to model potential injection scenarios.

Existing seismic line data covering the Swedish offshore sector of the Dalders Monocline should be calibrated to available well data and re-interpreted to identify any primary and secondary fault structures and to map reservoir porosity and permeability variations.

Further reservoir characterisation studies such as those discussed above should be combined with improved estimates of seal fracture pressures based on well leak off test data and core sample analyses.

Future exploration efforts should be focussed on areas where the best reservoir quality and storage potential are likely to be found. This should be done in parallel with more refined dynamic simulations to gain further understanding of the true storage capacity of various parts of the region.

Reservoir formation data from core samples and wire line logs should be obtained from any newly drilled wells in the area to improve the understanding of porosity, permeability and formation pressure values associated with the reservoir across the Baltic Sea region. As offshore and onshore well data indicate that the north eastern portion of the Dalders Monocline and onshore and offshore Kaliningrad appear to have better reservoir qualities than the current study area, new data covering this area, in particular offshore Latvia could help to identify more suitable sites for CO_2 storage.

Thus Baltic Sea region cooperation is imperative to ensure the success of any Baltic Sea CO_2 storage initiative. Additional efforts to increase this regional cooperation should be undertaken to ensure that an effective strategy for CO_2 storage in the Baltic Sea region is developed.

2.7 Summary

SLR was commissioned by Elforsk to identify and characterise the potential CO_2 storage sites in the southern Baltic Sea. The study determined that there is a theoretical regional capacity to store some 16Gt of CO_2 in the Middle Cambrian sandstone beneath 900 metres of caprock and 1.9Gt in the Dalders Monocline. There is theoretical storage capacity of some 743Mt CO_2 in hydrocarbon and saline structures, which are located mainly offshore Latvia. On the basis of the data available, there is no effective capacity proven within these totals, although the Dalders Structure, with 128Mt, could be considered better defined, albeit still within the theoretical category range. Thus the study has established a relatively large theoretical storage capacity for captured CO_2.

The southern Swedish sector, where dynamic modelling was undertaken by Uppsala University, has relatively poor permeability and porosity characteristics. In order to maintain the reservoir pressure at 50% above the hydrostatic pressure, the injection rate should be limited to 0.5Mtpa per well over a 50 year period if five wells were to be used. The indicative dynamic modelling suggests that with five injection wells, a total injection capacity of 2.5 Mt per annum could be achieved. Reducing the injection period to 25 years and increasing the number of wells could increase the total injection rate somewhat above this level. There may also be reservoir intervals with higher porosity and permeability where higher injection rates could be safely achieved. Thus it is possible that this area, including the Dalders structure, could be suitable as a storage site for CO_2 captured from a limited number of industrial facilities.

Other areas to the north east of the Monocline, where limited data is available, may have better reservoir qualities and allow a higher rate of injection. The regional storage capacity assessment demonstrated that there are sweet spots in the Cambrian reservoir such as onshore Latvia.

Three possible modes of seal failure have been identified. These include top seal failure, migration up the bounding fault planes and leakage across fault planes. All three possible modes of potential failure were investigated. The risk associated with all of these is considered low, based on currently available data. However the sealing integrity will require further investigation once new data becomes available and an injection site is selected.

A test injection methodology has been designed with the objective of assessing the viability of CO_2 injection in the Baltic Sea region. An outline measuring, monitoring and verification (MMV) programme has been developed based on the results of the dynamic modelling and the development phases of a CO_2 injection site. However, the details of this will be subject to site specific conditions and will need to be updated once new data is available.

Since the potential of the Swedish part of the Dalders Monocline to act as a regional storage site for significant quantities of CO_2 appears to be limited based on the geological information at hand, exploration efforts should be focused on areas where the best reservoir quality and regional scale storage potential are likely to be found. As well data indicate that the north eastern portion of the Dalders Monocline appears to have better reservoir qualities than the current study area, new well data covering this area, in particular offshore Latvia would help to identify more suitable sites for CO_2 storage. Regional reservoir quality maps based on the limited data available indicate that onshore and offshore Kaliningrad would also appear to have better reservoir qualities.

Recommendations for further work include a study of the Cambrian sandstone interval to better understand the heterogeneity and distribution of good quality reservoir; a seismic attribute study to investigate the porosity trends in the Cambrian reservoir; a structural geology study to understand the influence of faulting on diagenesis and fracture porosity within the Cambrian; and a fracture gradient study of the Cambrian interval.

3 Environmental impact

Yggdrasil Miljömanagement AB in collaboration with panaware ab have been assigned the task of undertaking a survey of current knowledge about potential environmental effects from offshore CO_2 activities and to identify knowledge gaps necessary to address in an environmental impact assessment for a pilot transport and storage project in the Baltic Sea region.

3.1 Background and approach to the task

The Bastor2 project set out to assess the opportunities and risks with transport and storage of carbon dioxide in the Baltic Sea region. The Baltic Sea being considered environmentally sensitive and CO_2 activities offshore a novelty, it was deemed important already at this exploratory stage of a potential pilot storage project, to map existing knowledge of risks and to pinpoint the main gaps.

The objective of the work was therefore to document current knowledge, hazards and risks on environmental impacts of a CCS pilot project offshore in the Baltic Sea Region. The objective was also to present a tentative Environmental Impact Assessment (EIA) work plan for a field trial project to store CO_2. The Bastor2 project's intention has been to add new knowledge about potential CCS activities in the offshore Baltic Sea Area.

Relevant studies for this report have been Nord Stream's EIA for Consultation under the Espoo Convention regarding installation of the offshore gas pipeline in the Baltic Sea and OPAB's EIA for the Application for permit regarding oil exploration drilling in the Baltic Sea. Other sources of information have been e.g. the Swedish Geological Survey, Helcom, CGS Europe, RISCS and numerous other projects and reports. No EIA data from offshore petroleum activities in Poland, Kaliningrad or the Baltic States have been incorporated in this report.

The main methods for data collection have been literature research and key person interviews. The work has been limited to transport and storage, i e (i) transport by ship, (ii) transport by pipeline, (iii) site preparation activities (construction of a future injection site) and (iv) injection and monitoring. By assembling a catalogue of risks and registered knowledge, the work has been able to highlight the relevant knowledge gaps. The report presents also an outline work plan for a full scale EIA, should a pilot storage project be decided for implementation.

3.2 Current knowledge and gaps

The Catalogue of Knowledge presented as an Annex to the work package is report, is a compilation of current knowledge and identified gaps linked to environmental impacts from past offshore activities. The analysed projects relate to oil exploration, construction of pipelines and environmental risks described for planned projects with CO_2 transport and storage. The catalogue is divided into three main categories; (i) General environmental knowledge of the Baltic Sea Region, (ii) Risks and consequences from generic industrial activities and (iii) Environmental risks and consequences from field trials for CO_2, transport and storage activities in the Baltic Sea Marine environment. The regional knowledge, i.e. not site specific data, is well documented in the EIA reports studied in this work. The current information and data can be used in a future EIA for CCS development in the region. However, the ecological and environmental situation is constantly changing so all data has to be reviewed and updated in a future EIA study. There is also a geographical limitation, such that the only detailed information available is restricted to the Nordstream pipeline corridor and to the Dalders area. Different field studies have initially been carried out in both projects. As an example, from the sea floor of the Dalders area sampling points have produced sediment cores which have been analysed for metals and environmental pollutants. The sediments were found to be burdened by the metals lead (Pb) and zinc (Zn) and above all, organic pollutants. In some cases they were heavily burdened by the pesticides chlordane and DDT. Oxygen levels and redox values in sediments were also measured.

Detailed seismic surveys together with side-scan sonar and video camera have been carried out resulting in detailed information about the physical situation on the sea floor.

The local knowledge described above was the situation at the Dalders location in 2007-2008 when the site survey was carried out. Obviously, the local knowledge can only be of use if a future CO_2 injection site will be located in, or close to the Dalders area or some point along the Nord Stream pipelines. As the Bastor2 geological assessment indicated that an area further to the north east from Dalders, towards Latvia could be of higher potential for storage, the key value of the two cases studied here is the methodology, whereas the actual results could serve rather as reference information.

3.3 Tentative EIA work plan

Annex 2 is a compilation of the minimum required topics of investigation to be included in an EIA for a field trial project involving CO_2 transport and injection and the ensuing monitoring. This may be modified, depending on the specific CO_2 related aspects identified. The data should be broad enough to provide a regional characterization of the offshore Baltic Sea Area and yet specific enough to adequately describe the local areas around the proposed transport and storage of CO_2.

The work has included a preliminary cost estimate for a field trial project EIA. The two main cost elements are the resources needed for analysis and documentation, estimated to between 162 and 278 work days and the extensive field activities, estimated to cost between 1.1 and 1.9 mSEK.

3.4 Summary

One objective of this work was to document current knowledge, hazards and risks about environmental impacts in the light of a possible future CCS project in the offshore Baltic Sea Area. Another objective was to present a tentative EIA work plan for a future CO_2-injection field trial with the intention to add new knowledge to what is already known or applicable to CCS activities in the offshore Baltic Sea Area.

The literature studies included Environmental Impact Assessment reports from the Nordstream pipeline project and from the proposed OPAB test drilling project. These have both documented the ecological and environmental status both regionally and locally in the offshore Baltic Sea Area. These data could be of generic value in a future EIA for CCS development in the Baltic Sea Area. Locally though, data is limited to on the one hand the corridor along the Nord Stream natural gas pipelines and on the other to OPAB's Dalders location south east of the island of Gotland. This means that if the CO_2 injection site would be located in the area described in the OPAB EIA report, a certain extent of the presented data there can be of use but updates are necessary due to the changes in the sea and bottom environment taking place over time.

The project has also studied EIA reports made for specific CCS projects. From these reports aspects relating to the handling and injection of carbon dioxide have been derived, which should be included in an EIA also in this area. A side effect is that key organizations with substantial competence within CO_2 transport, storage and environmental risk, are identified.

The catalogue of knowledge will be of use when an EIA team is planning the work and content, especially the identified knowledge gaps which might occur in connection with CO_2 injection activities and site development. The project has therefore also produced an outline work plan for a future EIA including a preliminary cost budget. Swedish regulations point out what must be included in an EIA for offshore activities. These mandatory items are pinpointed in the plan, along with a number of recommended items. The tentative work plan, proposed EIA content and time/cost estimation in this report can serve as basis documents for a tender process for a field trial EIA. The estimated cost for an EIA is in the range between 3.5 and 5.5 mSEK.

4 Communication and acceptance

IVL Swedish Environmental Research Institute in collaboration with the University of Linköping conducted a study about the plausible perceptions of CCS projects. A key part of the approach was to study three non-CCS but energy related projects of industrial size in the Baltic Sea region.

4.1 Background

In Sweden, CCS is included as a prioritised area within the energy and climate policy framework, recently documented by the Environment Protection Agency in its preparatory work for the Swedish Roadmap 2050 for reaching zero net emissions. Some early, continental European demonstration projects have faced opposition among different stakeholder groups. As a result, communication and acceptance of CCS is now seen as one of the subjects high on the CCS agenda. Importantly, this is not limited to the general public, as it includes perceptions among different stakeholder groups. For this reason, the study divides stakeholders into three main groups:

- Project owners – Organisations with an economic stake in the project
- Non-project owners – All other, non-state, organisations and individuals
- State – Public organisations, such as ministries, agencies, and municipalities

In order to evaluate the potential for storing carbon dioxide in the Baltic Sea, being the main scope of the BASTOR2 project, understanding the acceptance and various views of CCS, is a key element in the assessment of its potential feasibility. However, with the perceived low Swedish awareness of CCS and the fact that no CCS infrastructure exists in the Baltic Sea, surveys on the public's perceptions is likely to result in hypothetical results of poor quality. Therefore the team decided on a methodological approach to analyse three case-studies of large energy projects that have been planned or undertaken in the Baltic Sea. These projects are the SwePol Link, Nord Stream and oil prospection by OPAB. Compared to studying a hypothetical CCS project, this provides an experience-based and complementary approach which can provide realistic results. The case-studies were complemented by a literature survey of international lessons on communication, perceptions and acceptance of CCS. Feedback on preliminary results was gained through a closed workshop with project participants and case-study representatives.

The three studied projects were analysed in relation to the following research questions:

- Which stakeholders have opposed or supported the projects?
- Which have been the arguments within the different stakeholder groups?

The aim was to identify key aspects, recommended considering when initiating and executing a project to store carbon dioxide under the Baltic Sea. The purpose is to provide input to a subsequent phase of BASTOR, which would possibly engage in physical storage activities.

The communication around each project has been studied from the point in time when they occurred as an item for general discussion, to the point when decisions on operational permits had been made. This includes a period before the permitting process as well as the different stages and activities of this process. The latter can include environmental impact assessments and public consultations. The projects were studied by means of interviews with stakeholder groups and through analyses of media and published literature around the projects. Interviews were carried out between October 2013 and May 2014.

4.2 Discussion

The authors discuss the implications that the case-studies and literature review suggest in relation to societal aspects of a Baltic Sea storage project. This includes the topics, or contexts, most likely to influence social concerns:

- Proximity to operations (incl. offshore vs onshore)
- The Baltic Sea and its environmental status
- Differences between capture, transport and storage operations
- Climate change and type of emissions
- Economic benefits
- Investing to solve concerns
- Foreign interests and security
- Other

Looking at the results from a stakeholder group perspective, rather than each of the topics of concern as above, could provide additional societal insights. However, not much can be concluded in terms of uniform opinions across stakeholder groups and perceptions. From a general perspective, it should be emphasised that acceptance for CCS developments is not only a question of public perceptions. It is equally important in relation to industries and businesses, organisations, politicians and policymakers.

4.2.1 Conditions affecting perceptions and acceptance

The most commonly discussed factor influencing perceptions and acceptance among different stakeholders is spatial discounting (similar to NIMBY, i.e. “not in my back yard”). Individuals are increasingly risk averse, the closer a perceived hazardous activity is to places of living, working or other interest. This means that building a capture facility, transport solution or storage operation close to residential areas includes a gradually increasing risk of being opposed. This leads to one of the more common conclusions in terms of reducing general opposition, that offshore storage will in most cases be less opposed than onshore. Based on experiences in the EU and Norway, this argument appears robust and could imply that an offshore storage project in the Baltic Sea would face little opposition, being located a significant distance from land and not visible from land. However, a storage project that includes a platform would likely face more opposition, as was the case for the inspection platform originally planned as part of Nord-Stream.

