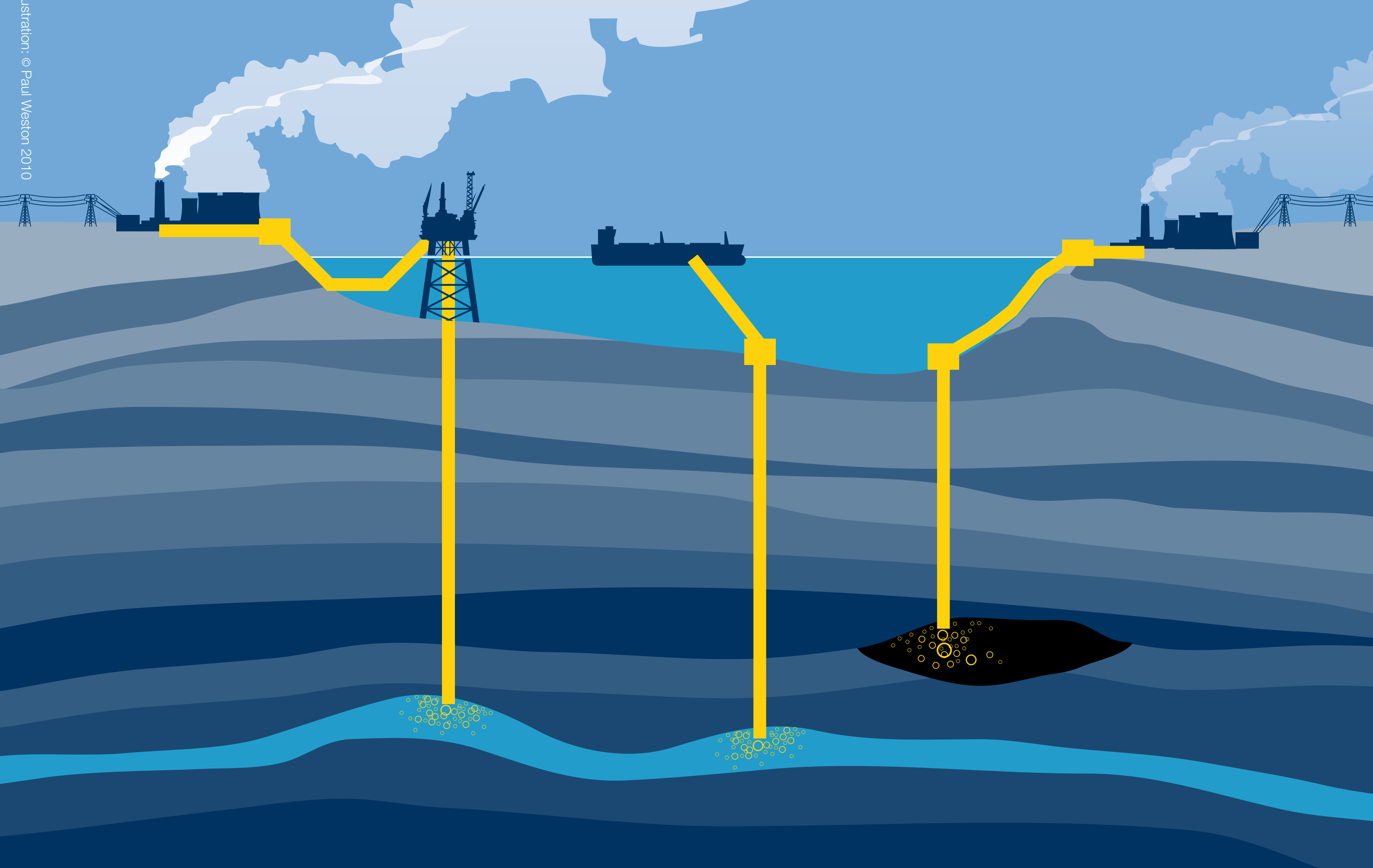
One North Sea

A study into North Sea cross-border CO_2 transport and storage



Report for:
The Norwegian Ministry of Petroleum and Energy
The UK Foreign and Commonwealth Office

On behalf of:
The North Sea Basin Task Force
www.nsbtf.org

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A study into North Sea cross-border CO_2 transport and storage

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Final Main Report For:

The Norwegian Ministry of Petroleum and Energy
and
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On behalf of:
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Authors:

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About the Authors

Element Energy Limited is a low carbon consultancy providing a full suite of services from strategic advice to engineering consultancy in the low carbon energy sector. Element Energy's strengths include techno-economic forecasting and delivering strategic advice to clients on all opportunities connected to the low carbon economy. Element Energy has experience in the design of strategies for the coordinated deployment of low carbon infrastructure.

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Contributing organisations

The following organisations provided important input into this study:

The **Norwegian Petroleum Directorate** provided data on Norwegian demand and CO_2 storage potential, and assisted with stakeholder engagement.

The British Geological Survey (BGS) provided input on sink assessment, a GIS database of storage sites around the North Sea and assisted with stakeholder engagement.

CMS Cameron McKenna provided input on legal and regulatory issues and assisted with stakeholder engagement.

Econ Pöyry developed and modelled scenarios for capture within the power sector and databases of potential locations for capture sites around the North Sea.

Carbon Counts provided feedback on the overall report and assisted with stakeholder consultation.

Det Norsk Veritas provided feedback on the report's conclusions and recommendations.

Caveat

While the authors consider that the data and opinions contained in this report are sound, all parties must rely upon their own skill and judgement when using it. The authors do not make any representation or warranty, expressed or implied, as to the accuracy or completeness of the report. There is considerable uncertainty around the development of CCS. The available data on sources and sinks are extremely limited and the analysis is therefore based around hypothetical scenarios. The maps and costs are provided for high-level illustrative purposes and no detailed location-specific studies have been carried out. The authors assume no liability for any loss or damage arising from decisions made on the basis of this report. The views and judgements expressed here are the opinions of the authors and do not reflect those of the Governments of Germany, the Netherlands, Norway or the UK, or Industry/Academic/NGO Representatives of the North Sea Basin Task Force, Contributing Organisations, or Expert Stakeholder Group.

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Highlights

Carbon Capture and Storage (CCS) in the North Sea countries could play an important role in European CO_2 emissions abatement by 2030, with capture volumes above 270 million tonnes (Mt) CO_2/year. By 2050 this could rise above 450 Mt CO_2/year.

The combination of abundant CO_2 storage capacity, clusters of CO_2 sources, world class research institutes and commercial stakeholders, and a strong demonstration programme makes the North Sea countries natural leaders for the development and deployment of CCS technology in Europe.

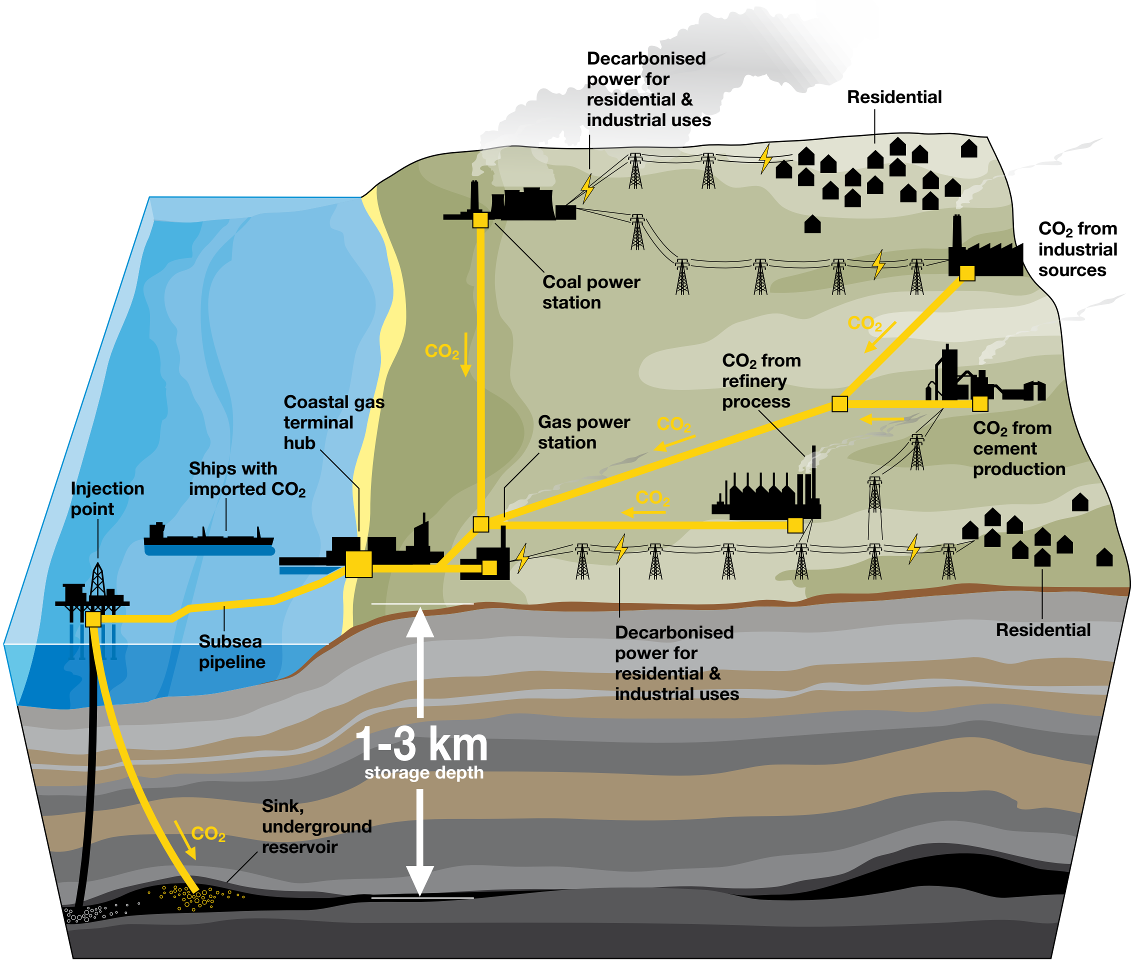
Around fifty per cent of European CO_2 storage potential is located under the North Sea. A large amount of predicted CCS demand is located within Germany, the Netherlands, Norway and the UK, the countries of the North Sea Basin Task Force. The geographical clustering of sources and/or sinks gives opportunities to develop efficient transport and storage networks.

Many stakeholders around the North Sea have already developed visions for deploying safe, cost-effective and timely transport and storage infrastructure, although challenges have also emerged.

The modelling and stakeholder consultation conducted demonstrate that:

- In a 'Very High' CCS scenario source 'clusters' or 'hubs' could be responsible for 80% of stored CO_2 in 2030.
- Cross-border transport could become increasingly important beyond 2020 in scenarios with high CCS growth and/or where storage is restricted(for example, in onshore sinks). Cross border transport volumes could contribute up to 25% of overall CO_2 flows in 2030.
- Uncertain CCS economic incentives, regulations and viability of specific sinks, and limited co-operation and organisation of stakeholders, work against private sector investment in capture and large scale transport and storage infrastructure.
- Uncertainties over capture demand and storage capacity also impede the public sector from making the clear commitments to CCS that the private sector requires.

Our analysis concludes that the rapid deployment of large scale low cost infrastructure by 2030 is technically achievable and is necessary for full deployment (e.g. the 'Very High' scenario described in this report which stores over 270 Mt CO_2/year in 2030). However this would require a step change in co-operation in planning by numerous stakeholders, favourable economic conditions and CCS cost reduction. With only modest further intervention, the market is likely to deliver only a few of the most straightforward CCS projects by 2030, storing up to 46 Mt CO_2/ year under the North Sea in a 'Medium'



graphic: © www.paulweston.info 2010

scenario. The shortfall between 'Very High' and 'Medium' scenarios would need to be met by other approaches to CO_2 abatement.

The focus for government and industry co-operation around the North Sea should be to:

1. Co-ordinate and lead the pre-commercial deployment of CCS in the period to 2020 and beyond.

2. Increase confidence in the location, volumes and reliability of sink capacity in and around the North Sea, and facilitate access to safe storage, for example through developing frameworks for managing cross-border CO_2 flows.

3. Recognise shared interests, speak with one voice and act consistently, where possible, to promote the development of CCS.

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Executive Summary

Background

The European Union, its member states and Norway, have pledged to dramatically reduce emissions of carbon dioxide over the next decades, in order to avoid dangerous climate change. Meeting CO_2 reduction targets will require action in every sector. Alongside renewable energy technologies, nuclear power, and energy efficiency measures, carbon dioxide capture and storage (CCS) has the potential to substantially reduce future CO_2 emissions from electricity generation and industry. Recent studies suggest that CCS could (in a cost effective manner) provide up to 20% of European CO_2 abatement by 2030, reducing emissions by 0.4 Gt CO_2/year (IEA, 2009, McKinsey 2008). By 2050 this could rise above 1 Gt CO_2/year.

Within Europe, the North Sea region has a natural role in the development of CCS, due to high concentrations of industrial and power sector emissions and access to an abundant and diverse resource of potential storage sites under the North Sea. Against this backdrop, the UK Foreign and Commonwealth Office and Norwegian Ministry of Petroleum and Energy commissioned the 'One North Sea' study in September 2009, on behalf of the North Sea Basin Task Force (NSBTF), to establish a vision of the potential role of the North Sea in the future deployment of CCS across Europe, and propose a strategy for its delivery.

To understand the role for co-ordinated activity amongst the governments of the NSBTF, a team led by Element Energy carried out an examination of **(i)** likely demand for cross-border transport and storage, and **(ii)** government actions and principles to support the management of CO_2 flows across national borders ('transboundary') and optimise the rapid development of CO_2 transport infrastructure.

Our Approach

The approach taken in this study combined a review of policies and initiatives to support CCS at EU level, and within Norway, the UK, the Netherlands and Germany, economic modelling of CCS demand and CO_2 transport and storage scenarios and networks, an analysis of legal and regulatory barriers to achieving CCS deployment, and a three-month consultation exercise involving more than forty government, industry and academic stakeholders.

Scenarios for investment in capture, transport and storage in 2030 and 2050 were developed by the project team and stakeholders to understand how the quantities and geographic distribution of CO_2 capture, transport and storage might develop.

Projected investments in capture technology at power plants were determined using a model of the European power sector, developed by Econ Pöyry. A database for storage capacities of potential sites in the North Sea countries was provided by the British Geological Survey and Norwegian Petroleum Directorate, drawing on the recent EU GeoCapacity study[1].

These data were used as inputs to Element Energy's CO_2 network optimisation model, which identified plausible matches of sources and sinks. The network model was used to analyse the distribution of CCS across the North Sea countries, with particular emphasis on cross-border transport of CO_2 for the different scenarios. All results

1 http://www.geology.cz/geocapacity

and interpretations were shared with the expert stakeholder group. The stakeholder engagement provided local knowledge and revealed where expectations differ.

CMS Cameron McKenna analysed legal and regulatory issues. The report was reviewed in full by Carbon Counts, and recommendations were additionally reviewed by DNV. This final version of the report incorporates feedback from stakeholders on the interim and draft final versions.

Analysis

At European level, the most important CCS policies have been:

- Passing of the CCS Directive in 2009, which has established a legal framework for geological CO_2 storage exploration, operation and closure.
- Partial funding for six large-scale CCS demonstration projects from the European Energy Programme for Recovery.
- A commitment to fund up to twelve large-scale CCS demonstration projects using 300 million emissions trading scheme allowances from the New Entrants Reserve.
- Inclusion of CCS within the next phase of the Emissions Trading Scheme.
- Funding research, development and communication activities, for example through the Framework programmes.

The four Governments represented on the North Sea Basin Task Force have devoted considerable efforts to removing legal obstacles and supporting research, development and demonstration of CCS. Norway already has two CCS projects in operation at Sleipner and Snøhvit, and a further two under development at Kårsto and Mongstad. The UK has a commitment to fund four CCS demonstration projects and is part-way through the development of significant long-term regulatory frameworks to support large scale deployment of CCS. The Government of the Netherlands is amending legislation and developing a Masterplan for CO_2 transport and storage infrastructure. German Government support is directed through two research programs, focused on power plant efficiency, capture and storage.

As a result of the policy support and public financing for CCS demonstration, CCS demand in 2020 is modelled as approximately 30 $MtCO_2/yr$ in the NSBTF countries.

Once satisfactory capture and storage locations have been identified, transport choices would primarily be based on considerations of capacity, distance and terrain which influence capital and lifetime costs, and planning and consenting risks and timescales. Additional drivers include financing, predicted utilization, economic use of CO_2 (such as for enhanced oil recovery or in greenhouses), infrastructure re-use, shipping and clustering.

Cross-border transport of CO_2 between NSBTF members before 2020 is not strictly necessary. This is primarily because each country has sufficient domestic capacity to match demand. Some stakeholders nevertheless express interest in cross-border CO_2 transport beginning after 2016, possibly by ship, from Germany, Belgium, Northern France, Sweden or Finland to British, Norwegian or Dutch sinks, and from the Netherlands to Denmark for CO_2-enhanced oil recovery. It is not clear how well developed these proposals are.

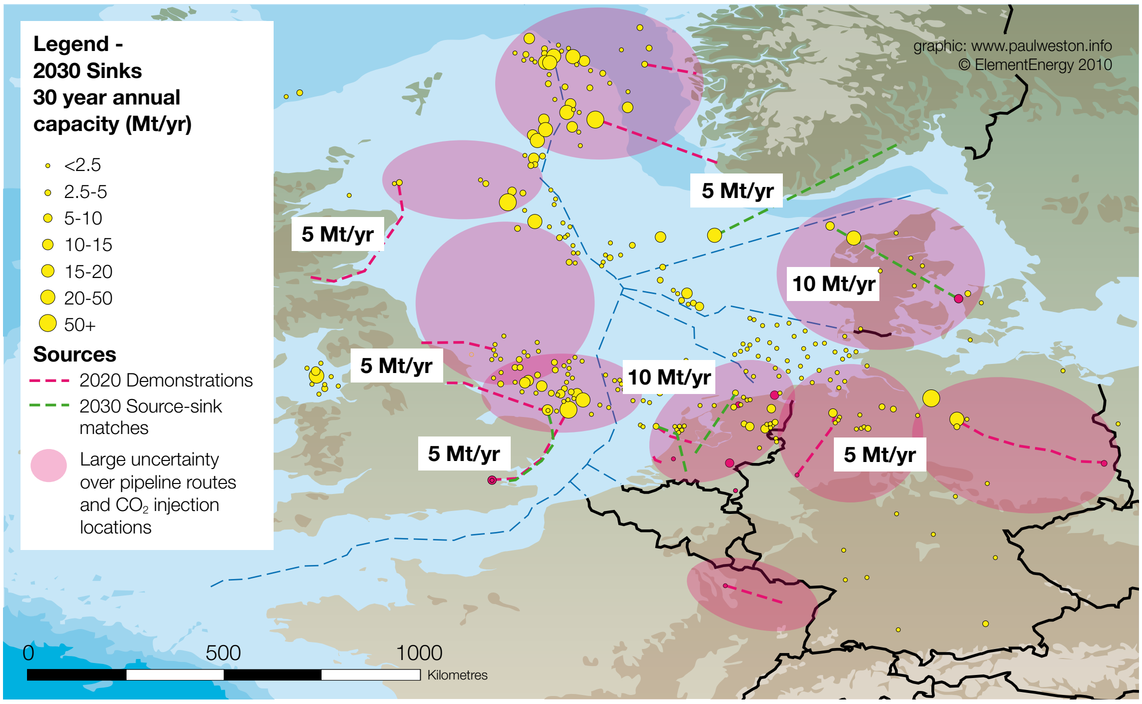


Figure 1: CCS activity in the 'Medium' scenario 2030

Source clusters with shared infrastructure are unlikely to occur before 2020, although careful design and implementation of the demonstration projects could expedite the development of larger networks between 2020 and 2030. The strengths and weaknesses in facilitating transport growth of point-to-point pipelines, shared rights of way, integrated pipelines and shipping are compared in the report.

For 2030, due to uncertainty, a range of different CCS deployment levels are analysed. The economic modelling and stakeholder feedback identify an overall demand for CCS in the NSBTF countries and Denmark of ca. 46 $MtCO_2$/year in 2030. This is the 'Medium' scenario, illustrated in **Figure 1**, and is consistent with modest policies and progress in CCS beyond currently announced CCS demonstrations. The scenario reflects a future where there are limited opportunities for storage, and relatively simple 'point-to-point' transport infrastructure.

However, with optimistic assumptions on CCS demand and a step-change in co-ordinated efforts to deliver large scale transport and storage, CCS could play a important role in European CO_2 abatement efforts by 2030. For example, **Figure 2** shows the overall quantity and distribution of CO_2 capture and storage projects in the NSBTF countries and Denmark in a 'Very High' CCS scenario, where 270 Mt CO_2/yr is captured and stored in 2030.

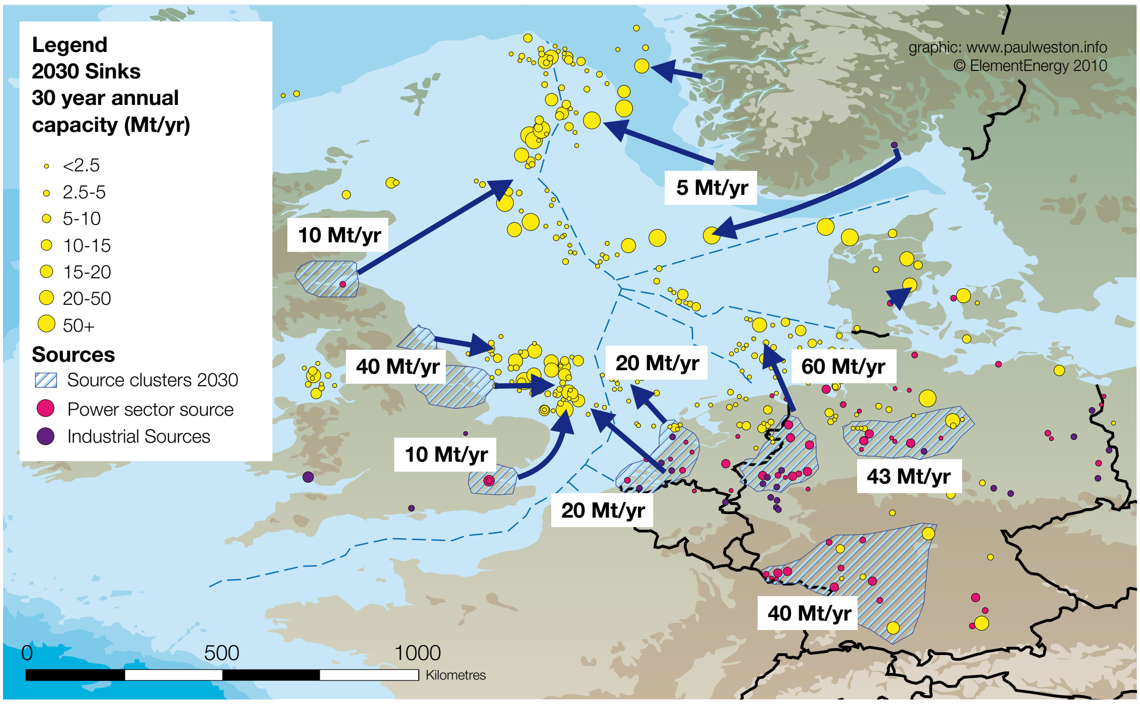


Figure 2: CCS activity in the 'Very High' scenario in 2030

In a 'Very High' scenario, CCS projects would share transport and particularly storage infrastructure due to geographical aggregation of sources and sinks. Seven such clusters in the North Sea countries are responsible for 80% of CO_2 transported in this scenario in 2030. In this scenario, 60% of CO_2 storage is under the North Sea. Cross-border transport comprises 10 – 15% of overall CO_2 storage by 2030.

Energy and climate policies are vital drivers for CCS in Europe in 2030. However, very large scale of CCS deployment by 2030 is additionally sensitive to restrictions on transport and storage, as well as the overall investment in capture technology by individual plants. **Table 1** (next page) shows the effect of some of these restrictions on the overall uptake of CCS in the North Sea countries by 2030. Storage restrictions also have a significant effect on CCS deployment, both on the number and cost on projects that may be forced to transport CO_2 to more distant sinks.

	Scenarios	Mt/yr stored in 2030	Cross-border transport permitted	Aquifer capacity	Onshore storage permitted	% Cross-border flow
Decreasing CO_2 volume ↓	'Very High' deployment	273	Yes	High	Yes	10%
	No cross-border transport and storage agreements	253	No	High	Yes	0%
	No hydrocarbon fields	205	Yes	High	Yes	8%
	Low aquifer capacity	191	Yes	Reduce by 90%	Yes	20%
	Restricted onshore storage	178	Yes	High	No	25%
	Low capture investment	65	Yes	High	Yes	21%
	Medium scenario	46	No	Reduce by 90%	No	0%

Table 1: Summary of effects of transport and storage restrictions on CCS uptake in the NSBTF countries and Denmark

The potential value of the CCS industry in Europe is very high. The IEA's CCS Roadmap envisages cumulative investment in CCS of US$6.8 billion in OECD Europe by 2020, with a total of $590 billion by 2050. For transport and storage alone, the comparable figures are US$2.6 billion by 2020 and US$140 billion by 2050. In some scenarios, the capacity of the transport and storage infrastructure would exceed the capacity of existing North Sea oil and gas infrastructure. The industries in the North Sea could leverage home-grown experience to capture a large proportion of the global market – the IEA estimates the cumulative value to be US$5 trillion by 2050.

There are long lead times for delivery of international legal agreements and major infrastructure. International agreements often take several years to broker, and it can take more than ten years from early design to the eventual operation of a large pipeline that crosses international borders. Therefore in the event of a 'Very High' scenario for CCS deployment in 2030, a number of legal and regulatory issues will need to be resolved before 2020. These include:

- Satisfactory regulations for exploration and storage licenses, particularly liabilities, within national laws.
- Clarifying jurisdictional responsibilities and approaches for elements of CCS – including handover of stewardship of hydrocarbon sites for CO_2 storage, risk management, site qualification, monitoring, verification, accounting, reporting, decommissioning, and monitoring.
- Legal rights to transport captured CO_2 across borders, which require ratification of the recent amendments to the Ospar Protocol and London Convention.