Interestingly, both the SwePol and Nord Stream case-studies highlighted that a relatively low opposition of the marine activities did not mean low opposition towards the project as a whole. In the SwePol-case, the opposition focused on the onshore activities. In the Nord Stream project the construction hubs became points of concern for both the general public and the state. Hence, even if the majority of the operations of a storage project are located offshore, such a project could face opposition on the basis of the land-based activities. Therefore, a project should not neglect the contexts within which onshore activities are embedded.

The sensitivity of projects located in the Baltic Sea was analysed, under the assumption that this would cause concerns of varying nature, like its history of providing foreign security, its economic and cultural values and for being home to inhabitants and tourists on the islands of Gotland and Öland and along the coastlines. However, the results indicate that the activities offshore do not cause strong concerns among the general public. Moreover, the Baltic Sea’s environmental status could be challenged if accidents would occur, possibly triggering stronger opposition. The studies showed that this was the case, but in different ways, suggesting that it is difficult to predict the actual focus points. The SwePol and NordStream cases resulted in concerns about the local environmental status of the seabed. The OPAB case however exhibited concerns more focused on the general environmental status. In sum, a storage project is likely to face arguments of opposition that relate to the environment in the Baltic Sea, but that these arguments may take different shapes and forms.

Perceptions and acceptance may differ for the capture facilities, transport solutions and the geological storage. Experiences from early CCS operations have proven that storage is the part of the technology which has faced most opposition, however less so for offshore activities. This does not mean that capture or transport solutions have not been opposed. For example, the Test Centre Mongstad faced opposition from local residents based on concerns about the toxicity of the amine acids transported to the plant and used in the process. These concerns were dealt with by testing and communicating the risk for emissions and the operational safety. The case-studies suggest that it may well be the emitting operations that will be in focus of opposition. In the cases of NordStream and SwePol, it was the pipeline and cable users who faced the strongest opposition, not the constructers. While not specifically analysed, and hence a point for additional research, this could mean that it is not the storage operator that will face most opposition when constructing CCS infrastructure. It could instead be the operator, whose emissions are subsequently stored. This would follow the logic that these operations would be perceived as the root of the problem (i e causing the need for a pipeline, cable or carbon dioxide storage) and those benefitting economically from the project in question.

However, the case studies and literature add complexity to the above. As was found in one study, the opposition may be significantly reduced when the transported and stored gas is biogenic. The same has been found in several expressions in media and by politicians, all in different ways concluding that applying CCS to biogenic emissions is more favourable than for fossil emissions. There is however less information on how perceptions and acceptance are influenced by emissions originating from industrial processes. A reasonable assumption would be that views on such emissions would be positioned between the views on biogenic emissions and fossil emissions. While CCS addresses concerns of climate change, a *very large* concern for 44 % of Swedish people (SOM, 2014), the technology can be perceived both positive and negative in the climate context. Positive perceptions include avoided emissions of carbon dioxide to the atmosphere. Negative perceptions include the potential prolongation of the use of fossil fuels and the risks of leakage. The NordStream case-study showed that perceptions of climate change worked in favour of the project. Some environmental organisations identified a reduction of EU emissions in the medium term, with the gas replacing coal. Consequently it could be favourable for an initial storage project to use carbon dioxide from Swedish biofuel combustion or process emissions from industries. This would provide a climate argument, while avoiding the negative fossil connotations, as well as a potential economic benefit through industries being able to use CCS as a tool to deal with a potentially higher future price on carbon dioxide emissions.

Literature provides strong support that economic benefits are an important factor in determining the level of support or opposition. Possibly even the strongest. A question for a Baltic Sea storage project is however what level of direct economic benefits that exists, which local groups may gain from and to which extent this gain is needed. The latter included as the economic benefits are a stronger factor if positioned within a community with low incomes or unemployment. The economic benefits also have a spatial component. As a pilot storage project will be small and be located far from land, it can be questioned to which extent there will be any perceptions of economic benefits. Being highly specialised, it can also be questioned to which extent the operation will use local businesses and other resources (i.e. in the areas most likely to strongly support or oppose). On the one hand, if relating to the need to handle emissions from the Swedish industry sector, the job argument may apply. This would however apply on a national level, which is likely to have smaller effects on local perceptions. In terms of storing carbon dioxide in the Baltic Sea, both Cementa’s Slite plant and SSAB’s plant in Oxelösund display local connections.

Both Nord Stream and SwePol paid a risk premium to avoid opposition in choosing technologies that were significantly more costly and less proven (i.e. assuming a technological risk as well as higher capital and operational expenses). These investments were chosen based on opposition against the initial plans. In the Nord Stream case, local concerns such as sound pollution, was also dealt with by funding sound proofing of windows where trucks could disturb residents. The project moreover dealt with opposition from the fishing industry by funding development and purchases of new trawling nets as well as insurances against damaged nets due to the pipeline. In the SwePol project, decisions were taken to invest in technologies that were less opposed, even if this increased both capital and operational expenses.

As a display of trust concerns, being a common determinant for acceptance, the key point of opposition towards the Nord Stream project and its plans, were the Russian interests in the project. This kind of opposition was not witnessed in the SwePol project, although being a transnational project. Two of the aspects differing between the projects is firstly that Sweden benefitted economically from the SwePol project, but not from Nord Stream, and secondly the historically less problematical relations with Poland relative to those with Russia. While being based on one single case-study, the conclusion on this aspect is that while a storage project may benefit a broad group of investors, including foreign interests may provoke opposition to a varying degree.

A storage project in the Baltic Sea will be the first of a kind in Sweden, which in itself will have several implications. As identified in the Nord Stream project, novel aspects meant a political contentiousness as well as uncertainties about the permitting process. Ministries as well as agencies with responsibilities in this process were, according to project owners, reluctant to engaging in an early dialogue or to providing guidance.

When comparing the cases of SwePol and OPAB, there is a phenomenon of incompatible perspectives, causing confusion of language and embittered feelings on behalf of those left feeling aggrieved. In the former case, the local opposition could not understand why their attempts to relate the planned project to a wider discussion about energy and climate change, always fell on deaf ears. In the latter case, it was instead the project owner who could not see the logic behind the Government's reasoning in turning the application down. In both cases, the Government has played a crucial role. In the cable project, it took a leading role in closing the issue for certain aspects, disregarding arguments relating to wider issues of climate change, whereas, in the latter, it did precisely the opposite, i.e. widening the issue to include deliberations on climate change. The conclusion is that there is a need for a more transparent and clear status of climate change aspects in large-scale infrastructure projects, since this would facilitate a discussion where the premises are obvious to all actors involved.

4.2.2 Methods to guide communication

In communication science and practice, there are several theories and methods that describe what is considered appropriate strategies and ways to formulate messages. Social site characterisation is one of the methods that aim for practitioners (project owners) aiming to analyse a project's social setting and its needs for a communication agenda. The common methodologies can be summarised as dividing the process in the following steps:

- Context analysis
    - Identify socio-economic context
    - Identify political context
    - Identify cultural context
- Stakeholder analysis
    - Identify stakeholders
    - Map stakeholder interests
    - Map stakeholder concerns and perceptions
- Project-related analysis

The above highlights the steps to consider and puts the previous sections' insights into a procedural perspective of project communication. The steps overlap to an extent, but the concept is to firstly identify the contexts in which the project is embedded. Thereafter stakeholders are identified and mapped. This data is then brought into the project's context, providing an analysis of which topics and concerns that are likely to be a result of the project plans. One of the ideas behind these methods is to identify whether a project is *de facto* feasible. Some projects will simply be difficult or even impossible to realise in some areas for a number of reasons.

4.3 Conclusions

Robust conclusions about the implications of the analyses made, for storing carbon dioxide in the Baltic Sea, are difficult to make. This follows the differences exhibited by the case-studies as well as lessons from literature and CCS projects. However, it is possible to point to topics that are more or less likely to cause opposition or support. These are topics that consequently should be seen as prioritised in developing and executing a communication agenda. Including these topics in a proactive, transparent and honest communication agenda would provide a deliberative and participatory agenda.

Two of the key determinants for opposition and acceptance are the proximity of the operations and the economic benefits. In terms of the former, the Baltic Sea appears to be further away than what would cause local concerns. However, this arguably also reduces the perceived rate of economic benefits as the socioeconomic context becomes largely nullified. Should the project however be positioned in relation to the long-term success of the Swedish industries, there could probably be those who would identify benefits. This would then mostly apply in a national context, rather than local.

Similarly to the above benefits, the climate change argument for CCS is more applicable on a national level. In a local context, CCS' contribution to mitigating climate change is more a side effect. Hence, for a project offshore, the local discussion is largely non-existent, meaning that regional and national communication will be relatively more important and as a consequence also the climate argument.

However, the presence of large point sources (Cementa in Slite and SSAB in Oxelösund) close to the prospective sites for Baltic Sea storage could provide a local context and increase perceived benefits. This could potentially be strengthened, should the stored carbon dioxide be captured at one of these operations, not merely offer a future potential of storing the emissions. The same could potentially also be achieved by storing carbon dioxide with a biogenic origin.

Acceptance should not only be seen as relating to the general public's opinions. Important stakeholders that may drive the need for communication can be businesses that do not have a stake in the project. It can be state actors on different levels and may, naturally, also be ENGOs.

Another important factor is that a storage project is likely to be a first of a kind project for the Swedish public, businesses and policymakers. This will add to the complexity of predicting perceptions and concerns of the respective stakeholders. Such a project should consequently acknowledge this challenge and engage in early analyses and communication in dealing with a broad group of stakeholders with different levels of awareness and perceptions on climate change, emitting industries, the Baltic Sea and CCS. Another conclusion is the importance to avoid focusing the communication on the results of an environmental impact assessment (EIA), as this can be perceived as technocratic and undemocratic. While an EIA can be an important tool, a range of other concerns should be included on the communication agenda.

As stated by Nord Stream project owners – prepare to discuss more concerns than you thought possible with more stakeholders than you thought would be interested.

4.4 Summary

Carbon capture and storage (CCS) has in many countries and regions been highlighted as one of the measures needed to manage the climate problem. The technical and commercial development has in some cases however been impeded by projects and project plans facing opposition. Against this background, this report describes the results of a study, within the BASTOR2 project, analysing which social factors that may influence the plans for a Baltic Sea storage project.

The analysis has been carried out through three case-studies of other energy related projects in the Baltic Sea. The reasons for this being the lack of storage projects to study in the region. At the same time, literature points to local and regional contexts as having a large influence on the perceptions and acceptance of CCS projects. The report consequently highlights a number of contexts, or conditions, that are identified as important for how the case-studies have been perceived and discussed as well as accepted or opposed in the local to national perspectives. These conditions should be considered when analysing the social contexts and need for communication by means of different methods (e.g. social site characterisation).

This includes:

- The proximity of an operation to populated areas (incl. whether the operation is onshore or offshore)
- The environmental status of the Baltic Sea
- Differences between capture, transport and storage operations
- Climate change (incl. from which operation the carbon dioxide originates from)
- Possible economic benefits from a storage project (e.g. job opportunities)
- Possibility to deal with concerns through funds or investments
- Foreign interests in the project (incl. foreign security)

However, while these are identified, differences between the case-studies make it difficult to draw robust conclusions. These findings are in agreement with literature on CCS and EU experiences from CCS projects. The general conclusion is that even the most well thought-out plan for communication may fail. The report however provides insights into which aspects should be considered and thus increased possibilities to identify and responsibly handle the social conditions associated with a Baltic Sea CO_2 storage project.

5 Legal aspects

David Langlet of Stockholm University was commissioned by Elforsk to analyze legal and fiscal aspects of CCS in the Baltic Sea region. The study was carried out jointly with Nils Rydberg, an independent consultant who brought expertize on the CCS value chain and its actors.

5.1 Background and approach

The purpose of the Bastor 2 project is to assess the potential for geological storage of CO_2 in the Baltic Sea and to identify barriers to CCS implementation. In the longer term, the project will also lay the groundwork for possible future commercial development of common cross border infrastructure for transport and storage of CO_2 in the Baltic Sea region. The evolution of a well-functioning legal framework for regional CCS operations is expected to be time consuming for which reason the early identification of potential hurdles is critical to all stakeholders.

The main outcome of this work on legal and fiscal aspects is an analysis of the current and suggested legal framework that would regulate CCS activities in Sweden and in the wider Baltic Sea region. Although taking Sweden as a starting point, this inevitably includes a significant focus on the EU CCS Directive (Directive 2009/31/EC) and related pieces of EU law and their implementation by relevant EU Member States. The report's core aim is to give an account of the legal framework and how it is likely to affect various actors along the CCS value chain. This includes the identification of legal obstacles and gaps as well as analysing the incentives and disincentives that are created by the law in its current form. Key to doing this is to understand the dynamics of the CCS value chain from capture to storage and to view the applicable rules in relation to this dynamics. The analysis also includes legal aspects of the classification and potential commercial use of captured CO_2 as well as issues pertaining to third party access to common transport and storage infrastructure with a focus on what (dis-) incentives are created through the existing rules (or the lack thereof) in this area. Since regional, and thus transboundary, CCS solutions are likely to be needed to make CCS feasible, the legal and fiscal impediments to transboundary movements of CO_2, above as well as below ground, are other important elements of the analysis. Particular attention is given to the implications of the EU-Russian border in the Baltic Sea (see Annex 1). Another consequence of the regional nature of the envisioned CCS infrastructure is that the extent to which the regulatory framework is harmonized between the countries in the region becomes an important issue which is dealt with as part of the assessment of regulatory obstacles to CCS deployment.

In addition to providing increased understanding of the legal framework and its defining impact on the CCS value chain, the objective was also to include recommendations as input to the discussions regarding the imminent (2015) revision of the CCS Directive.

In the work the legal aspects along the physical CCS supply chain were analysed by describing this as a decision tree in the shape of a flowchart. Geographically the study was limited to the countries bordering the Baltic Sea and had the Swedish legislation as its main focal point. By necessity several issues were dealt with at EU and international levels, e.g. because they are regulated by means of EU- or international law. The conclusions rest on analyses of applicable law, and reviews of academic literature and reports, including those generated within other Bastor2 work packages. In addition, interviews were carried out with key persons at some authorities and in one company. Data on the respective EU Member States' implementation of the EU CCS Directive were, except for the case of Sweden, derived from official EU (or other) publications.

In comparison with the project's Baltic Sea CCS vision, the EU CCS Directive has a narrower perspective, in terms of the means of transport, methods of storage and also a restricted territorial scope. The work was built on these but did also problematize this narrower understanding of CCS. In the EU regulatory framework the core notion of captured CO_2 has a rather clear endpoint, i.e. the storage, but the legislation lacks in clarity as to the exact point when CO_2 is to be regarded as captured. Whereas the EU Emissions Trading System, ETS deals with the operation of the cap and trade system and defines who is covered by it the CCS Directive regulates storage and indirectly to some extent capture of CO_2 and transport as processes. None, however, is very clear on the exact entry of captured CO_2 in the system. When the CCS legislation steps in, captured CO_2 already exists. One of the objectives of the report was therefore to assist in finding and defining the starting point of the captured CO_2 as relevant for the CCS value chain. Similarly, identification of the divergence points in cases where captured CO_2 ceases to be regarded as captured in the light of the EU ETS and the CCS Directive are highlighted in the report. It is also an important task to make the distinction clear between those potential operators along the CCS value chain who are covered by the EU ETS/CCS regime and those who are not and the implications of this.

5.2 Legal premises

The EU Member States carry a far reaching responsibility to ensure that the various elements of EU law become effective. This means that the Member States shall take any appropriate measure to ensure fulfilment of the obligations resulting from the acts of the institutions of the Union. These include directives such as the one on CCS. The Member States are also generally obligated to facilitate the achievement of the Union's tasks and to refrain from any measure which could jeopardize the attainment of the Union's objectives. These requirements, have been elaborated by the EU Court which has established that when an activity, such as the geological storage of CO_2, requires a permit under EU law, the Member States are obliged not only to set up a permitting system but also to make sure that the system is actually applied and complied with.

Currently, when very few CCS activities are yet in place within the Union, the issue of the Member States' compliance with the EU's CCS legislation is mostly formal and primarily concerns the correct and timely transposition of the CCS Directive in the Member States. Directives are not as such applicable in the Member States but must be implemented in national law in order to become effective. They leave considerable leeway for the individual Member States to achieve the results by means that are appropriate within the context of their own legal and administrative structures. In the specific context of the CCS Directive the Member States were required to bring into force the laws, regulations and administrative provisions necessary to comply with the Directive by 25 June 2011. By the deadline in June 2011 only a few Member States had reported either full or partial transposition, for which reason the Commission sent letters of formal notice to 26 Member States. The obstacles to transposition encountered by Member States have involved e.g. widespread public opposition to CCS and problems related to complex division of powers between regions and central government affecting the ability to put the required rules and regulations in place. By October 2013 however, all Member States had notified transposition measures. Sweden has adopted a government ordinance on geological storage of carbon dioxide (Swedish: Förordning 2014:21) and communicated its transposition measures. Against this background it may be concluded that the Baltic Sea coastal States that are also EU Member States, i.e. all except Russia, have by now taken measures to implement the CCS Directive. It should be noted though, that Member States are not actually required to allow the activity with which the Directive is concerned, for instance geological storage of CO_2. If a Member State does not allow such activity, there is also no need to establish a procedure for assessing applications for storage permits. Therefore, the action a Member State must take to correctly transpose the CCS Directive varies depending on whether it opts for allowing geological storage under its jurisdiction or not. Sweden has in its transposition of the CCS Directive allowed storage operations in its economic zone, whereas Finland and Estonia have opted for not allowing such storage. Interestingly, Germany has restricted the annual quantity of CO_2 that may be stored to 4 Mt CO_2 as a national total.

In the report is also discussed the issue of harmonization of the legal conditions for CCS operations between the Member States. While from an environmental and health perspective harmonization may be preferable, the CCS Directive is based on the EU's environmental policy which only establishes a minimum of harmonization. This means that a common minimum level of EU wide environment protection is guaranteed but that at the same time also that the burden imposed on operators may increase, since the actual protection required may differ between Member States, making the establishment of common standards for transboundary operations harder to achieve.

Although the right to take additional protective measures is not without limits, it is sufficiently wide to cause divergent national rules. The uncertainty that follows from this right, and the time required to challenge the legality of any national measure is in itself a significant obstacle to the initiation of CCS projects involving Member States with differing standards.

5.3 What is the CCS value chain, from a legal perspective?

The report provides a technical account of the various components, boundaries and types of actors in a perceived CCS value chain. This also entails technical definitions of the terms used in the ETS regime and in the CCS Directive, such as captured CO_2, transport, purity, pipelines, third party access, (TPA) and storage. The legal regime around the EU ETS plant comprises the emission permit, ETS process, ETS outcome, emission allowance management and allowance surrender/auction/market. The emission permitting process as the starting point is a precondition for an EU ETS plant. The plant operation inputs fuel, labour, raw material and capital; outputs the end product and CO_2 emissions. The continuous ETS process receives emitted CO_2 data and outputs the ETS outcome with which emission allowance management interacts by surrendering or purchasing allowances in auctions or on the market or selling them on the market. Figure 7 depicts the generic system boundary, building up from two components: legal regime and plant operation as a CO_2 emission source, of a plant covered by the EU ETS Directive.

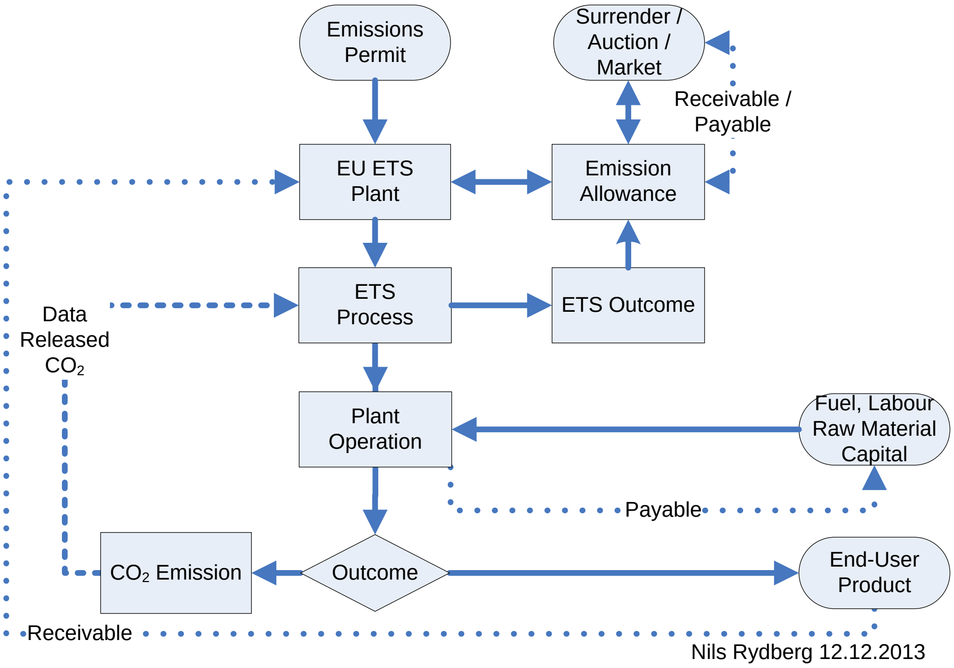

Figure 7 The generic system boundary

Captured CO_2

The CCS value chain extends the generic system boundary. In this context the logical component ‘legal regime’ remains the same but the ‘source’ has another meaning compared to the base line; it is simultaneously a CO_2 emission source and a CO_2 capturer, why these two together could be considered the one, main component ‘Plant Operation’. From there the term ‘captured CO_2’ can be further analysed, with the purpose of bringing clarity as to the exact point when CO_2 is to be regarded as captured. The authors ask the question: “Where does isolated CO_2 turn into captured CO_2 in the meaning of the ETS, CCS Directive and other relevant legislation?” and offer an answer based on the process steps involved. CO_2 separation is a complicated process, the characteristics of which may differ significantly between different technologies. After going through the conditioning phases, the CO_2 is expected to conform to the CCS and ETS regimes and according to the CCS Directive, the EU ETS, and other relevant legislation, CO_2 that has been captured is defined as ‘captured CO_2’ when it is an output from the final conditioning and compression process.

Purity

The requirements on the purity of the carbon dioxide is regulated under Article 12 of the CCS Directive, stating that the flow of substances that results from CO_2 capture processes must consist ‘overwhelmingly’ of CO_2. This is then elaborated by the statement that concentrations of all incidental substances from the source, capture or injection process as well as of any trace substances that may have been added to assist in monitoring must meet certain requirements. The fundamental requirement is that such substances may not adversely affect the integrity of the storage site or the relevant transport infrastructure or pose a significant risk to the environment or human health. Only streams that have been analysed as to their composition, and for which a risk assessment has been carried out, may be injected. Therefore, it is clear that the purpose of the purity requirement in the Directive is to uphold the safety of the transport and storage operations. There are non-binding values for CO_2 stream purity but the competent authority will have to determine an acceptable CO_2 stream composition in each case. The Member States are allowed to apply stricter purity standards than what is articulated in the Directive. The Swedish Ordinance (2014:21) requires the CO_2 stream to be 'composed exclusively of carbon dioxide' whereas the Directive states that it 'shall consist overwhelmingly of carbon dioxide'. This could become a complication as and when Swedish CCS project operators wish to export CO_2 for storage in another Member State with different or even less stringent purity requirements. The report therefore concludes that in cross boarder situations the relevant competent authorities from each country should work together to establish a cooperation structure that is transparent to the actors concerned.

Pipeline transport

CO_2 transport in pipelines is discussed from a legal perspective and it is stated that the aim of the CCS Directive is not only to control the technical properties and the technical use of the infrastructure but that its primary mission is to assist in developing a functioning market. A pipeline solution the way the CCS Directive sees it is purely theoretical while the third party access (TPA) regulation is a reality that entails market distortion risks. Thus it is well justified to advocate the participation of the competition authority in the early planning stages of any pipeline solution so as to forestall market distortions. Pipeline installations may be planned to cater for the demands from several ETS plants and if these are non-competitors the pipeline routing and dimensioning cause less threats of market distortion. The CCS Directive does not recognize market distortion as an argument for TPA refusal. This could potentially have a hampering effect on pipeline routing and ultimately on CCS deployment. In industrial cluster formations there is a risk that competitors become too transparent to each other, which from a competition point of view is unwanted in concentrated markets like energy, pulp and paper and steel industries. In case a cluster will be developed it ought to happen under the control of the competition authorities in order to prevent competition distortions.

Ship transport

CO_2 transport by ship may under certain conditions be the most cost-effective solution and also provide the flexibility that can be highly desirable during a ramp up phase of a regional CCS infrastructure. The Swedish Government has described ship transport of CO_2 as a likely prerequisite, at least initially, for making CCS commercially interesting. However, there are legal challenges confronting ship transport in a CCS scheme, linked to the fact that transport of CO_2 by ship is not covered by the EU ETS. This follows from ship transport not being mentioned in Annex I of the ETS Directive which sets out the categories of activities to which the Directive applies. In line with this the Commission Regulation on monitoring and reporting of greenhouse gas emissions pursuant to the ETS Directive defines 'CO_2 transport' as 'the transport of CO_2 by pipelines for geological storage in a storage site permitted under the CCS Directive without any mentioning of transport by ship. Clearly put, this means that captured CO_2, transported by ship, does not benefit from the exemption from the obligation to surrender emission allowances, since it is unlikely that CO_2 transported by ship could count as 'verified'. Article 24 of the ETS Directive provides a mechanism for unilaterally including activities not covered by the trading scheme. This opt in clause could enable shipping to be integrated in the ETS on a case-by-case basis although the report argues that this would be a lengthy, cumbersome and probably costly process for individual project operators to go through. Since regional CCS networks, like the one(s) envisioned for the Baltic Sea area, may be particularly reliant on the flexibility provided by ship transport it seems that an amendment of the ETS Directive and related EU legal acts to cover CO_2 transported by ship is an issue that representatives from the region may be well advised to push at the EU level. In fact, the Swedish Government has concluded that Sweden ought to pursue the inclusion of ship transports under the EU ETS.

Storage (sink)

The report goes on to discuss the various applications, where carbon dioxide is used for commercial purposes, but argues that from a climate perspective these merchant volumes are negligible with a total, global and annual volume of around 20 million tons and also that most of the applications do not keep the CO_2 away from the atmosphere more than very briefly, like for instance the carbonisation of beverages.

The ETS Directive does not explicitly include any such applications or uses of carbon dioxide, also not Enhanced Oil Recovery, EOR. The term EOR is here used synonymously with enhanced hydrocarbon recovery, EHR. Whereas none of the substantive provisions of the Directive mention EOR, the preamble (introduction) holds that 'EHR is not in itself included in the scope of this Directive.' The actual process of EOR is explained in quite some detail and it is stated that although typically 30-50% of the injected CO_2 remains in the geological formation after closing the EOR operations, the operation as such is thus not concerned with storage of CO_2 and from a regulative perspective does not qualify for any ETS credits. From a market point of view though, the price that the oil field operator is willing to pay for the CO_2, could still motivate the capture operator to send CO_2 volumes off for sale to EOR operations.

5.4 Transboundary issues

One of the pillars of the EU is the establishment of the "internal market", meaning a o the free movement of goods and the prohibition of customs duties between Member States. With respect to captured CO_2 intended for geological storage in accordance with the CCS Directive this means that no customs duties may be imposed as a consequence of the CO_2 being transported between EU Member States. CO_2 captured and transported for the purpose of geological storage according to applicable EU law has also been excluded from the general EU legislation on waste meaning that the additional restrictions and procedures that apply to waste management do not normally come into play.