- Clarifying emissions accounting rules for integrated CCS networks spanning multiple countries, with diverse sources, sinks and transport solutions.
- Agreements on the management of cross-border issues, such as transboundary transport and storage infrastructure, sinks that span national borders, and the management of potential impacts from a project developed in one country on a second country.

A 'One North Sea' Vision

The member states and commercial partners of the NSBTF are in a natural leadership position on CCS, due to:

- Abundant sink capacity and source clustering, potentially leading to lower costs for deployment.
- The opportunity to capitalise on commercial activity within NSBTF member states, to act as a supplier of CCS technologies and expertise, which, once proven, can be exported worldwide.

We suggest the following vision for CCS within the North Sea region:

Near term

A coordinated set of demonstration and pre-commercial projects in the period to 2020 proving key elements of the technology as economically viable, and thereby establishing the NSBTF countries alongside world leaders of technology development and deployment.

- There will be significant efforts by the governments and stakeholders of the NSBTF to coordinate efforts on the development of CCS incentives at European and global levels.
- A more detailed picture of the useful storage capacity within the North Sea will have been developed, increasing confidence for policymakers and commercial stakeholders alike.
- The demonstration projects will be optimised to ensure the necessary learning and growth is achieved efficiently, with best practices developed and communicated on capture, transport, and storage.
- Appropriate legislation will be in place to facilitate the large scale commercial storage of CO_2 under the North Sea, and its potential transfer between member states.

Mid-term

Assuming successful demonstration, a ramping up of commercial CCS deployment in the period 2020 – 2030 so that by 2030 the technology is making a significant contribution to CO_2 abatement within Europe.

- Incentives for CCS (such as CO_2 prices) will be sufficient and long-term so as to encourage a growing number of large scale commercial projects.
- The legislation developed in the near term, will support an increasing volume of cross border flows. This mutual support will help dilute and reduce risk and costs amongst North Sea member states.
- By the end of this period, the CO_2 flows in the North Sea region and the industry required to develop it, approach the capacity of the oil and gas industry in the North Sea.
- Industry in the NSBTF countries will exploit the knowledge acquired through demonstration and scale up, exporting technologies and services to a worldwide market.

Long term

Assuming successful CCS deployment, in the period up to 2050 where necessary we will see:

- Many additional sources, including industrial sources, will connect to CCS networks, further increasing overall abatement.
- A well-established transport and storage infrastructure will allow the region to attract and retain carbon- and energy-intensive industries, allowing them to operate cost-effectively within a low carbon economy.
- The CO_2 storage capacity of the NSBTF countries will be harnessed to facilitate the development of a low carbon economy beyond the NSBTF countries, for example, import of captured CO_2 or net export of low carbon electricity to other European nations.

Barriers to CCS in the North Sea region

The modelling and stakeholder review identified that although the potential for CCS in NSBTF countries is very large, there is uncertainty at every part of the value chain. Unless steps are taken to provide greater certainty, for example over capture incentives, the usefulness of specific storage sites, and the transfers of liabilities, there is a risk that the industry will not develop beyond a small number of demonstration scale plants between now and 2030. Currently, the barriers to CCS, and the progress being made to reduce them, vary substantially between the countries of the NSBTF.

Table 2 summarises the issues facing each country.

Table 2: Summary of capture, transport and storage issues in the NSBTF countries

Country	Norway	UK	Germany	Holland
Maximum annual Mt CO_2 captured in 2030	Up to 7	Up to 60	Up to 160	Up to 40
Progress with demonstration	Projects operational and under construction	Projects in design phase. Small pilots operational		
Capture policy	Strong policy support	Strong policy for CCS with new coal plant	Strong CO_2 reduction commitments but limited existing CCS polocies	CCS policies agreed by Parliament
Sufficiency of storage capacity for high demand	Excess capacity, with potential to store CO_2 from other countries	Excess capacity, but limited sink maturation so far	Sufficient theoretical capacity, but use sensitive to conditions. Cross-border transport reduces risks if domestic storage is not available	
Transport issues	Pipeline re-use potential	Intervention may be needed to facilitate optimal growth of networks. Some pipeline reuse potential		
Prevailing cross-border opportunity in 2030	Import	Import	Export	Import, export or hub

The barriers facing the CCS industry in Europe and the North Sea countries can be summarised as follows:

1. Insufficient incentives for CO_2 capture remain the biggest barrier to widespread CCS deployment in Europe.

2. Whilst overall theoretical capacity estimates are high, storage opportunities for CO_2 are highly site-specific. Information on the locations, capacities, suitability and availability of individual sinks is currently too limited to support Europe-wide policies and investments that would result in significant CCS activity.

3. A vicious circle comprising high uncertainties over the demand for CCS, investment in integrated infrastructure, sink suitability and availability, technology development and public policy across Europe creates a real risk that investments in CCS infrastructure, for example in shared pipelines, will not proceed quickly enough to enable a large-scale roll-out of CCS in the period 2020 to 2030.

4. There is limited clarity on CO_2 storage regulations, creating challenging business models for storage.

5. An absence of strong public support for CCS as a whole and for constituent elements.

Recommended actions

On the basis of the analysis undertaken and associated stakeholder consultation, this report identifies steps that need to occur at global and European levels to deliver CCS.

We make five specific recommendations for activities at North Sea level that should ensure CCS could be a viable large scale CO_2-abatement strategy for the NSBTF countries.

The first four of these require the organisation, expertise and interests of the governments of the North Sea countries, representatives of the CCS industry, and key independent stakeholders. Therefore, given its unique membership and terms of reference, these could logically be actions for the full NSBTF.

The fifth recommendation relates to facilitating cross-border CCS projects, and this would need to remain the exclusive responsibility of the Governments, although this could still occur within the auspices of the NSBTF.

Actions for the NSBTF (or other consortia combining the interests of public and private stakeholders in the region)

Recommendation 1

Recognising the limitations of existing data on sink capacity, availability, and suitability, and long lead times for storage assessment and validation, the NSBTF (or others) should, by 2012, consider a shared CO_2 storage assessment to improve the consistency, quality and credibility of North Sea storage capacity estimation, mapping, suitability assessment, and/or validation.

Recommendation 2

Recognising the potential for information to reduce uncertainties and optimise the development of CO_2 transport and storage infrastructure, the NSBTF (or others) should continue to assess and publish biennial long-range reviews of opportunities and challenges for CCS-related activity in and around the North Sea region.

The next review should include:

i. Updated assessments of the economic potentials, timing, organisation and implementation of capture, transport, storage, enhanced oil recovery, and infrastructure re-use.

ii. Updates on relevant national and European policies and guidelines, and comparison of technical, legal, regulatory or commercial barriers for CCS in the North Sea region with other regions of the world.

iii. A review of low cost near term measures that could substantially reduce the long-term costs of CCS, for instance data sharing, future-proofing specific sites or infrastructure, or increased organisation.

iv. Case studies providing as much detail as possible on site-specific opportunities and challenges for capture, transport and storage.

Recommendation 3

Recognising that depleted hydrocarbon reservoirs in the North Sea are promising early storage sites, in the period 2010 – 2015 the NSBTF (or others) should share experience and thereby develop guidelines on how stewardship should be transferred between hydrocarbon extraction, Government, and CO_2 storage.

Recommendation 4

Recognising that influencing policy development and sharing information at global and particularly European levels will be critical in developing CCS around the North Sea, the governments and members of the NSBTF (or others) must continue to show leadership and co-operation in the development of legislation, and in sharing information where appropriate, to support CCS, in their own countries, at European level and in global forums.

Actions for Governments to facilitate cross-border CO_2 flows

The analysis in this report identifies that cross-border CO_2 transport and storage could play a useful role by 2030. The Governments of NSBTF member states are best placed to address these cross-border issues, and we recommend the following actions:

Recommendation 5

Before 2014 the NSBTF Government Members should review progress on cross-border issues and expected demand, and if necessary the Governments should publish a formal statement of intent to agree terms where required in respect of the management of cross-border flows or potential impacts, infrastructure and storage complexes.

Whilst the exact timing and focus will depend on the outcome of this review and expected lead times, Governments should consider developing frameworks in the period 2015 – 2020 for:

- The management of potential impacts of CO_2 storage projects developed in one country on a second country.
- The management of liabilities for CO_2 transported from one country and stored in a second country.
- The management of CO_2 storage complexes that span national borders, for example exploration, leasing and licensing of pore spaces, short and long-term monitoring and liabilities.
- The permitting, construction, operation, decommissioning and liability issues for physical CCS infrastructure such as pipelines and injection facilities that span borders.

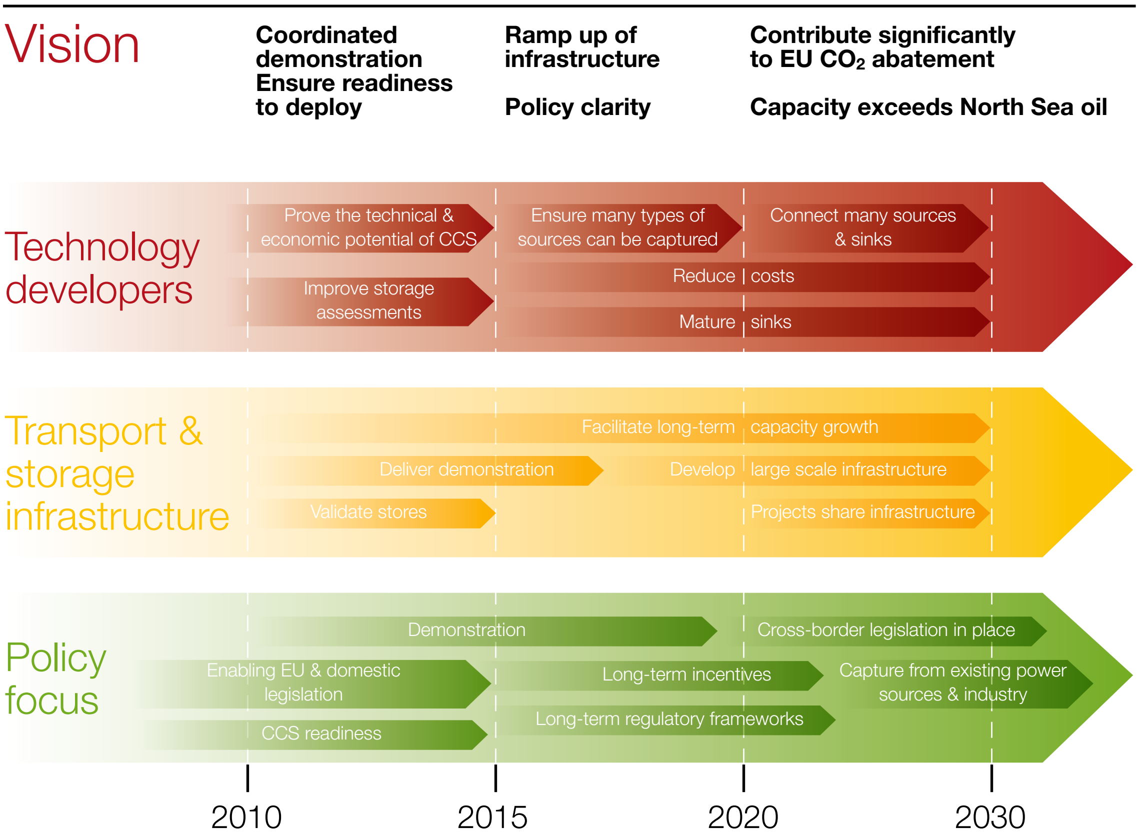
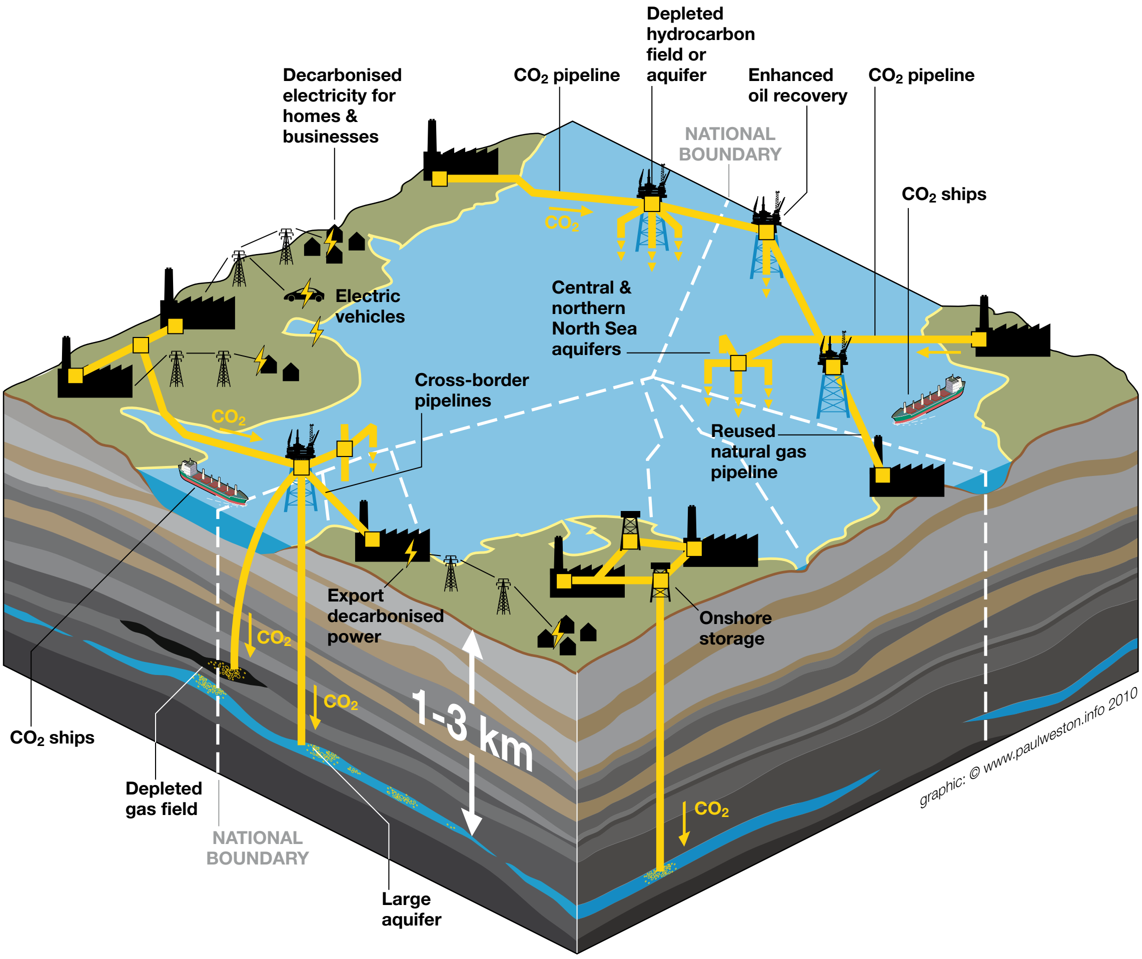