Export to a non EU Member State

With respect to any potential shipment of captured CO_2 outside of the EU, notably to Russia, the situation would be different. The rate of the import duty currently applied to

CO_2 when imported to Russia is 5 per cent of the customs value. The customs territory of the Russian Federation includes installations and structures situated in the Russian exclusive economic zone (EEZ) or located on its continental shelf and is subject to the jurisdiction of the Russian Federation in accordance with Russian federal law. It is hence not likely that shipments of CO_2 to an injection point within the Russian EEZ would be exempted from import duty on the basis that it does not reach Russian territory.

A second important issue to be considered in relation to any such export of CO_2 outside of the EU is that the CO_2 would no longer be verified as captured and transported for permanent storage to a facility for which a permit is in force in accordance with the CCS Directive since no such permit can be issued for a storage site outside of the EU.

There is however also a third, even more significant, obstacle with respect to prospective export to Russia, or any other non-EU Member State. The above mentioned exemption from the waste legislation of CO_2 captured and transported for geological storage is not applicable for export outside the EU. Since the amended waste definition only applies with respect to CO_2 managed in accordance with the CCS Directive and that the Directive only applies within the territories and marine jurisdictional zones of the EU Member States, CO_2 transported for storage beyond these areas will be considered waste under EU law. Geological 'storage' with no intention of ever retrieving the CO_2 qualifies as disposal, why the implication is that export of CO_2 for disposal is prohibited. The current state of the waste legislation thus in effect rules out projects involving injection of CO_2 from EU Member States in the Russian part of the Baltic Sea. However, the export prohibition does not apply to the EFTA States, including Norway, which are all parties to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal. To facilitate export to Russia, two options could be possible. Firstly, an amendment of EU waste law suspending the waste definition and secondly to subject CO_2 intended for storage outside the EU to the same procedure as currently applies to export of waste for disposal to EFTA countries, of which the latter appears a less far reaching option.

The London Dumping Protocol

Exporting captured CO_2 for storage in sub-seabed geological formations, the form of storage of most interest in the context of the Bastor project, is prohibited for the Parties to the 1996 London Dumping Protocol. Dumping at sea has since the early 1970s been regulated under the London Dumping Convention which was the first instrument to address marine pollution by dumping at the global level. In 2009 an amendment to the relevant article of the Protocol was adopted. It allows for export of CO_2 streams for disposal provided that an agreement or arrangement has been entered into by the States concerned. Such an agreement or arrangement must include 'confirmation and allocation of permitting responsibilities between the exporting and receiving countries, consistent with the provisions of [the] Protocol and other applicable international law'. However, the amendment will only enter into force once it has been formally accepted by two-thirds of the Parties. The acceptance procedure is expected to be given low priority by many of the Parties why it is today uncertain which effect the amendment will finally have and when, if ever, it will actually enter into force. There is activity to overcome this hurdle and not least the International Energy Agency (IEA) has proposed a number of options for the Parties to address the current stalemate, where the most promising seems to be the conclusion of a so called subsequent agreement. However, the Protocol includes obligations that are owed in relation to all Parties and for this reason any agreement that does not include all Parties must be construed in such a way that the rights of any Party to the Protocol who is not also a Party to such subsequent agreement are not injured in any substantive way.

Transboundary migration

Under the CCS Directive no site for the geological storage of CO_2 may be operated without a permit issued by the competent authority in the Member State under whose jurisdiction the site is located. A precondition for issuing such a permit is that the planned injection does not involve a storage site with a storage complex extending beyond the territory of any EU Member State. For the Baltic Sea region this could potentially be applicable for formations extending into the Russian exclusive economic zone, EEZ.

The Directive does not provide any reasons for disallowing the use of storage sites with a storage complex extending beyond EU territory but the fact that the concerned Member States, have very limited rights to carry out monitoring operations and take so-called corrective measures in order to prevent leakages or other irregularities beyond their respective territories and maritime zones, is likely to have been an important factor. Correctly accounting for any such leakage under the international climate regime is also likely to be challenging.

The authors discuss the extent to which this regulation might actually prohibit injection and note that the scientific estimates of the geological conditions that prevail in the southern Baltic Sea indicate limited movement of injected CO_2 and find it unlikely that any significant migration would occur for several thousand years. For this reason the remaining risk for such movements is unlikely to constitute any real problem for permitting in relation to actual storage sites as long as it is not a site where the actual storage complex stretches beyond the EU's outer boarders.

The above does not affect the right to make use of storage complexes that straddle the territories of two or more EU Member States. The utilization of such complexes is foreseen by the CCS Directive which requires the Member States concerned in such cases to jointly meet the requirements of the Directive and of other relevant EU law. The Directive does not, however, make it clear how the responsibilities are to be allocated between the Member States concerned.

As far as international law is concerned the Parties to the London Protocol have confirmed that transboundary movement of CO_2 after injection (i.e. migration) is not export for dumping and therefore not affected by Protocol's prohibition on export.

5.5 Third party access (TPA)

Pipelines connecting CO_2 sources to a storage site have been deemed to be so called natural monopolies. In order to address the problems associated with infrastructure monopolies the CCS Directive includes rules on TPA to transport networks and storage sites. However, the relevant provisions are not very precise and leave Member States considerable discretion when implementing and elaborating the requirements in national law. The EU Commission initially contemplated a more elaborate approach imposing specific rules for achieving equal access to relevant infrastructure, but it was deemed that far-reaching regulation of third-party access would not be a proportional measure at such an early stage in the development of CCS technology, not least since the Commission found it likely that there in practice will be separate operators for the combustion and capture phase, on the one hand, and transport and storage on the other. It is hence up to the individual Member States to regulate the manner in which TPA is to be arranged, which could ultimately call for arbitration. The Member States are obligated to implement dispute settlement arrangements, and are required to consult each other in order to ensure a consistent application of the TPA rules in respect of transport networks or storage sites that fall under the jurisdiction of more than one Member State. Yet, the current lack of clarity does not prevent the actors concerned from dealing with these issues by means of bilateral agreements. The report lays out situations and conditions for third party access and how hurdles can be overcome by free or regulated negotiations. It also describes different tariff regimes which could be applicable to CCS.

The CCS Directive appears to be based on the simplified view that projects build their own point-to-point pipeline connections, from capture source to storage site. As has been described in the Bastor2 work package on infrastructure and in other reports about CO_2 transport, it is however likely that clusters of capture sites will be formed and that project operators will join and form consortia in order to share infrastructure costs. This applies not least in the Baltic Sea region, with many smaller emission sources and longer transport distances, as compared to continental Europe, with large coal fired power plants and relatively short distances to suitable geological storage. Therefore, the authors suggest that issues such as ownership of captured CO_2 streams ought to be clarified in order to avoid confusion and to lower negotiation costs among the parties concerned along a pipeline route.

Third Party Access could easily also become an issue of costs and the price to be charged by the pipeline operator for shipping gas. Concerning the costs and burdens which may result from TPA, the CCS Directive stipulates that:

… access … shall be provided in a transparent and non-discriminatory manner determined by the Member State. The Member State shall apply the objectives of fair and open access, taking into account:

….

(d) the need to respect the duly substantiated reasonable needs of the owner or operator of the storage site or of the transport network and the interests of all other users of the storage or the network or relevant processing or handling facilities who may be affected.

The Swedish Pipeline Law is not very specific on the compensation, merely requiring the concession holder to transport CO_2 for others *on reasonable terms*. The Finnish CCS Law is somewhat more specific by requiring reasonable compensation including return on capital.

The report states that the way TPA is designed in the CCS Directive does not incentivize CCS infrastructure and may even lead to systematic access refusals. The main reasons are the vagueness of the rules and the uncertainty about how they will play out in real cases as well as the omission to address the complexities of CO_2 transport. To some extent these problems can be dealt with through negotiations and agreements between the actors concerned. However, the more CO_2 streams that are added to a network the more complex it will be to deal with such issues and the less willing to negotiate are the parties likely to be. The authors suggest that the Natural Gas Directive and the way in which it regulates the roles of the market actors and constructs the principles for ownership/operation could provide a valuable point of reference for further elaborating the TPA system for CCS.

As a final conclusion on the topic of TPA, the report notes that ship transport may serve to minimize the risk for market distortion as well as to avoid bundling of ownership and activities. Ship solutions provide more flexibility compared to pipelines and give a low threshold for business entries and exits. Naturally, the TPA regulation in the CCS Directive, does not concern itself with ship transport.

5.6 Conclusions and considerations for the CCS Directive review

Captured CO_2

The point at which CO_2 comes to be regarded as 'captured CO_2' is not clearly defined in the legislation despite 'captured CO_2' being a core term. This may cause problems in the negotiation of transport contracts and with respect to TPA related issues. A clear definition taking also cluster development into account may lower the threshold for CCS deployment.

EOR market development

EOR could act as an enabler towards the full deployment of CCS. The report lays out the severity of the potential legal problems relating to transport and storage of CO_2 in conjunction with EOR projects, which may jeopardize the development of competitive markets for the EOR application. As these issues could play a central role in market failure mitigation they should be elaborated in co-operation between market actors and legislators in order to create optimal preconditions for EOR.

Prohibition on geological storage extending beyond the EU territory

The CCS Directive prohibits the utilization of any storage complex extending beyond the territory of any EU Member State. Although the geological assessment in Bastor2 indicates that significant migration of CO_2 geologically stored below the southern Baltic Sea is unlikely the prohibition would preclude the use of any such potential storage facility possibly extending into the Russian continental shelf. This could be a problem if one or more suitable storage sites were to have this characteristic. A possible remedy could be to supplement the CCS Directive with an agreement with the non-EU State or States concerned.

Responsibility for transboundary geological structures

The respective CCS and ETS Directives contain very little information on how transboundary storage sites are to be regulated and managed. With respect to pipelines that cross boundaries between Member States there is even less guidance. This may result in unnecessary uncertainty among potential operators of such facilities as well as within national authorities. Even if a revision of the Directives may not be called for, guidelines or some other kind of recommendations may be desirable in this area.

Export of captured CO_2 for sub-seabed storage – the London Dumping Protocol
Exporting CO_2 for sub-seabed storage is prohibited for parties to the 1996 London Dumping Protocol, including Sweden. Although an amendment to the Protocol has been decided it is unlikely to enter into force in the foreseeable future. There are measures which do not require consensus that could be resorted to, which would at least enable a good argument to be made that the interests of the Parties who did not join such action, had not been injured in any substantive way.

Transport of captured CO_2 by ship
Ship transport of captured CO_2, is currently not covered by the EU ETS regime. This means that any CO_2 transported by ship is likely to be treated as emitted thereby effectively making ship transport a non-viable option. Although the ETS Directive provides a mechanism for unilaterally including activities not covered by the trading scheme, which may enable ship transport to be included in the ETS on a case-by-case basis, this is an untested option and hardly a satisfactory long-term solution. The problem is most probably best dealt with at the EU level by means of harmonized measures. It would therefore be beneficial for the planned revision of the CCS Directive to consider integrating ship transport into the trading system as a supplementary option to pipelines.

Biogenic CO_2
Particularly for Sweden and Finland the possibility of including CO_2 from biomass could contribute to the financial viability and also to the climate impact of a regional CCS infrastructure. Currently there are no financial incentives for capturing biogenic CO_2 since such emissions are not covered by the EU ETS. There may thus be good reasons from a regional perspective to push for an expansion of the ambit of the trading scheme to also cover biogenic CO_2. In fact, the explicit position of the Swedish Government is that CCS applied to bioenergy production should receive equal treatment as CCS applied to coal fired power generation.

Third party access
It would be beneficial to create additional predictability regarding the interpretation and application of TPA rules, both within individual Member States and in transboundary settings. This could be done in the context of a revision of the CCS Directive but also to a significant extent by action at Member State level. An important step would be to develop rules or at least guidelines that consider the complexities of actual pipeline operations. It would likely also be very beneficial if competition authorities were formally involved in the planning and operation of CCS infrastructure from an early date.

Market actors and activities
Although the CCS value chain differs fundamentally from that for natural gas, the Natural Gas Directive provides a valuable point of reference in the way it regulates the roles of the market actors and constructs the principles for ownership and operation of structures including TPA concerns. The current Natural Gas Directive unbundles ownership of transmission system operators, requires the establishment of operator’s cooperation in Europe, and increases the powers of the national authorities. The authors therefore suggest that parts of the Natural Gas Directive with some minor amendments could become suitable for the regulation of CCS operations.

5.7 Summary

The purpose of the Bastor 2 project is to increase awareness of the potential for geological storage of CO_2 in the Baltic Sea and to identify barriers to CCS implementation. This report – the main outcome of work package 4 on legal and fiscal aspects of the Bastor 2 project – provides an analysis of the current and suggested legal framework that would regulate CCS activities in Sweden and in the wider Baltic Sea region. The evolution of a well-functioning legal framework for regional CCS operations is expected to be time consuming for which reason the early identification of potential hurdles is critical to all stakeholders.

This report's core aim is to give an account of the legal framework and how it is likely to affect various actors along the CCS value chain. This includes the identification of legal obstacles and gaps as well as analysing the incentives and disincentives that are created by the law in its current form. Although taking Sweden as a starting point the report inevitably has its main focus on the EU CCS Directive and related pieces of EU law.

The report utilizes a decision tree structure to describe the key interlinked business processes which form the CCS value chain, thereby enabling the identification of ambiguities or gaps in the regulatory system and highlighting the multiple factors that determine the effect of decisions made along the chain.

In addition to providing an increased understanding of the legal framework and its defining impact on the CCS value chain the report sets out a number of recommendations, primarily intended as input to the discussions regarding the imminent (2015) revision of the CCS Directive. Among these are a clearer definition of 'captured CO_2' and that more consideration should be given to potential market failures and the role of competition authorities in the build-up of CCS infrastructure. Particularly the rules on third party access to pipelines and storage sites are found to be quite vague at the EU level and thereby create room for problematic discrepancies between the Member States. In this regard the EU Natural Gas Directive could provide a valuable point of reference. The responsibility for any transboundary CCS installations or structures is also underregulated thereby causing significant uncertainties that ought to be addressed e.g. by means of relevant guidelines. As to the potential for storing CO_2 captured in the EU outside of the union, something which may be relevant in a regional Baltic context since parts of the Baltic Sea is under Russian jurisdiction, this is found to be impossible without significant amendments to applicable EU law. It is also concluded that further efforts should be made to enable transport of captured CO_2 by ship, something which currently is problematic due to the details of the EU emissions trading system (EU ETS), and that the inclusion of biogenic emissions under the EU ETS may also benefit the deployment of CCS in the Baltic Sea region.

6 Infrastructure for transport

The Bastor2 project's fifth work package has analysed the demand for transport infrastructure for carbon dioxide and possible transport solutions based on cost estimates for different scenarios. The work was commissioned to *panaware ab* and Chalmers University of Technology.

6.1 Methodology

The approach has been to first identify the five largest, single sources of carbon dioxide emissions, which could likely become first movers in deploying Carbon Capture and Storage, CCS, in Finland and Sweden, respectively. Although Bastor2 is a project funded and based essentially in Sweden, Finnish sources have been included since there is a good potential for combined cross-border transport and storage systems around the Baltic Sea. It has then been assumed that regional CO_2-hubs will evolve at the sites of the ten selected sources collecting captured CO_2 from other potential capture plants in the region. For all sources it has been assumed a flat capture rate at 85% of the official year 2010 CO_2-emissions. The ten selected sources and their CO_2 emissions (in tons per annum, tpa) and the assumed capture volumes are shown in Table 5.

Table 5 The five selected, assumed first CCS-projects in Finland and Sweden

First movers/hubs	Location	Sector	CO_2-emissions (tpa)	Captured CO_2 (tpa)
Rautaruukki	Raahe	Iron and steel	3 970 000	3 374 500
Neste Oil	Porvo	Oil refinery	2 930 000	2 490 500
Fortum	Meri-Pori	Power & heat	2 814 000	2 391 900
Vaskiluoto 2	Vaasa	Power & heat	1 330 000	1 130 500
Fortum	Turku	Power & heat	1 640 000	1 394 000
SSAB	Oxelösund	Iron and steel	2 170 000	1 844 500
LUKAB	Luleå	Power & heat	1 990 000	1 691 500
Cementa	Slite, Gotland	Cement	1 430 000	1 215 500
Korsnäsverken	Gävle	Pulp and paper	1 330 000	1 130 500
M-real	Husum	Pulp and paper	1 690 000	1 436 500

The next step was to define the battery limits of transport and to describe the logistic chain and its main components. Transport systems have been divided into three sub systems; 1) the onshore collection system (feeders), 2) the bulk transport system (the spine) which may be onshore and/or offshore and either pipeline or ship and 3) the distribution system at the storage site, which consists of offshore pipelines. Transport costs have been calculated for the three sub systems isolated as well as for complete systems comprising all three parts.

Two potential storage reservoirs have been selected as end points for all transport systems; the Dalders structure southeast of Gotland in the Baltic Sea and the southern parts of the Utsira aquifer in the North Sea. All cost estimates were made for transport to both these storage locations.

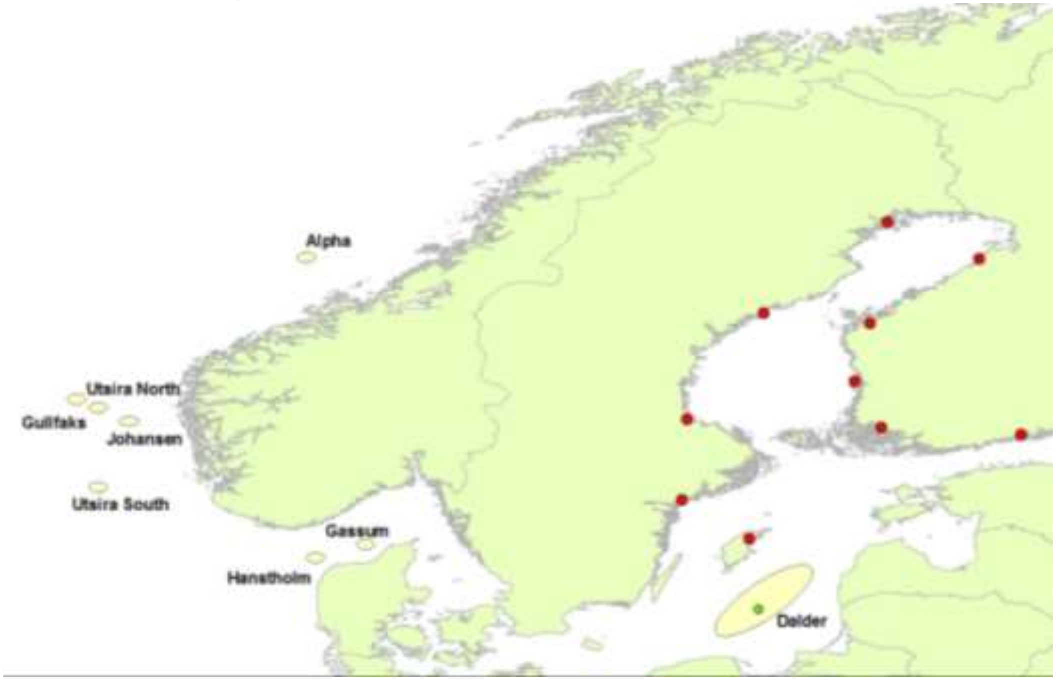

Figure 8 Selected “first movers”, location of hubs and storage sites

Pipeline transport cost has been calculated using a modified cost equation from IEA (2005) benchmarked against cost for specific pipelines provided by ZEP (2011). The modifications to the applied cost equation from IEA have been done after talks with the oil and gas industry on, among other things, cost for on- and offshore pipeline connections and subsea equipment. Pipeline cost calculations have been based on full capacity utilization from day one of operation, which again is a theoretical assumption but considered better than speculating in which plant (and consequently also what CO_2-volume) would connect to the transport system at which time. Therefore a separate chapter discusses the effects on the specific costs of pipeline underutilization. Ship transport cost has been estimated by using a proprietary model, based on an industry cost model for hydrocarbon gas transport. The model was built to optimize the ship size after the volume requirement which means that the ships theoretically in this study have been assumed to operate at full capacity.

6.2 The three transport sub systems

The report analyses each part of the transport system separately as well as how the separate systems can be integrated into complete systems, see Figure 9. Cost estimates for each of the three sub systems may be combined to provide relatively accurate cost estimates for most potential transport systems in the region. The main disadvantage of this approach is that in a complete pipeline system, the various pipeline segments will affect each other, leading to a different selection of optimal pipeline diameters, number of boosters and pressure levels. However, this is assumed to have a relatively marginal effect on cost and the spine will anyway account for the bulk of the cost in most of the systems along the Baltic Sea due to the long transport distances.

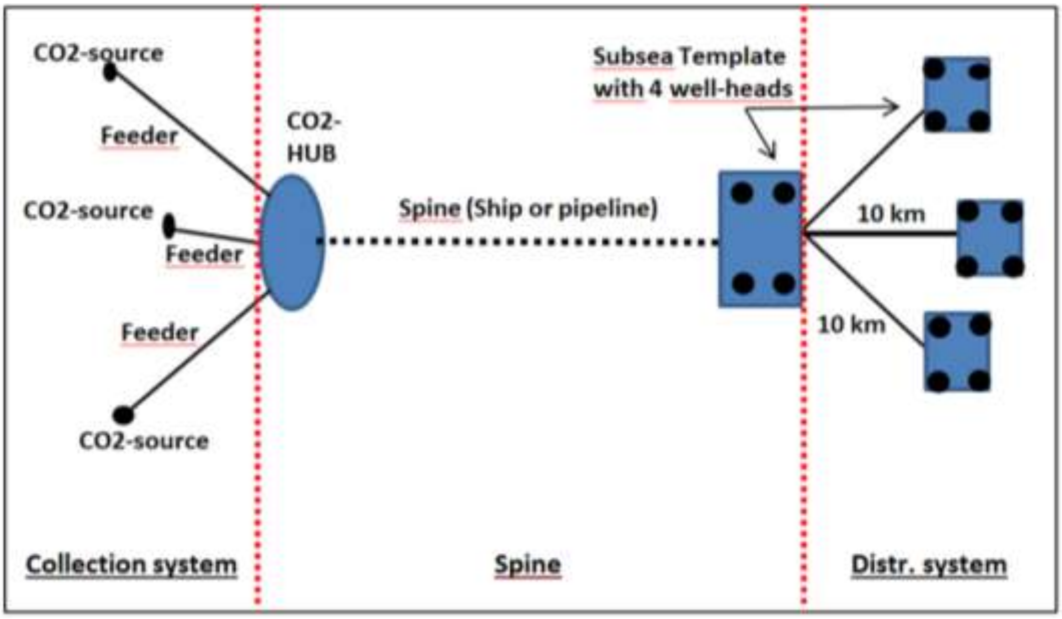

Figure 9 The components of a complete transport system

The complete transport system comprises an onshore collection system, an onshore or offshore spine from the regional CO_2-hub to the injection site and an offshore distribution system at the storage site. Figure reprinted at the courtesy of Nils Henrik Eldrup, Tel-Tek.

6.2.1 Collection systems - Feeders

The collection system, or the feeders, refers to pipelines from potential capture plants in the hinterland of the ten selected hubs thus forming the basis for a cluster development. All potential capture plants have been assumed to connect to the closest located hub unless otherwise stated explicitly. All feeders are assumed to start at the capture plant after compression up to the critical pressure, i.e. up to 73.8 bar and to terminate at the hub.

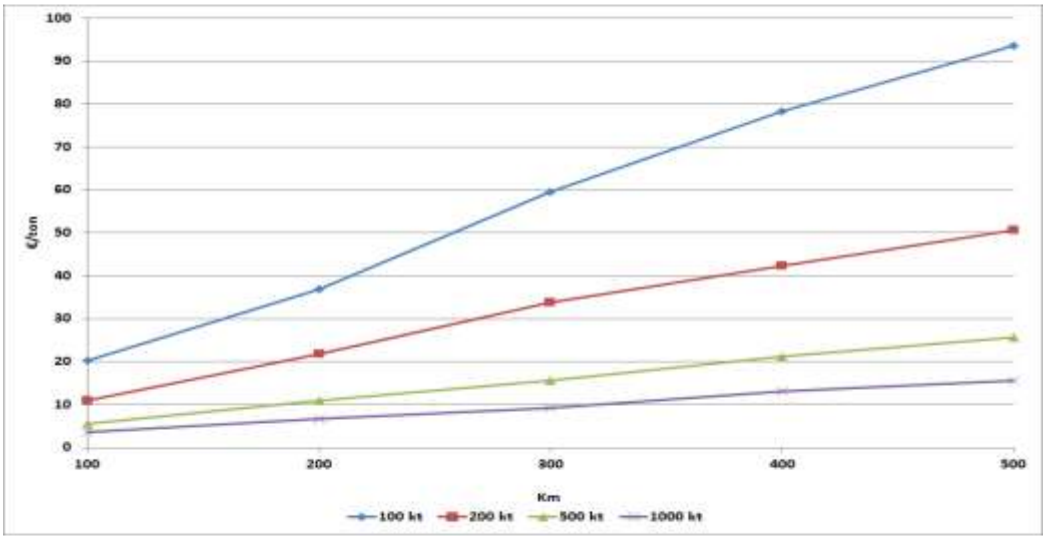

Figure 10 Specific cost for generic feeders as function of volume and distance

Cost of feeders has been analysed by assuming standard volumes being transported over standard distances, e.g. 100 to 1700 Kts over 50 to 500 km. The aim of this part of the work was to cover most of the potential feeders that may develop in the region. It is notable that many of the sources emit less than 1 Mtpa, why the specific cost for collection pipelines even for the shorter distances can amount to € 10-15/ton.

6.2.2 Spines for the bulk transport

The spine is the main part of the transport system (see Figure 9), taking the collected CO_2 from the hub to the storage site either by pipeline or by ship. In the following, the respective characteristics of pipeline and ship transport of gas are briefly described.

Pipeline transport
Transport of CO_2 by pipeline has been assumed at a minimum pressure of 70 bar and a maximum onshore pressure of 110 bar. Offshore pressure is based on a minimum pressure of 70 bar upon arrival at the storage site assuming no offshore boosters. The pipelines are assumed to be made of carbon-manganese steel. Modelling pipeline transport of CO_2 is characterised by the relationship between the pipelines diameter and the pressure of the CO_2, i.e. the larger the diameter the lower the pressure loss for any given CO_2-volume (expressed as mass flow) over a given transport distance. Chalmers' pipeline design and cost model is formulated as an optimisation problem where the pipeline diameters and booster station locations are determined by the model to achieve the lowest possible total cost of a transport system without violating any physical constraints.

Ship transport
For ship transport, the CO_2 has been assumed to be in a liquid state at -55°C and 8 bara. The alternative of transporting the gas in a compressed mode has not been taken into account as this technology has no track record for marine transport. Figure 12 illustrates the main components in a ship logistic system.

Transport by ship is a batch type of transportation, assuming that the injection process at the storage site is intermittent. Therefore, onshore buffer storage has been included, to allow the capture and liquefaction processes to continuously produce liquid carbon dioxide while the ship is in transit between the capture and storage sites. The offshore discharge is assumed to be done directly to the injection process.

Figure 11 Ship transport system scope

The design and operation of CO_2 carriers is assumed to be similar to that of semi-refrigerated carriers for liquefied petroleum gases (LPG) with typical sizes ranging from 8 - 10 000 m^3 to around 40 000 m^3. As the storage locations are assumed to be offshore, the ships should be equipped for dynamic positioning and for submerged turret buoys. The offshore system solutions for the discharge of liquid carbon dioxide need technology verification whereas the equipment and procedures for manoeuvring and connecting to the turret represent proven technology, in use since many years for oil shuttle vessels, for example in the North Sea.