Figure 3: Timeline reflecting the focus of CCS stakeholders in the North Sea region (assumes 'Very High' scenario).

Figure 3.1:

A ‘One North Sea’ vision



Introduction

1

1 Introduction

1.1 The role of CCS in meeting European CO_2 reduction targets

National, European and global models for keeping within levels of atmospheric CO_2 concentrations that could restrict climate change to within 2ºC of mean temperature change conclude that Carbon dioxide Capture and Storage (CCS) is likely to be part of a cost-effective CO_2 reduction strategy. The International Energy Agency (IEA, 2008) conclude that CCS could provide 19% of world CO_2 emissions abatement in 2050, and that without CCS, the costs of constraining emissions increase by 70%. McKinsey (2008) demonstrates that CCS could provide 20% of European emissions abatement by 2030.

Of more than 70 CCS demonstration projects proposed worldwide for the period 2011-2020,[2] approximately one third are located in the four NSBTF countries. The NSBTF countries therefore have the opportunities to become world leaders in CCS implementation in the next decade and to capture a share of a potentially large global market (valued at potentially several trillion dollars[2]) for CCS technologies and services in the future. Therefore, in addition to facilitating CO_2 emission reduction from carbon-intensive industries, the CCS industry could become an important export industry[3].

Most European countries are expected to remain reliant on fossil fuels beyond 2030. CCS allows the use of fossil fuels (especially coal) in power generation and industry in a carbon-constrained economy. For Europe as a whole, the ability to use coal decreases reliance on natural gas for which security of supply is an important concern. In the longer term, CCS can also be applied to biomass power or biofuel production, potentially resulting in "negative CO_2 emissions".


Picture: iStockphoto © Alohaspirit

2 IEA CCS Roadmap (2009), available at www.iea.org

3 Scottish Enterprise (2005), Carbon capture and storage market opportunities
http://uk.sitestat.com/scotent/secom/s?carbon_caspture_and_storage&ns_type=pdf
An Industrial Strategy for CCS in the UK is available at www.decc.gov.uk

Table 3: CCS demand in Europe in 2030 in four recent studies

Region modelled	Capture Mt CO_2/year			
	2020	**2030**	**2050**	**Reference**
OECD Europe	37	300	1000	IEA CCS roadmap 2009
Europe	40	400	Not determined	McKinsey 2008
EU27	Not published	65-517	Not published	University of Athens Primes model

1.2 The One North Sea Project

In September 2009, the UK and Norwegian governments commissioned the 'One North Sea' project on behalf of the North Sea Basin Task Force.

The One North Sea project extends previous analysis by the Task Force[4] and aims to establish a vision of the potential role of the North Sea in the future deployment of CCS across Europe, and propose a strategy for its delivery.

The key objectives of the study are to:

- Establish the likely demand for North Sea CO_2 storage, including when this will arise.
- Identify key government and industry actions and principles to support the management of transboundary CO_2 flows and optimise the rapid development of CO_2 transport infrastructure.

The study was led by Element Energy Ltd, with significant input from Econ Pöyry, the Norwegian Petroleum Directorate, Cameron McKenna, The British Geological Survey, and Carbon Counts. This report presents the outcomes from the study, which was based on an extensive scenario development, modelling and consultation with key stakeholders listed in the Acknowledgements. This document represents the final report and major deliverable from the study. The final report accommodates feedback received from stakeholders on interim and draft final versions of the report.

4 Available at www.nsbtf.org

1.3 Structure of the report

The report is ordered as follows:

- **Section 2** provides an overview of current CCS activity within the European Union, and, the four countries of the North Sea Basin Task Force - Germany, Netherlands, Norway, and the UK.
- **Section 3** describes the approach taken to understanding the demand for storage, which involved scenario development, technical modelling and stakeholder engagement. The section includes a critical review on data quality, particularly with respect to estimating storage capacities.
- **Section 4** presents the results of CCS deployment scenarios. It includes analysis of the overall quantities and patterns of CO_2 activity in the North Sea countries, and investigates the effect of restrictions on CO_2 transport and storage within and between countries.
- **Section 5** analyses additional drivers for CCS development, including infrastructure re-use, EOR, shipping, and source clustering.
- **Section 6** presents legal and regulatory issues surrounding CCS deployment in Europe, with a focus on issues affecting cross-border transport and storage of CO_2.
- **Section 7** brings together the preceding analysis, and suggests a vision for the development of CCS as a safe and cost-effective CO2 abatement technology for the North Sea region.
- **Section 8** lists the main barriers to delivering this vision.
- **Section 9** proposes a strategy for delivering this vision.
- **Section 10** lists the expert stakeholder group who provided input to this study.

The report is supplemented with appendices that provide:

- A technical description of the methodology used to estimate CO_2 storage potentials with a critical review on the consistency of methodologies used to calculate CO_2 storage capacity.
- A technical description of the CCS demand scenarios and results identified in this study.
- A map and description of proposed CCS demonstration projects in Europe.
- A description of the North Sea Basin Task Force.
- A list of important European CCS Research and Development programmes of relevance to the North Sea Basin Task Force.
- A commercial perspective on legal and regulatory issues for integrated transport networks.


Picture: iStockphoto © Vera Tomonkova

Overview of current CCS activity in Europe

2

2 Overview of current CCS activity in Europe

To understand the potential for CO_2 storage under the North Sea and the role of cross-border CO_2 transport and storage in facilitating this, this Chapter identifies relevant existing and planned EU, Norwegian, British, Dutch and German CCS policies and initiatives. These will be the principal determinants of CCS demand around the North Sea in the period up to and beyond 2020.

2.1 European Union CCS initiatives

The EU's strategic energy technology roadmap foresees an important role for CCS. The EU is directing resources[5] towards developing the political, economic, social, technological, legal and environmental foundations for safe and successful CCS demonstration and deployment.

Of note, the European Technology Platform for Zero Emission Fossil Fuel Power Plants (known as 'ZEP'), initiated by the European Commission in 2005, is an influential coalition of European utilities, power companies, equipment suppliers, academics, and environmental NGOs. Working with ZEP, the European Commission has developed CCS legislation (the CCS directive), passed by the European Parliament, and the EU has agreed to co-fund a programme for CCS demonstration. These are described below. On the basis of ZEP's 2009 CCS knowledge sharing proposal, the EU is launching its CCS project network.

2.1.1 The CCS directive

The CCS Directive, adopted in 2009, establishes a legal framework for the environmentally safe geological storage of CO_2 in the territory, exclusive economic zones and continental shelves of EU member states. Key elements of the framework are:

1. CO_2 exploration must only be carried out with a permit.

2. CO_2 storage must only be carried out with a permit from a competent authority in a Member State. Member States must put in place **(i)** a system for granting permits objectively and transparently; and **(ii)** arrangements for financial security.

3. CO_2 streams must consist "overwhelmingly" of carbon dioxide.

4. During injection, operators must monitor storage sites – and competent authorities must carry out routine inspections.

5. Operators remain responsible for on-going monitoring, reporting and corrective measures, as well as obligations regarding the surrender of allowances in the case of leakage and all preventative and remedial action.

6. Closure requires that **(i)** all available evidence indicates that the stored CO_2 will be completely and permanently contained; **(ii)** 20 years has elapsed since injection; **(iii)** the site has been sealed and injection facilities have been removed; **(iv)** the operator has made a financial contribution to the anticipated cost of monitoring for 30 years after closure. If the site is closed, the liabilities for monitoring and corrective measures, the surrender of allowances in the case of leakage, and preventative

5 For a recent comparison of investment in CCS by the EU, member states and industry, see http://setis.ec.europa.eu/capacity-map/analyses/2009/report/3-2-5-%20Results%20CCS.pdf

and remedial action are transferred to the competent authority.

7. Operators of CO_2 networks provide non-discriminatory access to third parties, and may be required to provide additional network capacity in order to accept third party connections.

To date, no country has fully implemented the CCS Storage Directive in national law. Some storage developers criticise the Directive for creating, in their view, onerous requirements in respect of financing unclear and potentially large post-closure costs and liabilities. Challenges in managing liabilities for multiple users injecting into different locations - or at different times - within the same storage unit, remain unresolved.

2.1.2 EEPR funding for CCS demonstration

The EU has approved the allocation of Eur 1.05 billion from the European Energy Programme for Recovery to the following CCS projects, which includes three projects in the NSBTF countries.

- Pre-combustion capture at Powerfuel Ltd, Hatfield, UK
- Oxyfuel and post-combustion at Vattenfall Europe Generation, Jaenschwalde, Germany
- Post-combustion CCS at Maasvlakte, Rotterdam, the Netherlands
- Post-combustion CCS at PGE Elektrownia Belchatow, Belchatow, Poland
- Oxyfuel CCS at Endesa Generacion, Compostilla, Spain
- Post-combustion CCS at Enel Ingegneria e prod, Porte Tolle, Italy

2.1.3 NER300 funding for CCS demonstration and innovative renewables

The EU has agreed that 300 million emissions allowances will be set aside from the new entrants reserve to stimulate the construction and operation by the end of 2015 of up to 12 commercial CCS demonstration projects as well as Renewable Energy demonstration projects across the EU. Proposals will need to be submitted in 2010, with awards made by the end of 2011 and 2013. How quickly developers will be able to access these funds and under what contractual conditions remains unclear.

2.1.4 Funding CCS deployment via the EU-ETS

From 2013, CCS will be included within the EU Emissions Trading Scheme. Allowances will not need to be surrendered for emissions that are avoided through the permanent storage of CO_2 in licensed sites. The situation for vertically integrated projects is therefore relatively straightforward. However, before 2030 the rules on CCS within the ETS may need to be modified if transport and storage infrastructure become increasingly networked, spans multiple countries, includes commercial applications for CO_2 or involves sources capturing CO_2 derived from biomass.

Uncertainty about the long-run price of emissions allowances under the EU ETS is the largest financial risk facing commercial development of CCS projects and infrastructure. Unlike renewables, energy efficiency, and even nuclear energy, for which technology and commercial risks are smaller, CCS project revenues are critically dependent on prices for avoided CO_2, and additional incentives prior to commercial roll out. Capital intensive investments, highly uncertain revenues, and novel technology/supply chain combinations together discourage investment in CCS.

2.1.5 Funding research and development in CCS

The EU also supports CCS research and development projects through its framework programme (FP5, FP6[6], FP7). A list of collaborative European CCS research programmes is provided in the Appendix.

2.1.6 EU CCS Network

The European Commission is establishing a CCS Network (www.ccsnetwork.eu). The main objective of the network will be to facilitate knowledge sharing among participants and stakeholders in the demonstration programme.

2.2 CCS Activity in Norway

Norway has undertaken to reduce its greenhouse gas emissions by 30% of its 1990 emissions by 2020. It has also pledged to achieve carbon neutrality, reducing global greenhouse gas emissions by the equivalent of 100% of its own emissions by 2050. CCS is viewed as an important tool to achieve this goal.

Norway has 13 years' experience of CCS operations, which started in 1996 with CO_2 storage at the Sleipner field in the North Sea (10 Mt CO_2 has been stored so far). A second project at the Snøhvit field for liquefied natural gas in the Barents Sea began in 2008. 0.7 Mt CO_2/year are separated from natural gas onshore every year and re-injected in the formation below the seabed. These projects were permitted by the Norwegian Pollution Control Authority (SFT) under the Pollution Control Act.