For costs of shipping to be at all comparable to pipeline transport costs, auxiliary equipment has been cost estimated and added to the shuttle shipping costs. These elements then include a standard charge of an additional € 5.00 per ton CO_2 for the liquefaction process and costs for export point buffer storage and loading equipment and storage location installations like STL and gas processing equipment.

The bulk transport or spine, regardless if pipeline or ship, is assumed to start at the hub and to terminate in a 4-slot subsea template with four well heads at the storage site. In the Baltic Sea region, the spine may be entirely offshore or part onshore and part offshore.

Starting at the selected hub, the spine transports the CO_2 to the two alternative storage locations, at Dalders and Utsira. Spines have been analysed in four ways;

1) As a stand-alone offshore spine transporting only the CO_2 captured at each of the ten selected capture sites individually (see Table 5). This analysis covers both pipeline and ship transport.
2) As a stand-alone offshore spine from each of the ten selected hubs raising the annual transport volume from 1 Mt to 20 Mt (in steps of 1 Mt). This analysis covers both pipeline and ship transport.
3) Offshore as part of a complete transport system covering five specific clusters in Sweden and three in Finland.
4) Onshore and offshore semi-spines connecting CO_2 collected at each of the five selected Swedish hubs.

Points 1) and 2) compare cost of the ship spine with the corresponding cost for the pipeline spine yielding the least costly transport mode for the selected source itself, the least costly transport mode for volumes between 1 to 20 Mt per year and finally, the volume required and the associated cost for pipeline to be the least costly transport mode.

As mentioned in point 3), costs were calculated also for three cluster systems in Finland and three cluster systems in Sweden where a cluster on the Finnish side of the Baltic Sea is assumed to combine offshore with a cluster on the Swedish side of the Baltic Sea to form one, single spine to the storage site. This has been done for potential hubs at Raahe and Luleå, at Husum and Vasa and at Korsnäs and Meri-Pori, respectively.

In addition to the three combined Finnish-Swedish transport systems, costs were calculated for two altogether Swedish cluster systems being developed at Oxelösund (4) as well as for an on- and offshore semi-spine in Sweden stretching from Luleå in the north to Oxelösund in the south assuming the various hubs are connected via an on- and offshore pipeline via Gotland to the storage site. Table 6 shows the specific cost for a spine carrying captured CO_2 from the selected source only, to either Dalder or Utsira (corresponding to point 1 above).

Table 6 Specific cost for spine to Dalders and Utsira

			Dalders, €/ton		*Utsira, €/ton*	
Source/Hub	**Location**	**Volume, (tpa)**	**Pipeline**	**Ship**	**Pipeline**	**Ship**
Rautaruukki	Raahe	3 374 500	34.2	14.4	77.7	21.1
Neste Oil	Porvo	2 490 500	24.7	12.2	79.7	19.5
Fortum	Meri-Pori	2 391 900	26.3	12.4	83.6	19.9
Vaskiluoto 2	Vaasa	1 130 500	64.7	19.7	165.3	25.4
Fortum	Turku	1 394 000	34.2	16.0	118.9	21.8
SSAB	Oxelösund	1 844 500	16.6	12.5	84.5	18.1
LUKAB	Luleå	1 691 500	61.5	17.2	137.0	25.9
Cementa	Slite	1 215 500	15.0	14.5	106.8	21.8
Korsnäsverken	Gävle	1 130 500	47.1	18.3	146.9	24.2
M-real Sverige	Husum	1 436 500	53.2	17.3	134.6	22.7

As can be seen from Table 6 the cost for ship transport is considerably lower than that of transport by pipeline as a function of the relatively modest volumes and long distances. Also, the incremental cost for transporting the CO_2 by ship an additional 1,400 km to Utsira is relatively low, again compared to the pipeline cost addition. However, the costs are considerably higher than what has typically been reported in literature, for transport from large coal fired power plants (some 5-10 €/ton). This is due to the fact that emission sources in the Nordic countries are a magnitude smaller than a typical large coal fired power plant and that the transport distances are generally longer.

6.2.3 Distribution systems

Since the spine is assumed to terminate in a 4-slot subsea template with four well heads, distribution pipelines will be added to the transport system only if more than four injection wells are required. Each distribution line is assumed to have a length of 10 km and terminate in another subsea template with four well heads. Thus the number of distribution lines will depend on the number of injection wells which in turn will depend on reservoir and well injectivity and the total volume to be injected. In this work, the alternative injection rates of 0.5 and 1.0 Mtpa per well have been applied. A control cable is assumed to connect the first template with a land- or platform based control station. Figure 13 shows a potential distribution system and its link to the spine.

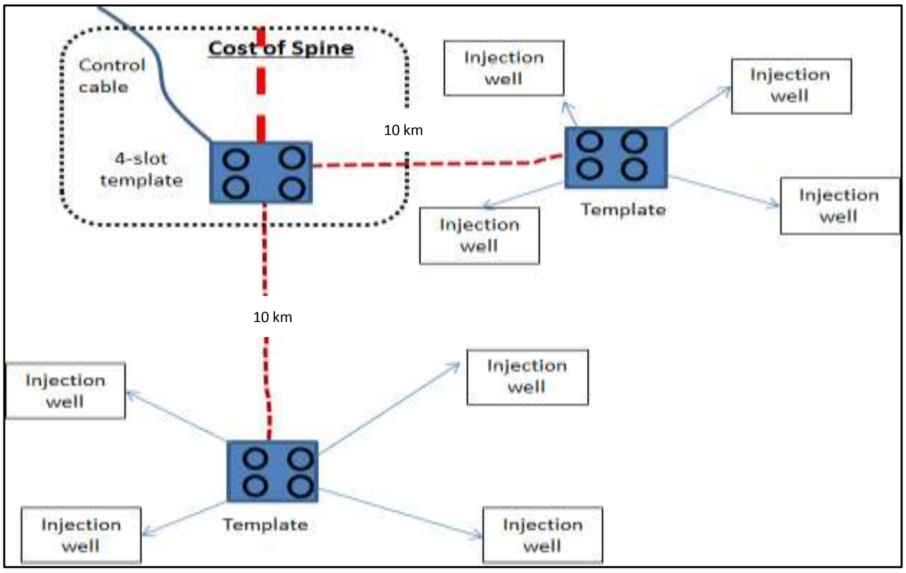

Figure 12 The transport (distribution) system at the storage site

Figure reprinted at the courtesy of Nils Henrik Eldrup, Tel-Tek.

Starting from the first injection site, distribution lines at Dalders are assumed to go in a north-eastward direction towards the Bay of Riga while at Utsira the distribution lines are assumed to go in a northern direction from the first injection point. Cost for water producers to manage pressure increase within the reservoir has not been included. Figure 14 compares the cost of distribution lines as a function of increasing volume for the two assumed well injectivity rates; 0.5 and 1.0 Mtpa.

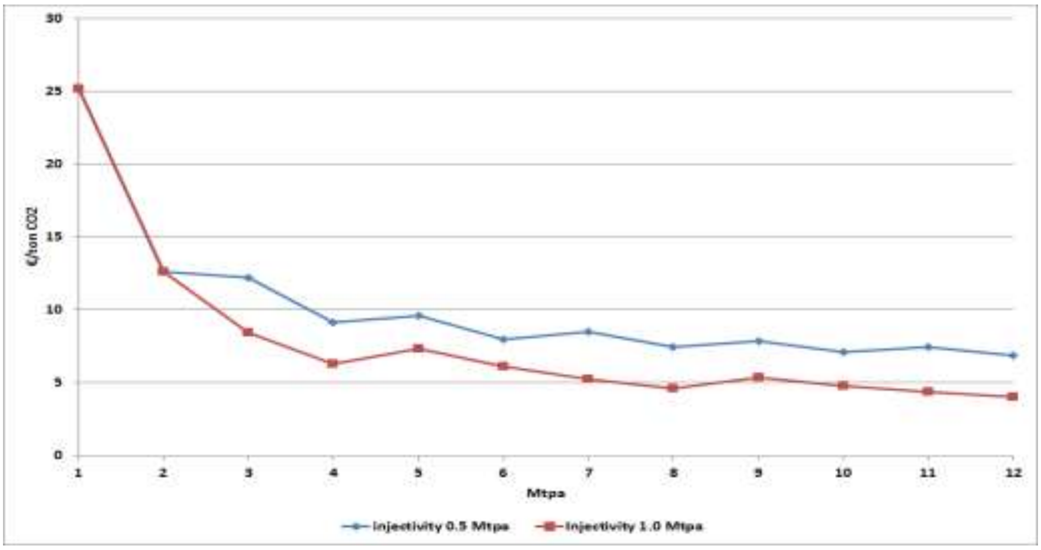

Figure 13 Cost for the distribution system as a function of volume and well injectivity

6.3 Cluster system costs

The clusters have been designed on the basis that 1) all sources that are included in a cluster are connected to its closest hub (unless otherwise stated explicitly) and 2) that a sufficient number of sources is connected to each hub so that the threshold volume is reached where pipeline transport becomes the least costly transport mode. The report presents the results of the cost estimation for pipeline transport from three combined Swedish-Finnish clusters and two Swedish systems to Dalders, based on anticipated hub developments around the ten selected sources. Table 7 specifies the number of sources and estimated captured CO_2 volume for four of the clusters (the so-called “small Oxelösund cluster” is not shown in Table 7) along with the total estimated capital expenditure and specific cost for pipeline transport assuming the higher injectivity rate of 1.0 Mtpa per well in the Dalders reservoir.

Table 7 Compilation Cluster systems to Dalder

Cluster	***No of sources***	***CO_2 volume Mtpa (of which bio)***	***CAPEX M€***	***Specific cost €/ton***
Bothnia Bay	28	20.2 (8.7)	4 861	19.11
Husum-Vasa	23	13.5 (8.0)	3 394	20.07
Korsnäs-Meri-Pori	22	12.0 (5.9)	2 586	17.28
Oxelösund large	32	13.6 (7.8)	2 120	12.48
All systems	**105**	**59.3 (30.4)**	**12 961**	

As an example of the spatial extent of the clusters, Figure 14 shows the Bay of Bothnia cluster with collection system pipelines and assumed capture volumes per site.

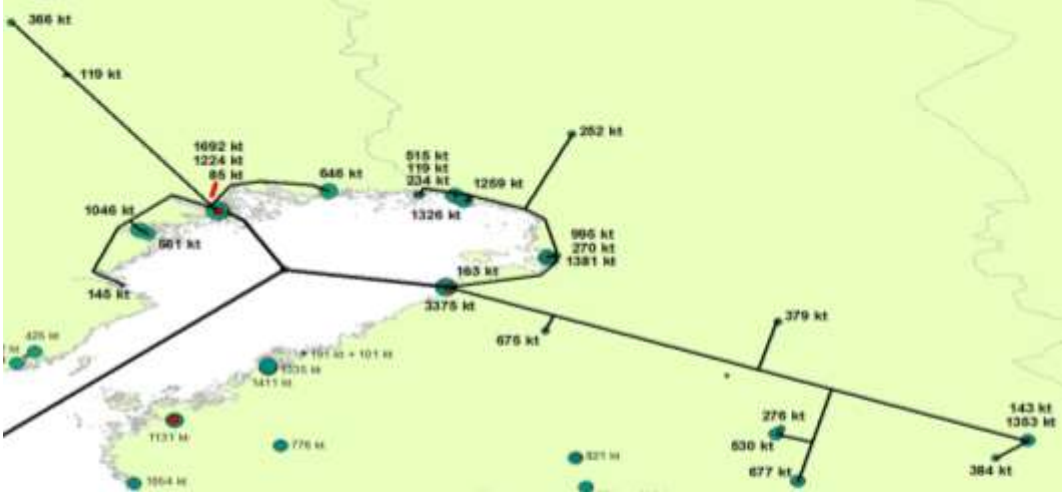

Figure 14 Collection system (feeders) in the Bay of Bothnia cluster

6.4 Pipeline underutilization and scale effects

The above has been based on the simplified and theoretical assumption that all sources are connected to the cluster from the first day of operation. A more likely development is instead that capture projects come on stream over a long period of time, making it very hard to model transport costs with any accuracy. Thus, it is interesting to analyse the effect of the degree of underutilization, providing some insight into possibly both more realistic specific costs and into the investment risk involved. Figure 15 shows specific cost of the four offshore spines from Bothnia Bay, Husum-Vaasa, Korsnäs and Oxelösund, as a function of increasing utilization ratio until full capacity is reached after ten years.

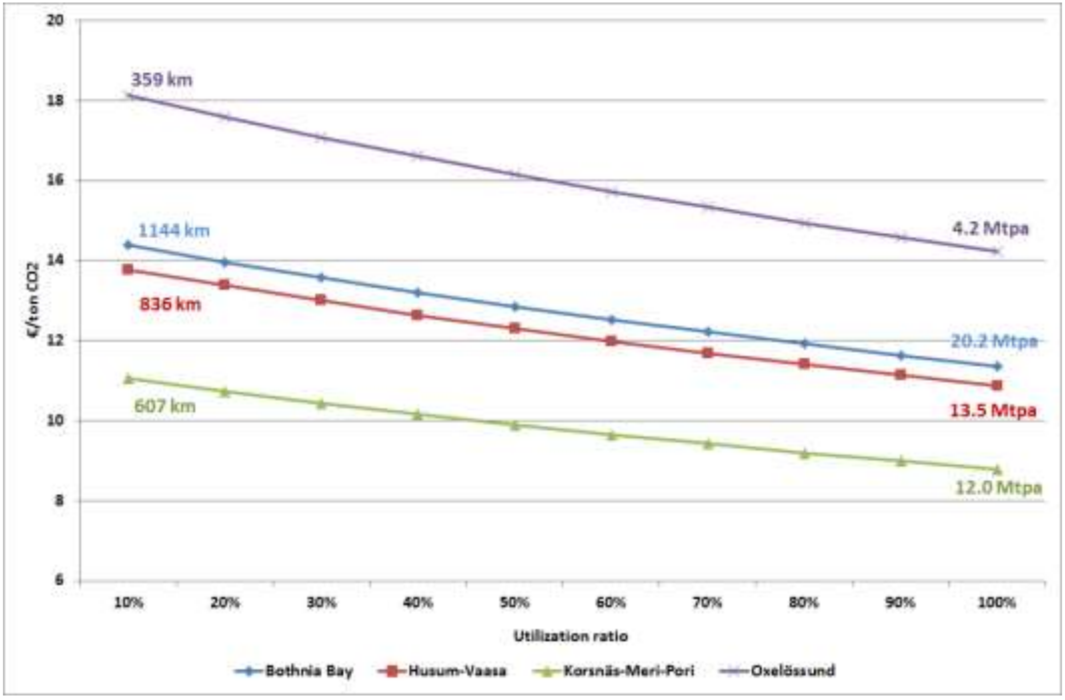

Figure 15 Specific cost of offshore spines from clusters

Specific cost increases by 26-27% if the spine is utilized only to ten per cent of its full capacity over the first ten years before reaching full capacity in year eleven while the corresponding cost increase is around 13% if the spine is utilized to fifty per cent of its full capacity. For single project developers, this effect might prevent investment in oversized pipelines.