In January 2008, Gassnova SF, a state-owned enterprise designed to manage the government's investments in CCS, was established. Its responsibilities include research and development funding advice (CLIMIT programme, see below), large-scale CO_2 projects development and execution, and acting as an adviser to the Norwegian government.

Gassnova's projects include:

- The European CO_2 Test Centre Mongstad (TCM): construction of TCM started in June 2009 and the centre should be operational by the end of 2011. The plant will have the capacity to capture up to 0.1 Mt CO_2 /year.
- The full scale CO_2 capture plant from gas turbine power at Mongstad, which should become operational in 2014 and will have capacity to capture 1.3 million tons of CO_2 .
- Large-scale CO_2 capture from a gas turbine power plant at Kårstø; and
- The large-scale CO_2 transportation and storage from Kårstø and Mongstad projects to subsea storage locations, most likely the Utsira or Johanson formations.

Gassnova SF together with the Research Council of Norway administers a Research and Development Programme on Power Generation with Carbon Capture and Storage (CLIMIT). The programme provided funding up to NOK 68.5 m (£7.5 m) in 2009 for activities aimed at research, development, and demonstration up to early commercialisation of CCS solutions for emissions from fossil fuel-based energy production. The programme has a total budget of NOK 180 m in 2010, and the mandate will be extended to include CO_2 emissions from industry sources.

In Norway, the government plays a very active role in executing CCS projects which involves

6 EU FP6 funding for CCS has been of the order of 70 million Euros or 17 million Euros per year of the programme

contracting with companies to build the projects (through Gassnova SF) and providing full funding.

However, the Gassnova projects have still encountered challenges that may be relevant for projects elsewhere:

- Costs for storage evaluation may prove higher than initially expected.
- The timescale for developing projects has been longer than originally estimated. Political agreement has taken longer, as have the collection, processing and interpretation of seismic data and securing agreements with oil- and gas industry stakeholders.
- Restrictions have emerged on storage potential, which is therefore lower in capacity than originally envisaged, and on where and when CO_2 injection will be allowed which has added to storage costs.

CCS as part of petroleum activities (whether for EOR or permanent storage) can today be regulated under the legal regime for petroleum activities, i.e. the Petroleum Act and Regulations (including HSE), the Pollution Control Act and Regulations, and the CO_2-levies Act. Since Norway has passed legislation for a national emission trading scheme to allow it to link the EU ETS, it will likely harmonise rules for CO_2 storage with those in the EU ETS.

The Norwegian Petroleum Directorate (NPD) has worked for some years on the mapping of offshore CO_2 storage sites related to specific CCS projects. In 2009 The Ministry of Petroleum and Energy asked NPD to start a mapping programme and present possible secure geological sites for storing CO_2[7].

2.3 CCS Activity in the UK

The UK has a legally binding target of at least an 80% cut in greenhouse gas emissions by 2050, as well as a reduction in emissions of at least 34% by 2020, against a 1990 baseline. Analysis by the UK's Committee on Climate Change suggests that complete decarbonisation of the electricity sector by 2030 is essential to meet the 2050 target.

The UK government acknowledges that CCS could play a major role in decarbonising the electricity sector, and has taken significant steps to encourage its demonstration and deployment. The gross value added to the UK from new advanced coal-fired power generation including with CCS industry has been estimated[8] as £20-40 billion in total between 2010 and 2030 with

- £1 – 2 bn/year in 2020 with 2,100 CCS-related jobs
- £2 – 4 bn/year in 2030 with up to 30,000 CCS-related jobs

The Energy Act 2008 creates a legal and regulatory framework for CCS, which implements part of the EU CCS Directive. Implementation of the recent Marine and Coastal Act and Planning Act should also streamline the planning process.

Highlights of current UK policy are:

- DECC has recently published its "A Business Strategy for Carbon Capture and Storage" and selected projects for which it will fund the detailed design (FEED) stage prior to selecting the winner of its competition to demonstrate the full chain of CO_2 post-combustion capture, transport and storage on a 300 MWnet coal-fired power plant.

7 http://www.regjeringen.no/en/dep/oed/press-center/Press-releases/2009/unprecedented-allocation-of-funds-toward.html?id=579459

8 AEA (2009) Future value of coal carbon abatement technologies to UK industry, available at http://www.decc.gov.uk/Media/viewfile.ashx?FilePath=What%20we%20do\UK%20energy%20supply\Energy%20mix\Carbon%20capture%20and%2storage\1_20090617131417_e_@@_coalcatfuture.pdf&filetype=4

Picture: iStockphoto © Oversnap

- In 2010 DECC will select the winner of its competition to demonstrate the full chain of CO_2 post-combustion capture, transport and storage on a 300 MWnet coal-fired power plant.
- Commitment to funding a further three CCS demonstration projects over the next decade through a levy on electricity suppliers.
- Carbon capture readiness is mandatory for all new generating plants with a rated electrical output of 300 MWnet or more.
- A new coal policy framework has been established, emphasising **(i)** there will be no new coal power stations without CCS, and **(ii)** there will be a long term transition to clean coal power.

The UK Government recently consulted on the regulatory regime for offshore storage. The proposals adapt thinking from hydrocarbon field development and envisage the following sequence of permissions:

1. For non-intrusive exploration, a combined Petroleum and Energy Act licence is sufficient. No Crown Estate lease is required.
2. For intrusive exploration, an exploration/appraisal permit and Crown Estate lease are required.
3. A carbon storage permit can be issued once a field development plan (including monitoring and remediation plans) are submitted. A Crown Estate lease would be additionally required for the injection period.
4. After post-closure monitoring (likely 20 years), there can be handover to the State, which takes responsibility for post-handover monitoring.

The UK has a well-developed offshore infrastructure from decades of hydrocarbon production, with potential for re-use in CCS projects. However, in view of the UK's obligations under OSPAR, the Department of Energy and Climate Change expects the removal of disused installations not to be delayed unless a robust case demonstrates there is a specific reuse opportunity or other justifiable reason for deferring decommissioning.

2.3.1 Current and planned programmes and projects

The previous NSBTF study identified that the UK has clusters of large CO_2 sources near the Humber, Teesside, Merseyside, Firth of Forth and Thames estuaries.[9] Importantly, regional studies have now been conducted to understand the opportunities for CCS for businesses, including shared CCS infrastructure in the Humber, Scotland, Thames estuary, North East and East of England.

At a national scale, work is being undertaken to better characterise the storage sites in the UK Continental Shelf. The £3.5 million UK Storage Appraisal Project, funded through the Energy Technologies Institute[10], will carry out a detailed review of potential sites suitable for storing CO_2 offshore to assess the realisable storage capacity at individual sites.

2.4 CCS Activity in the Netherlands

The Dutch government aims to achieve a reduction of greenhouse gas emissions of 30% by 2020 and expects CCS to play an important role as part of its strategy to create a sustainable energy sector.

9 Element Energy et al. (2007) Development of a CO2 transport and storage network in the North Sea.
10 http://www.energytechnologies.co.uk/Home/Technology-Programmes/carbon-capture.aspx

To help create the conditions for large-scale deployment of CCS in the Netherlands, the Ministries of Economic Affairs and Housing, Spatial Planning and Environment established a CCS Taskforce in March 2008.

In June 2009, the Dutch Government outlined a number of preconditions for the development of future large-scale projects, including:

- Further research to develop large-scale capture technology while reducing costs;
- Development of a long-term infrastructure and storage strategy;
- Evaluation of other measures to promote large-scale CCS, such as mandatory CCS.
- Clarity on the administrative and legal framework for CCS.

This 'policy letter' has now been backed by the Dutch Parliament. The Government aims to satisfy the first precondition by providing financial support to the CATO2 CCS research programme, to small-scale demonstration projects and also to the launch of large-scale CCS projects in the Netherlands.

With Dutch effective storage capacity distributed across a number of relatively small fields and with complex issues on timing[11] the Government will in spring 2010 decide on a Masterplan for transport and storage infrastructure for CCS. This will address the selection and scheduling of gas fields for CO_2 storage and the delegation of tasks and responsibilities between the different stakeholders.

Current legislation on decommissioning of hydrocarbon sites may hinder CCS: By 2020 most surface facilities and wells will have been permanently abandoned, and access and redevelopment may then become prohibitively expensive.

The Mining Act is being amended to reduce conflicts of interest between CCS and hydrocarbon exploration activity.

The FP7 study, "NearCO_2" led by ECN[12], is examining public engagement around CCS projects. Concerns raised by the public for Shell's onshore CO_2 storage project in the Barendrecht field include safety, monitoring, property values, as well as more general concerns that CCS is unnecessary or ineffective - however the Dutch Government and Shell remain committed to the Barendrecht project.

CASE STUDY

The Rotterdam Climate Initiative

Since 2007, the city of Rotterdam, the Rotterdam Port Authority, Deltalings (representing companies in the Rijnmond) and DCMR Environmental Protection Agency have been working together, and now with industrial partners, as the Rotterdam Climate Initiative (RCI), to realise a 50% CO_2 emissions reduction in 2025 compared to 1990 levels. Two thirds of this reduction (20 Mt CO_2/year) is to be achieved through CCS.

In 2008 the Rotterdam Climate Initiative published a feasibility study that demonstrates that 5 Mt CO_2/year in 2015 with 20 Mt CO_2/year by 2025 could be captured.

In 2009, RCI published a study that examines capture, transport and storage options, costs and means of financing phased development in more depth, including considering alternative uses of CO_2 such as in greenhouses. The study confirms that Rotterdam offers a favourable location for a CCS network due to the high concentration of industrial emissions in the Port of Rotterdam area, the Port's proximity to significant volumes of storage capacity, both offshore (on the Dutch continental shelf) and onshore, and potential flexibility with respect to transport.

11 Nogepa (2008) Potential for CO2 storage in depleted gas fields on the Dutch Continental Shelf
12 Presentation by D. Reiner at the 3rd Annual European Carbon Capture and Storage Summit on 18th November 2009. For further information see http://www.communicationnearco2.eu

A portfolio of CCS pilots and large-scale demonstration projects are being developed in the Northern Netherlands, involving Nuon, RWE, Akzo Nobel, Advanced Power, SEQ, Electrobel and Gasunie. €8 m has been earmarked for work on transport, storage and communication.

2.5 CCS Activity in Germany

Germany's integrated energy and climate package aims to deliver a 30% cut in CO_2 emissions against a 1990 baseline. The Government currently expects CO_2 reduction to be dominated by renewable energy and energy efficiency, with some switching from coal to gas. The phasing out of nuclear energy in Germany is currently under discussion. The environmental Ministry is aiming for ca. 100% renewable energy by 2050.

The German Government has adopted a 'no-regrets' strategy with the aim that CCS, including secure CO_2 storage, is commercially viable by 2020. Recommendations for action agreed by the German Cabinet in 2007 include creating the legal framework for CCS, supporting demonstration projects, expanding R&D activities on capture and storage, including site-specific research, and providing public information.

Capture is mainly governed by the Federal Pollution Control Act (Bundes-Immissionsschutzgesetz). Transport and storage are subject to various regulations under state building law, nature conservation law, and mining law.

Experience suggests that, in the short term, individual pipelines will be developed by the entities also running the power plant and/or the storage site.

The political discussion in Germany has focussed on longer term objectives for renewable energy, with concerns over continued use of fossil fuels and the safety of (onshore) storage sites. With safety issues being a key part of the political debate in Germany, the draft CCS Act proposed safety standards beyond those required by the CCS Directive:

- Operators must provide post-closure security at storage sites for 30 years, 10 years longer than in the EU Directive.
- Operators must contribute to monitoring costs for a further 30 years after handover.

2.5.1 Current programmes and activities

The German government funds two research and development programmes:

- COORETEC is focussed on power plant efficiency and capture.
- Geotechnologien is focussed on long-term safe and environmentally friendly CO_2 storage and corresponding storage technologies.

Pilot plants are testing capture technologies at Vattenfall's Schwarze Pumpe and RWE's Niederaussen facilities. These are small-scale pilots with the latter capturing 300kg of CO_2 per hour.

Geological storage is being tested at the Ketzin test site in Brandenburg, while the national and regional geological surveys started in 2008 a detailed study of capacities in German sinks including the North Sea sector.

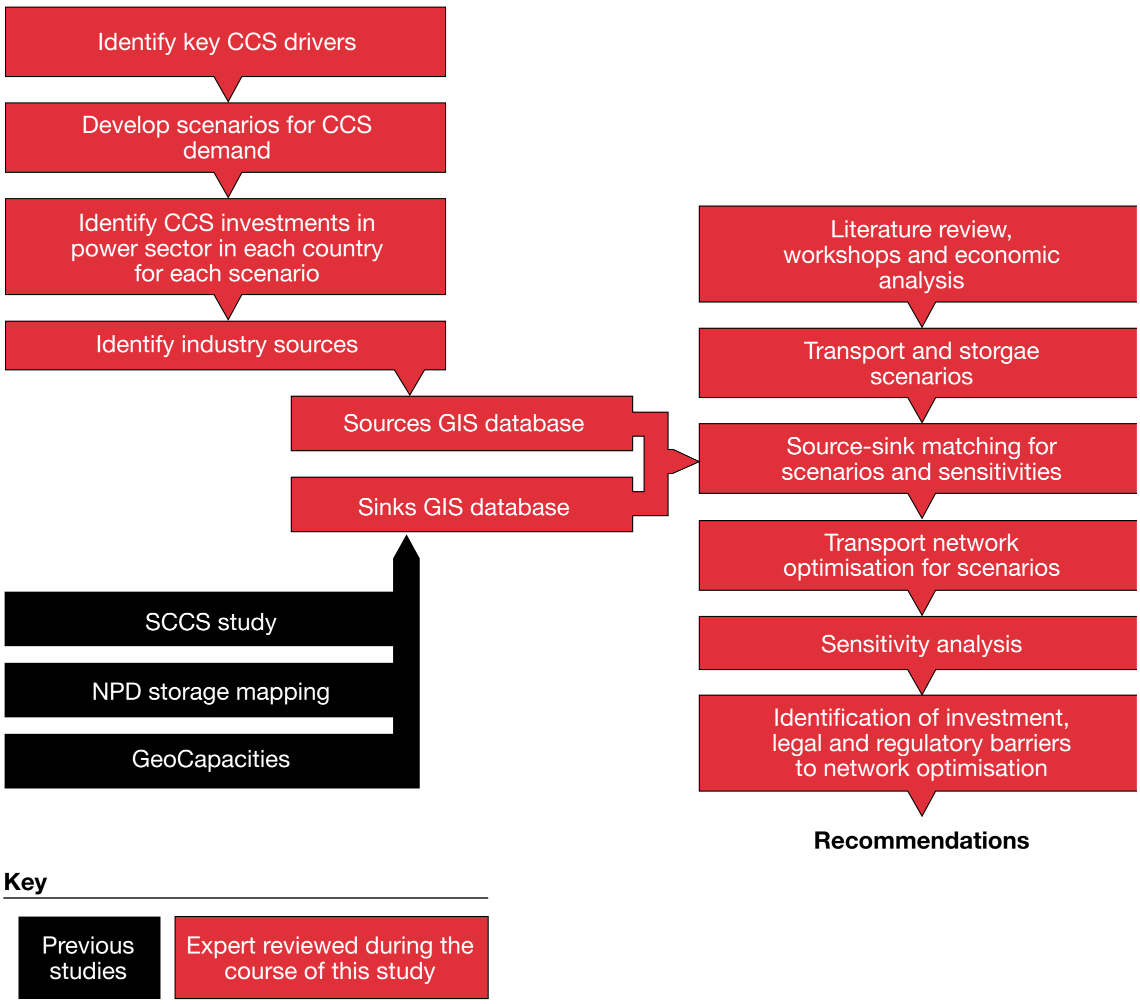
Predicting deployment of CCS in the North Sea countries

3

3 Predicting deployment of CCS in North Sea countries

The preceding analysis highlights the demonstration efforts in Europe and specifically in NSBTF countries, underpinned by public and private investment. Despite many uncertainties, existing national and EU policy commitments provide some clarity as to overall CCS demand up to 2020. There is much less clarity beyond 2020, and a range of deployment levels are possible. This chapter describes the approach used to develop scenarios for deployment of CCS in the North Sea region between 2020 and 2050, in terms of the input data and the modelling methodology.

Figure 4: Approach taken to identify cross-border CCS demand around the North Sea and requirements for NSBTF to facilitate optimum transport and storage networks.



3.1 Our approach

Projections for CCS demand and databases for CO2 storage potential in Europe were developed as inputs into Element Energy's source-sink matching model. The model was run to identify plausible source-sink matches across Europe under a series of scenarios reflecting the influence of key CCS drivers. This in turn was used to quantify cross-border volumes of CO_2 associated with different scenarios for 2020, 2030 and 2050.

In parallel, stakeholder workshops and interviews were conducted to review the inputs, approach and outputs.

3.2 CCS demand

There are clearly continua in the extent to which climate policies are implemented through global markets or through fragmented, regulated and regional initiatives, and the degree of CCS cost reduction possible.

Nevertheless, three plausible, independent, and internally consistent market- and policy-driven combinations were developed. These combinations, named 'mandatory', 'fragile' and 'competitive' are summarised in **Table 4** and their rationale described fully in the appendix.

These combinations were used as inputs to Econ Pöyry's Classic Carbon model, which is one of the leading models for predicting investment in the power sector across Europe. A full description of the Classic Carbon model is provided in the Appendix. The model was run to project the amounts and possible locations of investment in CO_2 capture in the power sector for each combination of inputs.

Table 4: Summary of the market and policy combinations in 2030 used as inputs for the Classic Carbon model

Driving force	Mandatory	Competitive	Fragile
Power demand	High	Business as usual	Business as usual
Renewables	90% of 2020 target	90% of 2020 target	100% of 2020 target
CO_2 cap	30% reduction relative to 1990	40% reduction relative to 1990	25% reduction relative to 1990
CCS costs	35% reduction relative to 2008	25% reduction relative to 2008	20% reduction relative to 2008
CCS efficiency penalty	6% gas, 8% coal	8% gas, 10% coal	8% gas, 10% coal
Gas prices	$19/MWh	$22MWh	$27/MWh
Coal prices	$70/tonne	$70/tonne	$70/tonne
Nuclear	Known investments only	Known and new investments	Known investments only
Mandatory CCS	New investments from 2020	None	None

Country	Mandatory projection 2030 ($MtCO_2$/yr)	Competitive projection 2030 ($MtCO_2$/yr)	Fragile projection 2030 ($MtCO_2$/yr)	PRIMES 2030 ($MtCO_2$/yr)
Denmark	10	4	4	5 - 7
Germany	219	4	23	32 - 186
Netherlands	59	1	27	5 - 14
Norway	1	1	1	not included
United Kingdom	27	13	13	1 - 62
TOTAL	**315**	**23**	**95**	**43 - 269**
CO_2 price in 2030 (€/t)	€14	€47	€42	€24 - 60

Table 5: Projected CO_2 capture investment from the Classic Carbon and PRIMES models

Table 5 shows the projected capture investment and resulting CO_2 prices for the 'mandatory', 'fragile', and 'competitive' combinations, and also compares CCS investment predicted from the Primes model (described below).

A detailed analysis of the projections, including commentary on the interdependence of countries, is provided in the Appendix. The main conclusions are:

- Projected demand for capture in 2030 around the North Sea could be as high as 315 Mt CO_2/year.
- With the 'mandatory' combination, the projected capture requirements differ by more than an order of magnitude between the countries of the North Sea Basin Task Force and are not correlated with current CCS activity.
- However the demand in 2030 is highly sensitive to assumptions for the North Sea region as a whole and within individual countries. The range of projected capture demand in 2030 spans at least one order of magnitude.
- The overall range and country-specific distribution of outputs from the Classic Carbon model are consistent with the outputs from the Primes model, developed by the University of Athens, which is the standard model used by the European Commission.
- Projected CO_2 prices vary substantially, posing a substantial risk for investors.

3.3 Sinks

Although capture is the dominant cost, the amount and geographic distribution of storage capacity are key factors determining the potential for cost-effective CCS. A full description of how CO_2 is stored and how storage potential is assessed is provided in the Appendix.

CO_2 can be stored in depleted hydrocarbon fields as well as deep saline formations (aquifers). Hydrocarbon fields are relatively well characterised, but there may be commercial and legal challenges in accessing the storage at reasonable cost, and there may be technical concerns, such as injection rates into low pressure gas fields or on seal integrity for fields with multiple wells. Competition for use of depleted hydrocarbon fields with temporary natural gas storage is theoretically feasible, although differences in technical requirements work against this.

The storage potential of saline aquifers could be very large, but these are insufficiently understood. The complete appraisal of an aquifer could be very resource intensive – lasting many years and cost several tens of millions of Euros each[13].

A few studies have attempted to estimate the CO_2 storage potential across Europe and in sectors of the North Sea. With very limited operational experience in CO_2 geological storage worldwide, there is only limited agreement on how storage should be evaluated. Often studies carried out by different geological surveys use different assumptions on the difference between theoretical versus realisable capacity, for example rules-of-thumb multiplication factors for storage efficiency (which can be defined as the proportion of the pore space that is available for storage once geological limitations are considered)[14]. Since full access to underlying data is often restricted, this makes comparing datasets between countries difficult, if not impossible. Importantly, there is currently no universally accepted database of CO_2 storage potential in Europe, or even in the North Sea, developed in a consistent, robust and comparable manner. All stakeholders caution that many published estimates for storage capacity should be treated with a high degree of scepticism. Consistent and better validated methodologies for North Sea storage capacity estimation would be important but are lacking.

The sink GIS database created in this study draws heavily on the EU GeoCapacity project. This provides a reasonably up-to-date and mostly internally consistent estimate of European sink capacity. The GeoCapacity project was an FP6-funded project. However the ability to access these storage data is subject to complex issues on intellectual property. The scope of this study was limited to those countries that were willing to share data.[15] GeoCapacity built on work carried out under the previous GESTCO project, completed in 2003, and attempted to assess total sink capacity in the EU countries using comparable assumptions.

GeoCapacity suggests a total storage capacity in depleted hydrocarbon fields and saline aquifers of over 300 Gt across Europe. Of this capacity, 55% is found in the four countries of the NSBTF, rising to 60% when Denmark is included. For the NSBTF countries plus Denmark, nearly 80% of this sink capacity is under the North Sea itself.

In addition to the sink data from GeoCapacity, this study employed additional data from two other sources to overcome limitations in that work. First, additional data on Scottish aquifers from a recent study carried out by the Scottish Carbon Capture Consortium , were added to the UK data, which is now significantly larger than that published previously[16]. The

13 See for example van den Broek et al. (2009) Feasibility of storing CO_2 in the Utsira formation as part of a long-term Dutch CCS strategy. International Journal of Greenhouse Gas Control

14 Some guidelines for capacity estimation have already been developed, e.g. Development of Storage Coefficients for CO_2 storage in Deep Saline Formations (IEA, 2009) and Storage Capacity Estimation, Site Selection and Characterisation for CO_2 storage projects (CO2CRC, 2008)

15 The project team encountered a notable reluctance from many national geological surveys to share sink data. Partly this is due to intellectual property and commercial concerns. In some cases withholding data appeared to be based on limited confidence in the methodology/data. The geographic scope of the project was restricted as only the geological surveys of Britain, Norway, The Netherlands, Denmark, Germany, Poland, Italy, Spain and Estonia consented to sharing data within this project.

default storage efficiency in the SCCS study is assumed as 2%. With this assumption, these aquifers add 43 Gt of CO_2 storage to the total in GeoCapacity. The Scottish Study also identifies a scenario where storage efficiency is only 0.2% - in this case the aquifer capacity would be 4.3 Gt CO_2. Secondly, the Norwegian Petroleum Directorate (NPD) provided updated data on Norwegian sink capacity[17]. Consideration of the potential for conflicts of interest with existing hydrocarbon production by NPD resulted in the reduction of the overall aquifer capacity from ca. 150 Gt to 100 Gt. Depending on uncertain close of production dates, possibly only half of the revised capacity may be available by 2030. The remainder would be available by 2050 when conflicts with existing hydrocarbon production are likely to have ceased.

For hydrocarbon fields, CO_2 storage cannot occur before the close of hydrocarbon production, except in the case of CO_2-enhanced hydrocarbon recovery. The close of production dates are often commercially sensitive, as well as heavily dependent on future fossil fuel prices, technologies and revisions to reserve estimates. DECC and the NPD estimated close of production dates for British and Norwegian hydrocarbon fields respectively, although an uncertainty range of up to 5 – 20 years was noted. Based on a published study[18], the close of production date for all gasfields in the Netherlands was assumed as ca. 2023, except for the Groningen giant gas field, which was assumed to close after 2050 and was therefore excluded from this study. In the absence of close of production data for Denmark, Germany and other countries, it was assumed that depleted hydrocarbon fields would become available for storage from 2030 onwards. The same assumption was made for saline aquifers, except for those in Norway which NPD has identified as interfering with hydrocarbon production as discussed above.

Table 6 and **Table 7**(next page) show the CO_2 storage capacities in depleted hydrocarbon fields and saline aquifers in the GIS database used for this study. Although these data represent the best available for this study, the estimates should be treated with appropriate caution and may represent upper limits. The appendix describes the basis of the sink assessment in more detail. The transport and storage workshops and stakeholder interviews during this study concluded that the use of numerous small sinks is unlikely to be attractive for CO_2 storage from large commercial-scale projects in 2030 that would likely each capture several million tonnes a year. This study follows the stakeholders' recommendations that, for economic reasons, those sinks with a capacity less than 30 Mt (in other words those that cannot store 1 Mt per year for 30 years) are excluded from the analysis[19]. No Close of Production data were provided for this study for the hydrocarbon fields in Germany, the Netherlands, or Denmark.

The total storage available in hydrocarbon fields in the GIS database is nearly 20 Gt in 2030 in Norway, Germany, Denmark, the UK and the Netherlands, rising to over 28 Gt by 2050 as additional fields are decommissioned. Although more uncertain, the storage capacity of saline aquifers in the database is considerably higher, with over 150 Gt available in 2030, rising to over 200 Gt by 2050. Over 70% of this capacity is in the UK and Norway. The timing of storage capacity in the Netherlands is highly dependent on the close of production of hydrocarbon fields.