The possibility to utilize ships for extended periods of volume ramp up is indicated through the report's comparison of specific cost for volumes from one to twenty Mtpa, (Annex 3) showing the volume where a switch from ships to pipelines could yield the lowest system cost over time. Annex 3 also indicates the scale effects on specific costs, for ships with around 50% cost reduction between 1 and 10 Mtpa and for pipeline costs with 85% for the same volume interval.

6.5 Conclusions

Onshore transport of CO_2 by pipeline has been operating for several decades in the US and although there is limited experience with offshore CO_2 pipelines this is not believed to be particularly challenging. Shipping of hydrocarbon gases dates back more than seventy years and of CO_2, some twenty-five years, albeit in smaller parcels, than what is required by the CCS industry. There are some technical issues related to the offshore discharge of ships, like the transfer of the cold gas without risking ice formation and the need for reliable sea keeping capabilities in harsh weather conditions. The need for solid technical solutions is acknowledged by the shipping industry, but the current technology gaps have not been considered to significantly impact the cost estimates in this report.

The cost of CO_2 transport by pipeline has been compared to the corresponding cost by ship for volumes and transport distances relevant to the Baltic Sea region. In order to reach the volumes required for pipeline transport to yield the lowest cost, almost all sources, both in Finland and Sweden had to be included in the three most northerly clusters modelled in this work. The results show that ship transport could be both the short and the long term mode of transport with the lowest specific cost, for many of the CO_2 sources in Finland and Sweden.

A tentative conclusion is that the total capital investment required for developing the transport infrastructure necessary to cope with the volumes in question, is so large that no single project operator will be able (or willing to) to carry all the risk. This is probably true for shipping and certainly for pipelines where there is an additional risk of pipelines operating either below optimal volume or under capacity utilization. This leads to the conclusions that for build-up of CO_2 transport systems optimized for a number of capture projects in a regional cluster would require some kind of involvement from the Government, either as a sole owner/operator or through risk-sharing in for instance a Public Private Partnership (PPP). Sweden and Finland jointly enjoy the advantage that most emission sources are located along, or very close to the coasts, thus facilitating build-up of CCS transport systems by ship. The Oxelösund cluster stands out from the other clusters, as it offers a strong, long term case for pipeline transport, on the condition that the storage and injection capacity in the Baltic Sea region is sufficient.

The cost estimates presented in the report could be considered to be in alignment with those of two reference reports, the Zero Emission Platform, Cost of CO_2 transport and the CO_2 Europipe report, both from 2011. A marked difference is the absolute cost level, which is essentially due to the lower emission volumes per site and the longer transport distances in the region. The lowest specific cost for pipeline transport presented, is the one representing a large cluster concentrated around Oxelösund, € 12/ton.

Ship is for most of the selected hubs and clusters the most attractive transport solution with specific costs safely below € 15 per ton for the shortest distances, like Slite, Oxelösund and Gävle. It provides the lowest capital cost, higher flexibility and near linear scalability but as stated above, relating to the offshore discharge of CO_2 from ships, technology verification is still required.

An important conclusion is that shipping could simplify the CCS deployment decision making process, simply by offering a lower threshold for investment. In comparison with pipelines, ship transport requires lower capital expense and with the possibility of re-deploying the vessels into another product segment, should the CCS trade be reduced or aborted, it offers reduced capital risk than the pipeline business case. This could be applicable in four different situations, like

- In the final characterization of an offshore storage location
- Cost sharing between demonstration projects
- Wider CCS deployment, once demonstration projects have proven technologies
- For the Baltic Sea region, provide transport to alternative or combined storage facilities in e g the North Sea

6.6 Summary

The Bastor2 project’s vision is the development of cross border infrastructure for transport and storage of CO_2 in the Baltic Sea region. Transport is considered the technically most mature part of the CCS supply chain (capture, transport and storage) why the main consideration in this work is cost rather than technology. The report therefore presents an analysis, including costs, of CO_2 transport solutions and how these could evolve from the first individual CCS projects towards complete transport infrastructure for the CO_2 emitting industries and power plants in the Baltic Sea region.

The work has taken its point of departure in calculating the specific spine transport costs for the five largest CO_2 sources in Finland and Sweden respectively to the two alternative storage locations at Dalders in the Baltic Sea and at Utsira South in the North Sea. This analysis was made for both pipeline and ship transport. Additionally, assuming that regional hubs could be developed at each of the ten selected sites, specific cost for the spine was calculated as a function of increasing volume from 1 to 20 Mtpa in steps of 1 Mtpa, thus yielding not only specific cost of the spine for each selected source itself but also specific cost of the spine for most relevant cluster combinations situated around the ten selected sites as well as the specific volume required to make pipeline transport more cost efficient than ship transport. These estimates indicated that ship transport is the most cost efficient transport mode not only for each of the ten selected sources individually but also for most of the relevant clusters in the region. The exercise also revealed that the volumes needed to make pipeline transport the less costly solution in most cases would require almost all sources in the area, fossil as well as biogenic, to form a cluster for export through the hub. Specific cost for ship transport to Dalders for the ten selected sources ranged from € 12 to € 20 per ton. It should be noted that elements of the ship offshore discharge activity are untested and need technology verification.

Assuming that CO_2-hubs would evolve at the sites of the ten selected sources connecting additional capture plants in the area cost was calculated for a large amount of feeder (collection) pipelines covering CO_2-volumes and distances relevant for the region. The results demonstrated clearly the importance of volume to make pipeline transport achieve the lower ranges of specific cost.

Depending on the actual volume to be stored and on the assumed reservoir injectivity, distribution systems were outlined and cost estimated. Assuming a well injectivity of 0.5 and 1.0 Mtpa, specific cost for the distribution system was calculated to € 10 and € 5 per ton respectively.

The study concludes that ship transport for most of the selected hubs and clusters is the most cost effective transport solution. The main reason is that shipping offers the lower cost and also provides the lower capital risk. This is a deviation from earlier publications and is attributable to the fact that both the Finnish and Swedish individual sources account for relatively low annual emissions and are geographically more distributed in comparison to the large coal or gas fired power stations in continental Europe and in the UK, often referred to in previous literature.

It is concluded that shipping could simplify CCS deployment, thanks to its inherent nature of comparatively low capital cost and with a near perfect scalability. This is under the assumption that there is a competitive CO_2 shipping market in place. This facilitating role of shipping was found applicable to four critical phases of CCS deployment:

- To facilitate the transport element in the characterization of an offshore geological storage site.
- For the transport leg of CCS demonstration projects, shipping could offer opportunities to share cost. Particularly interesting is the possibility to share resources, risk and costs for geological storage if transport to the North Sea should be an option, where the geological risk is currently considered much lower than in the Baltic Sea.
- Following successful demonstration projects, wider, large scale deployment could be based on ship transport.
- Should Baltic Sea storage offer less storage capacity than required, CCS deployment could be based on ship transport. This would enable an approach to first use (and possibly deplete) Baltic Sea storage and then turn to storage at an alternative location, likely to be the North Sea.

Results from the Zero Emission Platform (ZEP, 2011) and the CO_2 Europipe (2011) projects are used as benchmark for the cost estimations. These comparisons show strong correlation between the presented specific costs for the various transport assignments. It should be noted, however, that the total, specific transport costs in the Baltic Sea region are considerably higher than those presented in the benchmark reports. As said, this is mainly due to the lower annual volumes, the geographically distributed sources and the longer distances.

With the above conclusions, values for the cost of transport of CO_2 in the Baltic Sea region are presented. This information should be of use not only to policy makers attempting to establish economic drivers for faster CCS deployment but also for a long needed discussion about how suitable CO_2 transport business models could be conceived and implemented. A firm statement is that the investment numbers illustrate that no single industrial company can or will take the entire burden of investing in CO_2 transport systems.

7 CCS Network and communication

As an integrated part of the Bastor2 project, the development of regional contacts in the CCS domain was an essential part of the objective.

The project has therefore taken an active role in communication and been represented in more than ten external seminars and workshops. An opening conference was arranged in September 2012 with international speakers and audience and the final dissemination of the project's research results will be made in an open seminar in Stockholm, 14th October 2014. Papers and presentations from the five work packages have been presented in different conferences in Sweden, Poland, Austria, Norway, Finland and Latvia. The project participants have delivered four manuscripts for scientific articles for publishing in international science magazines.

Progress and results have been distributed through five Newsletters in English and Swedish. In July 2014 a seminar was organized jointly with the company Cementa, during the political week at Almedalen, Gotland, Sweden. The seminar attracted some 75 people on site and around 100 on-line viewers.

With the support of the Global Carbon Capture and Storage Institute, two webinars have been organized, one project internal in January and one external (open on invitation) in May 2014, to discuss the findings in the work package on geological assessment. Within work package 3 a workshop was organized in Stockholm in May 2014, to present and discuss the findings about communication and acceptance issues with an international audience.

The project has also supported an initiative of the Baltic Sea Region Energy Committee, to establish a regional network of CCS expertise, the purpose of which is to gather the region's professionals in the work to develop and drive joint research projects. This kind of regional collaboration is one of the key recommendations from more than one of the work package teams.

Finally, the work in Bastor2 has been keenly supported by the Finnish CCSP and its host organization, VTT. With their assistance in reviews, the quality of some of the reports has been enhanced. In addition, prior CCSP reports have provided a solid foundation for some of the Bastor2 research. The CCSP together with the Finnish Geological Survey, GTK have also been instrumental in developing contacts and supporting financially, the procurement of geological information. Through these relations, the project has undersigned Memoranda of Understanding with institutes in Russia and Poland. In summary, the project has been able to expand its network, laying the foundation for further regional cooperation.

8 Project participants

The research was conducted by the following individuals:

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	Joodaki	Saba	Uppsala University
	Jung	Byeongju	Uppsala University
	Lewis	Deirdre	SLR Consulting
	Niemi	Auli	Uppsala University
	O’Neill	Nick	SLR Consulting
	Palmlöv	Eric	OPAB
	Pasquali	Ric	SLR Consulting
	Ström	Ragnar	OPAB
	Tian	Liang	Uppsala University
	Vernon	Richard	SLR Consulting
	Yang	Zhibing	Uppsala University
Environment	Faxelid	Helena	Yggdrasil Miljömanagement
	Nilsson	Per Arne	panaware
	Wadstein	Per	Yggdrasil Miljömanagement
Public perception	Buhr	Katarina	IVL Swedish Environmental Research
	Haikola	Simon	Linköping University
	Hansson	Anders	Linköping University
	Stigson	Peter	IVL Swedish Environmental Research
Legal/Fiscal	Langlet	David	Stockholm University
	Rydberg	Nils	CCS Wirtschaftsberatung Rydberg
Infrastructure	Kjærstad	Jan	Chalmers University of Technology
	Nilsson	Per Arne	panaware

The project was overseen on an operative basis by an Executive Committee:

	Family name	***Given name***	***Affiliation***
Chairman	Kärsrud	Kim	SSAB
Member	Bida	Jan	MinFo
Member	Johansson	Lars B	Elforsk
Project Manager	Nilsson	Per Arne	panaware

9 References

The following work package reports are accessible and can be downloaded on line at www.elforsk.se:

14:53	WP1	Geological Assessment
14:54	WP1	Annex: Dynamic modelling
14:46	WP2	Environmental Impact
14:47	WP3	Social Aspects for Baltic Sea Storage
14:48	WP4	Legal & Fiscal Aspects
14:49	WP5	Infrastructure for CO_2 transport in the Baltic Sea Region

LIST OF ABBREVIATIONS

ANSI	American National Standards Institute
ASU	Air-Separation Unit
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilization
CCUS	Carbon Capture Utilization and Storage
CEER	Council of European Energy Regulators
CMU	Carbon Mineralization Utilization
CO_2	Carbon dioxide
ECBM	Enhanced Coal Bed Methane
EEZ	Exclusive Economic Zone
EFTA	European Free Trade Association
EGR	Enhanced Gas Recovery
EGS	Enhanced Geothermal System
EHR	Enhanced Hydrocarbon Recovery
EIA	Environmental Impact Assessment
EOR	Enhanced Oil Recovery
ESG	Enhanced Shale Gas
EU	European Union
EU Court	Court of Justice of the European Union
EU ETS	European Union Emission Trading System
IEA	International Energy Agency
IED	Industrial Emissions Directive
ILC	International Law Commission
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
O_2	Oxygen
OECD	Organisation for Economic Cooperation and Development
PPP	Public-Private Partnership
SPIRE	Sustainable Process Industry through Resource and Energy Efficiency
TEU	Treaty on European Union
TFEU	Treaty on the Functioning of the European Union
TPA	Third Party Access
UNCLOS	United Nations Convention on the Law of the Sea