16 Scottish Centre for Carbon Storage (2009) – Opportunities for CO_2 storage around Scotland
17 The storage capacity in oil and gas fields are reduced whereas aquifer potential is now higher than previously estimated in NSBTF (2007) Development of a CO_2 transport and storage network in the North Sea. The aquifer capacity is however reduced compared to the GESTCO report, as some aquifers have been excluded
18 NOGEPA (2008) Potential for CO_2 storage in depleted gasfields on the Dutch continental shelf
19 The impact of this simplifying assumption is largest on the Netherlands where there are a large proportion of fields below the 30 Mt CO_2 cut-off

Table 6: Modelled Mt CO_2 storage capacity in depleted hydrocarbon fields in the GIS database with 30Mt filter

Country	2030 storage (Mt)	2050 storage (Mt)	Reference
Denmark	753		GeoCapacity
Germany	1816		GeoCapacity
Netherlands	1532		GeoCapacity
Norway	4283	6302	NPD
UK	7141	7910	GeoCapacity
TOTAL	**15525**	**18313**	

Table 7: Modelled Mt CO_2 storage capacity in saline aquifers in the GIS database

Country	2030 storage (Mt)	2050 storage (Mt)	Reference
Denmark	16672		GeoCapacity
Germany	27120		GeoCapacity
Netherlands	428		GeoCapacity
Norway[20]	48488	97059	NPD
United Kingdom	60971		GeoCapacity and SCCS (2% efficiency)
TOTAL	**153689**	**202260**	

3.3.1 Limitations in the sink data

The approach outlined above is based on the best available data within the timescale and resources available within this study. Estimates of sink capacities span several orders of magnitude. This is due to limited geological characterisation, and differences in methodologies. This uncertainty could be resolved by a step change improvement in the level of analytical effort and operational experience in CO_2 injection, migration, long-term performance of storage.

Discussions with stakeholders identified the most important sensitivities as restrictions

20 Data for Norwegian aquifers were revised by NPD. This revision included an assessment of which aquifers are located to current and planned hydrocarbon exploration activity. It is assumed that these sinks are unavailable before 2050

in onshore storage, due to public uncertainty, low aquifer availability and low hydrocarbon field availability. The impacts of these are described within the Results chapter.

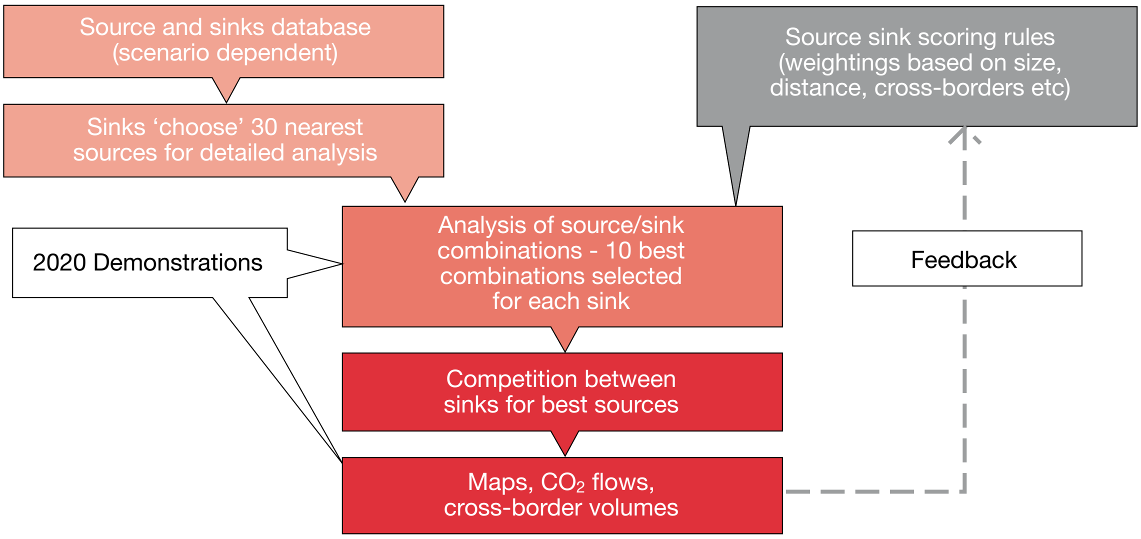
3.4 Source-Sink matching

The sources and sinks databases formed inputs to a network model developed by Element Energy, which matches sources and sinks under different assumptions, for example the availability of storage sites or the overall demand for CCS. This network model builds on the previous NSBTF analysis of pipeline infrastructure[9], and has been used and enhanced through a number of projects to assess the role of clusters versus point to point pipelines. The methodology used in the model is as follows:

- The sinks and sources databases, including locations, capacities and availability dates, are imported into ArcMap, a Geographical Information System (GIS).
- ArcMap is used to select and record the distances to the nearest thirty sources for each sink. This is repeated for each CCS demand scenario, and the resulting distance matrices are imported into the network model.
- The model scores each source and sink combination based on proximity, the size of the emitter, whether or not the sink has sufficient capacity or the pipeline crosses national boundaries or is partially offshore. A project lifetime of 30 years is assumed, so sinks must have sufficient capacity to store 30 years' worth of emissions from a particular source to be matched up by the model algorithm.
- Since it is possible that an individual source could be selected by more than one sink at the scoring stage, the sinks are then allowed to compete with one another. This results in the sources being matched with the sink with the best score, for example because it is closer or because the capacity of the second sink has already been allocated to other sources.
- These source-sink matches are then exported back to the mapping software. The model provides summary outputs of total matched capacities for each country in 2030 and 2050, as well as the cross border flows of CO_2.

The architecture of the model is shown in **Figure 5** (next page).

Figure 5: Methodology for source-sink matching



3.4.1 Scenarios for the deployment of CCS in the North Sea

To investigate the role of cross-border CO_2 transport and storage between the North Sea countries, diverse scenarios and sensitivities of CCS deployment between 2015 and 2050 were examined by the project team, reflecting assumptions on the nature of key drivers and progress in removing barriers as identified through the stakeholder consultation.

Each scenario makes different assumptions about overall CCS demand, the development of transport infrastructure, and the availability of storage. Scenarios are not intended to represent predictions – rather they are used to help inform decision-making in a subject with significant uncertainty. For simplicity, key insights can be summarised between three of these scenarios, termed 'Low', 'Medium' and 'Very High', reflecting very pessimistic, neutral and very optimistic assumptions respectively on the impacts of drivers.

'Low' scenarios, whereby CCS deployment is negligible in 2030 might arise if CCS technology demonstration is unsuccessful in the period up to 2030, if costs for CCS increase substantially, and if there are widespread economic, legal, regulatory, political or social obstacles to implementing CCS projects. The 'Low' scenarios are not discussed further in this report as they pose no requirement for cross border CO_2 transport and storage, and require no further actions on the part of the members of the North Sea Basin Task Force to facilitate transboundary transport or storage infrastructure or legislation.

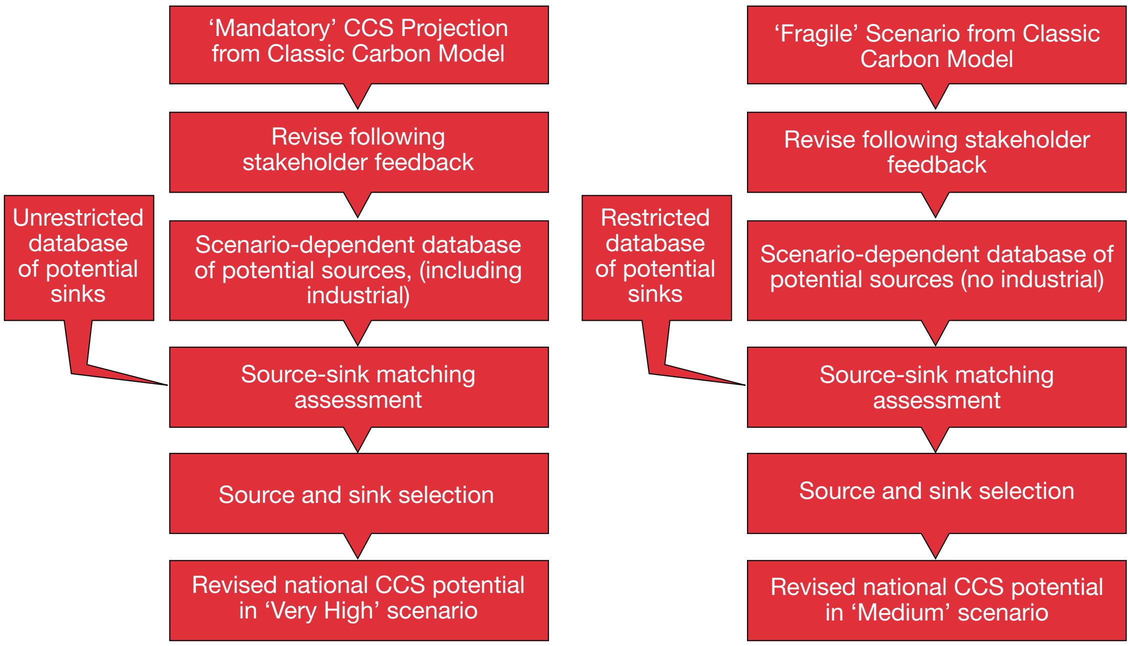


Figure 6: Development of '**Very High**' and '**Medium**' CCS deployment scenarios

The outputs from the Classic Carbon model were reviewed with local stakeholders in the UK, Netherlands, Norway, Germany and Denmark, to prepare sources databases for 'Very High' and 'Medium' CCS scenarios (which include transport and storage) are described below.

The **'Very High'** scenario reflects a world where CCS becomes technically proven within the next decade, and there is sufficient regulatory certainty and financial incentives to create high demand for the technology between 2020 and 2030 and beyond, including from industrial sources. Meanwhile, uncertainty surrounding sink capacities is reduced through widespread surveys and mapping exercises, so that all of this capacity is available for CO_2 storage. Additionally, it is assumed that robust agreements on the transport of CO_2 and storage across borders are in place, and CO_2 can be stored in both on- and off-shore sinks. The high demand for CCS in this scenario and high certainty on storage leads to co-ordination of transport infrastructure deployment, with clusters of sources sharing trunk pipelines to connect to CO_2 sinks.

The **'Medium'** scenario reflects more cautious assumptions at every stage of the CCS chain. Demand for CCS and hence investment in capture equipment is substantially lower, due to weak incentives and strong competition from other CO_2 abatement measures. It is assumed that only 10% of the published capacity of each aquifer is available for storage in this scenario, due to limited sink mapping. Furthermore, it is assumed that no CO_2 storage occurs in onshore sinks. In addition, it is assumed that CO_2 transport is restricted compared with the 'Very High' scenario, and no cross-border transport is permitted.

The input conditions 'Medium' and 'Very High' scenarios are summarised in Table 8. These scenarios are intended to show that very different paths for the growth of CCS in the North Sea countries are possible in the period 2020 to 2030.

In addition to the two main scenarios, a sensitivity analysis was conducted to assess the effects of changes to individual assumptions on CCS demand or storage and transport within the 'Very High' scenario.

Scenario	CCS demand	Transport	Storage
Very High	Very high (Mandatory projection. Sources database includes industrial sources)	Integrated (inc. cross-border if needed)	Unrestricted – all depleted hydrocarbon fields and saline aquifers in database are matured and assumed can be fully accessed.
Medium	'Fragile' No industrial sources	Mostly point-to-point up to 2030 No cross-border transport before 2050	No onshore storage permitted Aquifer storage limited to 10% of published capacity due to limited maturation
Low	Negligible	Highly restricted	Very low availability

Table 8: Summary of transport and storage inputs for the CCS deployment scenarios

Results

4

4 Results

This chapter shows the results of the demand estimation. Four sets of results are presented.

- The first section presents assumptions on CCS deployment between 2010 and 2020 and is based largely on announced demonstrations.
- The second and third sections describe two alternative deployment paths between 2020 and 2030, based on either 'Medium' or 'Very High' growth trajectories of the industry.
- The final set of results shows a long-term projection of CCS deployment in 2050, based on optimistic assumptions about CCS demand and transport and storage restrictions.

4.1 2020 – Demonstrations

Given the long development times for large-scale CCS projects and the current uncertainty over both technical and economic aspects of the technology, large scale CCS deployment before 2020 is assumed dominated by demonstration projects, supported largely by public sector funding. The demand modelling conducted in this study suggests that there will be no purely commercially driven roll-out occurring before this date even in the most optimistic scenarios. As described in section 2, the EU has committed to partly supporting up to 12 demonstration projects to be operational between 2010 and 2020. These are likely to include projects distant from the North Sea, for example in Spain, Italy and Poland. As also described in section 2, the UK and Norway have made clear their own additional funding commitments towards CCS demonstration.

Figure 7 shows the expected CCS demonstration projects in the North Sea countries in 2020. In many cases, while the emission source is known, the choice of store for the demonstrations is not publicly available information. For these projects, sources have been connected to the nearest suitable sink within the GIS database[21].