LIST OF FIGURES

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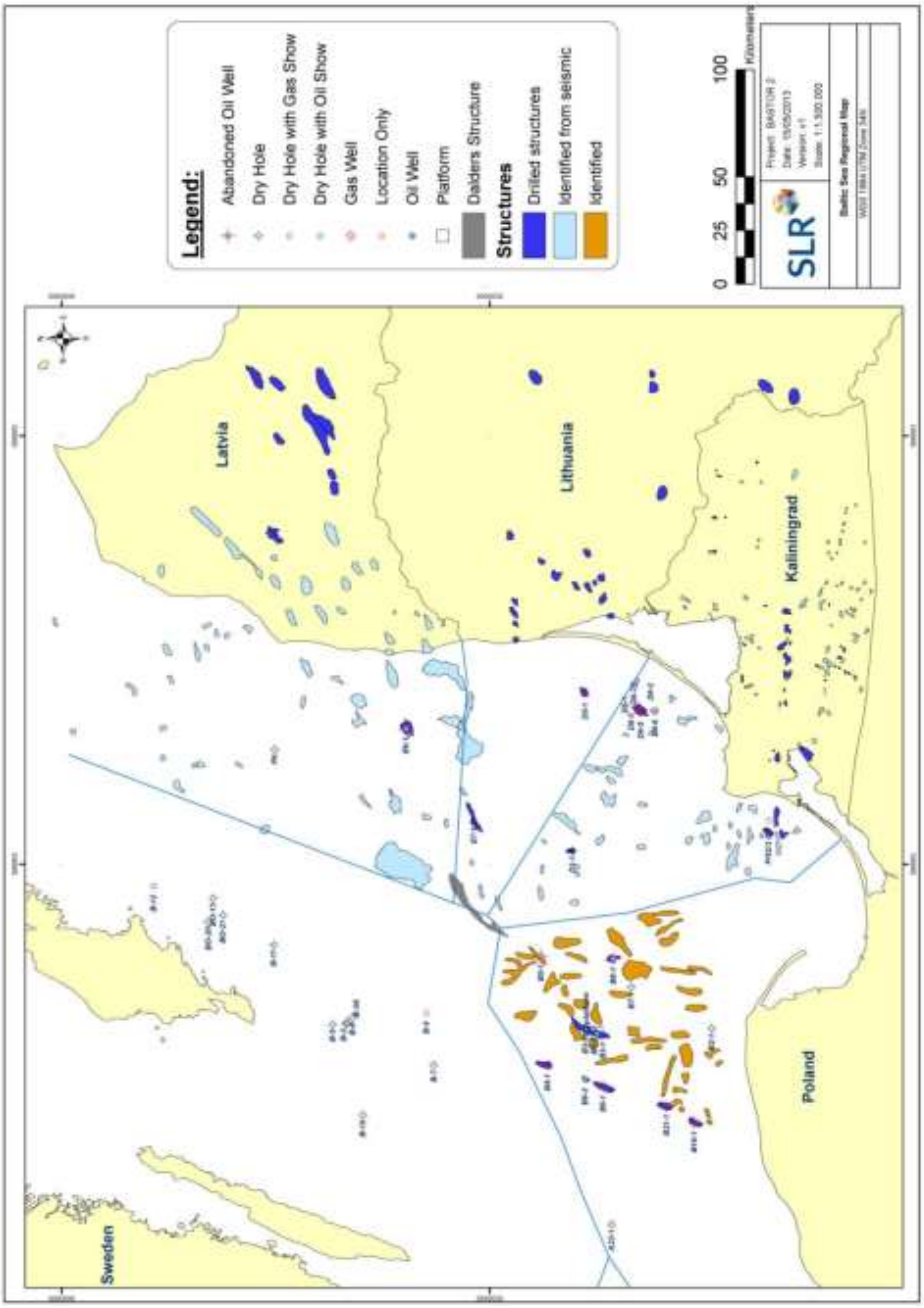
ANNEXES

Annex 1 The Jurisdictional challenge of CCS in the Baltic Sea region



Annex 2 Recommended EIA content – Field trial project

*Structure compiled from EIAs by OPAB and Nord Stream	Time estimates (work days)
1 A NON-TECHNICAL SUMMARY	4-6
2 ADMINISTRATIVE DATA	
3 BACKGROUND	
4 ACCESS TO AVAILABLE DATA	5-10
5 PLANNED ACTIVITIES Localization Description of planned activities Chemical products - classification and listing of chemicals Energy Consumption Water Supply Discharges to water Emissions to air Waste	4-7
6 PREREQUISITES The Baltic Sea- Influx areas; Islands Coastal areas; Bathymetry Climate- Wind Conditions; Visibility/fog; Air Temperature; Precipitation Oceanographic data- Currents and tides; Waves; Ice Conditions; The water's chemical composition Sediment Ecology- Benthic zone - Flora & Fauna; Pelagic zone - Flora & Fauna Current pollution- Point Releases; Fugitive emissions; Eutrophication; Metals; Persistent organic pollutants; Oil Socio-economically sensitive areas- Fish stocks and the fishing industry; Marine mammals (seals, etc.) and their breeding areas; National parks; Recreational Areas; Fish Farms; Other Activities; Archaeologically valuable objects; Sea bird areas; Marine reserves; Endangered species Other conditions- Historical military activities (dumping of munitions, etc.)	40-60
7 APPLICABLE REGULATIONS Global conventions Regional conventions EU legislation National legislation	4-6
8 ENVIRONMENTAL CONSEQUENCES – HAZARDS AND RISKS Visual appearance Natural/cultural values Discharges to water (impact on ecosystems, zooplankton, fish, birds, marine mammals, etc.) Emissions to air Noise/sound Waste	20-40
9 HAZARDS AND RISKS DURING FIELD TRIALS Normal operations Drilling (Cuttings and additives) Drainage from the platform Sanitary waste water Other emissions Waste Air Emissions Geological storage of CO_2 Transport of CO_2 Injection of CO_2	34-60

	Offshore CO_2 buffer storage Offshore CO_2 transport Injection of CO_2 Accidents and breakdowns Shipping Risks associated with: - Storage of CO_2 - Transport of CO_2 - Injection of CO_2 The risks of military material being disposed of (fighting gas, ammunition, mines) Natural Disasters Breakdown of equipment/human factor Sabotage and terror activities Unplanned releases Dispersion (scattering models) Impact/consequences	
10	THE IMPACT ON INDIVIDUAL AND PUBLIC INTERESTS	4-6
11	ALTERNATIVE DESIGN (E.G. BAT-QUESTIONS) AND ZERO OPTION[2]	4-6
12	ANTI-POLLUTION MEASURES	10-15
13	MONITORING AND FOLLOW-UP	4-6
14	CONSULTATION Consultations according to the applicable national legislation International consultation	20-40
15	NATIONAL ENVIRONMENTAL OBJECTIVES	2-4
16	REFERENCES	3-6
TOTAL ESTIMATED TIME FOR EIA		**162-278**

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[2] A presentation of alternative sites, if such is possible, as well as alternative designs along with a statement of reasons why a particular option is selected, a description of the consequences of the action or the action does not come to fruition.

Annex 3 Comparison Specific Cost to Dalder (5 first sites)

Comparison Specific cost (€/ton)
Raahe to Dalder, 1-20 Mtpa

Mtpa	Ship	Pipeline
1,0	22,49	92,45
2,0	15,86	50,84
3,0	15,24	36,28
4,0	13,34	29,12
5,0	13,57	24,93
6,0	12,50	22,23
7,0	12,81	19,33
8,0	12,08	18,05
9,0	12,39	17,13
10,0	11,83	15,59
11,0	12,13	15,10
12,0	11,66	13,99
13,0	11,26	13,07
14,0	11,54	12,88
15,0	11,21	12,15
16,0	11,45	12,08
17,0	11,15	11,47
18,0	**11,38**	**10,94**
19,0	11,11	10,97
20,0	11,33	10,51

Comparison Specific cost (€/ton)
Porvo to Dalder, 1-20 Mtpa

Mtpa	Ship	Pipeline
1,0	19,72	54,20
2,0	13,47	29,60
3,0	11,21	21,67
4,0	11,33	16,69
5,0	10,23	14,21
6,0	9,47	12,61
7,0	9,89	11,07
8,0	9,33	10,26
9,0	8,89	9,34
10,0	**9,27**	**8,87**
11,0	8,91	8,23
12,0	8,60	7,95
13,0	8,94	7,48
14,0	8,66	7,09
15,0	8,43	6,93
16,0	8,71	6,61
17,0	8,50	6,35
18,0	8,31	6,25
19,0	8,57	6,02
20,0	8,39	5,82

Comparison Specific cost (€/ton)
Meri-Pori to Dalder, 1-20 Mtpa

Mtpa	Ship	Pipeline
1,0	19,8	55,52
2,0	13,5	30,33
3,0	11,2	22,21
4,0	11,4	17,81
5,0	10,3	14,57
6,0	9,5	12,92
7,0	9,9	11,35
8,0	9,4	10,52
9,0	8,9	9,57
10,0	**9,3**	**9,09**
11,0	8,9	8,44
12,0	8,6	8,15
13,0	9,0	7,66
14,0	8,7	7,49
15,0	8,5	7,10
16,0	8,7	6,78
17,0	8,5	6,69
18,0	8,3	6,41
19,0	8,6	6,17
20,0	8,4	5,97

Comparison Specific cost (€/ton)
Vaasa to Dalder, 1-20 Mtpa

Mtpa	Ship	Pipeline
1,0	21,1	72,94
2,0	14,7	40,09
3,0	14,2	28,59
4,0	12,3	22,94
5,0	11,2	19,63
6,0	11,6	16,66
7,0	10,8	15,22
8,0	11,2	14,20
9,0	10,6	12,81
10,0	10,1	12,26
11,0	10,5	11,30
12,0	10,1	10,52
13,0	**10,4**	**10,28**
14,0	10,1	9,68
15,0	9,8	9,55
16,0	10,1	9,06
17,0	9,8	8,64
18,0	10,1	8,60
19,0	9,8	8,24
20,0	9,6	7,93

Comparison Specific cost (€/ton)
Turku to Dalder, 1-20 Mtpa

Mtpa	Ship	Pipeline
1,0	19,5	46,15
2,0	13,3	25,19
3,0	11,0	17,75
4,0	11,1	14,19
5,0	10,0	12,08
6,0	9,3	10,71
7,0	**9,7**	**9,41**
8,0	9,1	8,72
9,0	8,7	7,93
10,0	9,1	7,53
11,0	8,7	6,99
12,0	8,4	6,57
13,0	8,7	6,34
14,0	8,5	6,01
15,0	8,2	5,75
16,0	8,5	5,61
17,0	8,3	5,38
18,0	8,1	5,19
19,0	8,4	5,11
20,0	8,2	4,94

Annex 3 Comparison Specific Cost to Dalder (5 last sites)

Comparison Specific cost (€/ton)
Oxelösund to Dalder, 1-20 Mtpa

Mtpa	Ship	Pipeline
1,0	17,9	28,64
2,0	12,0	15,78
3,0	9,9	11,01
4,0	**10,0**	**8,86**
5,0	9,0	7,38
6,0	8,3	6,47
7,0	7,8	5,78
8,0	8,2	5,28
9,0	7,8	4,87
10,0	7,4	4,56
11,0	7,2	4,28
12,0	7,5	4,07
13,0	7,3	3,86
14,0	7,1	3,70
15,0	6,9	3,55
16,0	7,2	3,42
17,0	7,0	3,33
18,0	6,8	3,21
19,0	7,1	3,11
20,0	7,0	3,05

Comparison Specific cost (€/ton)
Luleå to Dalder, 1-20 Mtpa

Mtpa	Ship	Pipeline
1,0	22,56	94,99
2,0	15,92	52,24
3,0	15,30	37,28
4,0	13,40	29,93
5,0	13,63	25,62
6,0	12,56	22,85
7,0	12,87	20,96
8,0	12,14	18,55
9,0	12,45	17,61
10,0	11,89	16,02
11,0	12,19	15,52
12,0	11,72	14,38
13,0	11,32	14,12
14,0	11,60	13,24
15,0	11,27	12,49
16,0	11,51	12,41
17,0	11,21	11,79
18,0	**11,44**	**11,25**
19,0	11,17	11,27
20,0	11,39	10,80

Comparison Specific cost (€/ton)
Slite to Dalder, 1-20 Mtpa

Mtpa	Ship	Pipeline
1,0	16,6	17,99
2,0	**10,8**	**9,68**
3,0	8,8	6,87
4,0	7,7	5,46
5,0	7,0	4,58
6,0	7,4	4,04
7,0	6,9	3,58
8,0	6,5	3,26
9,0	6,2	3,01
10,0	6,0	2,81
11,0	6,4	2,63
12,0	6,2	2,50
13,0	6,0	2,37
14,0	5,8	2,27
15,0	5,6	2,18
16,0	6,0	2,09
17,0	5,8	2,03
18,0	5,7	1,96
19,0	5,6	1,90
20,0	5,5	1,86

Comparison Specific cost (€/ton)
Gävle to Dalder, 1-20 Mtpa

Mtpa	Ship	Pipeline
1,0	19,6	51,96
2,0	13,4	28,37
3,0	11,2	20,77
4,0	11,3	15,99
5,0	10,2	13,62
6,0	9,4	12,08
7,0	9,8	10,61
8,0	9,3	9,83
9,0	8,8	8,95
10,0	**9,2**	**8,50**
11,0	8,9	7,89
12,0	8,5	7,62
13,0	8,9	7,16
14,0	8,6	6,79
15,0	8,4	6,64
16,0	8,7	6,33
17,0	8,4	6,08
18,0	8,3	5,99
19,0	8,5	5,77
20,0	8,3	5,58

Comparison Specific cost (€/ton)
Husum to Dalder, 1-20 Mtpa

Mtpa	Ship	Pipeline
1,0	21,12	72,35
2,0	14,67	39,76
3,0	14,16	28,36
4,0	12,33	22,75
5,0	11,18	19,47
6,0	11,56	16,52
7,0	10,79	15,09
8,0	11,17	14,08
9,0	10,59	12,70
10,0	10,13	12,16
11,0	10,48	11,21
12,0	10,09	10,44
13,0	**10,39**	**10,19**
14,0	10,07	9,60
15,0	9,78	9,47
16,0	10,05	8,99
17,0	9,80	8,57
18,0	10,04	8,53
19,0	9,82	8,17
20,0	9,61	7,86

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