21 Progressive Energy at Teesside (UK), and Vattenfall at Jaenschwalde (Germany), have identified alternative storage locations that are not listed in the GeoCapacities databases

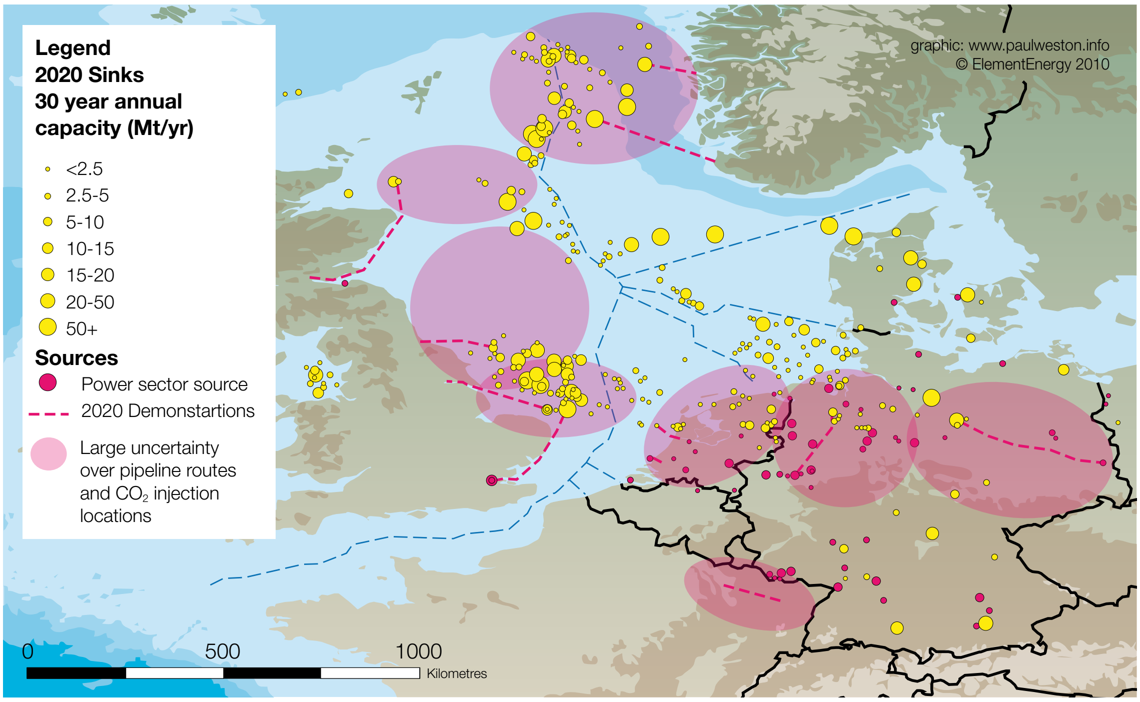


Figure 7: Map of 2020 Demonstrations projects

2020 Highlights:

- The modelling predicts overall CCS demand in 2020 is approximately 30 Mt/yr in the North Sea countries – these are 'policy-backed' investments rather than purely commercially driven.

- Cross-border transport of CO_2 between NSBTF members before 2020 may occur but is not predicted to be necessary or important. This is primarily because each country has sufficient matched domestic capacity.

- Some stakeholders nevertheless express interest in cross-border CO_2 transport beginning after 2016, possibly by ship, from Germany, Belgium, northern France, Sweden or Finland to UK, Norwegian or Dutch sinks, and from the Netherlands to Denmark for CO_2-enhanced oil recovery. It is not clear how well developed these proposals are.

- Demonstrations could choose to transport CO_2 across borders due to faster permitting times in neighbouring jurisdictions, lower cost or other transport barriers, or if domestic storage opportunities were restricted[22]. Source clusters and shared infrastructure will be uncommon by 2020, although careful design and co-ordination could result in demonstration pipelines nucleating larger networks developed between 2020 and 2030.

22 Provided there were not restrictions on cross-border CO_2 transport and storage

4.2 2030 – 'Medium' Scenario

The 'Medium' scenario combines moderate drivers for CCS demand (i.e. weak CO_2 caps and limited cost reductions) with plausible restrictions on cross-border and integrated transport networks, and onshore and aquifer storage as a result of limited preparation in the period before 2030. Transport and storage are 'cherry-picked', i.e. developed on a point to point basis to match the requirements of each source.

Figure 8 (next page) shows plausible source-sink matches in the medium scenario in 2030, corresponding to a total of 46 Mt CO_2/yr stored in 2030 in the NSBTF countries and Denmark.

The UK and Norway are not affected by the onshore storage limitation. Subject to hydrocarbon fields being available, reduced aquifer capacity is unlikely to be limiting in 2030 in the UK or Norway in the event of low demand. The restrictions on transport and storage are particularly important for Germany and Holland in this scenario.

Table 9: Development of 'Medium Scenario'

Country	Germany	UK	Netherlands	Norway
Unconstrained Mt CO_2/yr in 2030 in 'Fragile' combination using Classic Carbon	23	13	27	1
Stakeholder feedback on demand levels	Realistic if cross-border transport is allowed	Increase required to reflect regional ambitions for CCS from industry	Represents maximum demand	Increase to reflect national ambitions for possible industrial sources
Revised demand for 'Medium' Scenario following source-sink matching with transport and storage restrictions	5	15	10	7
Impact of transport and storage restrictions in 'Medium' Scenario	Restrictive	Negligible impact	Restrictive	Negligible impact

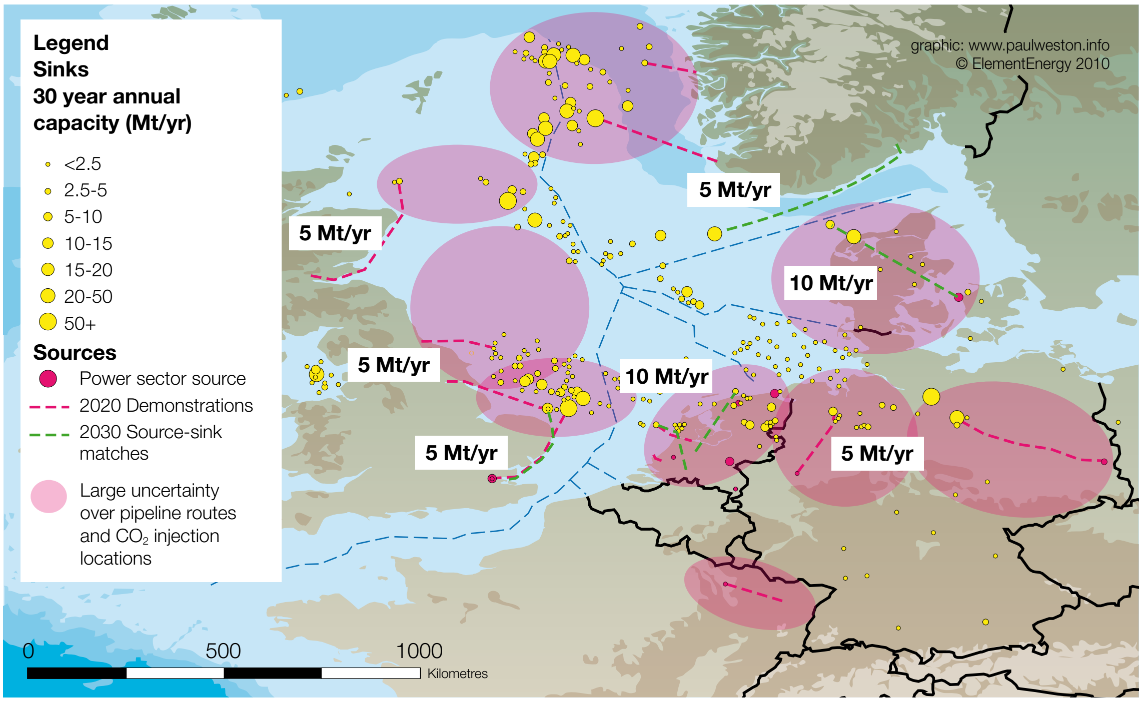


Figure 8: Map of source-sink connections in 2030 – 'Medium' Scenario

Key points for 2030 'Medium' scenario:

- CCS in Germany and the Netherlands is sensitive to the ability to take advantage of low cost onshore storage or cross-border transport.
- Restrictions on storage capacity or cross-border transport are unlikely to significantly retard CCS in the UK or Norway in 2030.
- If CCS demand is limited, integrated clusters of sources or sinks are less relevant to improving economics or extending capacity.
- Transport and storage infrastructure can develop in a more opportunistic manner without the need for co-ordinated strategic control.

4.3 2030 – 'Very High' Scenario

If CCS demonstration projects are successful during the 2010s, accelerated commercial deployment could follow, with large volumes of CO_2 transported by 2030. In the 'Very High' scenario, which is characterised by very high CCS demand and low restrictions on transport and storage, over 270 Mt/yr are stored by NSBTF countries in 2030.

The overall Mt CO_2/year described in the 'Very High' scenario falls slightly short of the projection identified in the 'mandatory'. From a transport perspective, the main challenge is to match the high demand in Germany and the Netherlands (using the sources identified in the Classic Carbon model with sufficient capacity in German and Dutch sinks (above 30 Mt CO_2 listed in the GeoCapacity database) using pipeline networks that do not entail pipeline lengths that would be considered excessive for 2030.

Conversely the review of regional CCS studies and the stakeholder feedback revealed capture potential in industrial clusters – which has led to increases for the UK and Norway compared to the values projected in the mandatory scenario.

Figure 9 (next page) outlines plausible flows of CO_2 within and between NSBTF countries. In the interests of clarity, the 2020 demonstration projects are not shown separately in the map, and are included within the clusters shown.

Table 10: Development of 'Very High Scenario'

Country	Germany	UK	Netherlands	Norway
Predicted Mt CO_2/yr in Mandatory scenario using Classic Carbon	219	27	59	1
Stakeholder feedback on demand in 'Mandatory' scenario	Represents upper limit – suggests reduce	Increase required to reflect regional ambitions for CCS from industry	Represents upper limit – suggests reduce	Increase required to reflect national ambitions for possible industrial sources
Revised Mt CO_2/yr demand for 'Very High' scenario following source-sink matching and stakeholder feedback (no restrictions on storage)	160	60	40	7

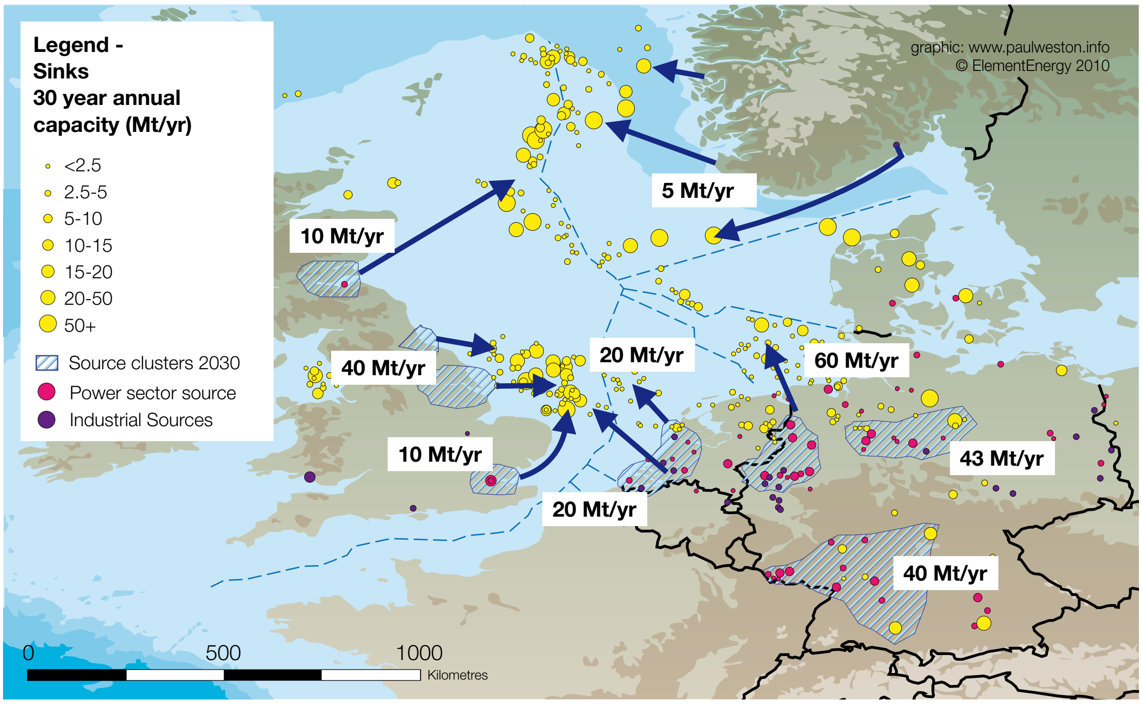


Figure 9: Map of CCS transport and storage in 2030 – 'Very high' scenario

The majority of the CO_2 transported and stored originates in Germany and the UK, which capture 160 Mt/yr and 60 Mt/yr respectively. The UK stores all captured CO_2 in offshore sinks, mainly depleted hydrocarbon fields, while Germany stores up to 80 Mt/yr in onshore aquifers.

The analysis suggests that cross-border transport may be efficient for the Netherlands, due to the very high demand for CCS in the Netherlands in this scenario. The Netherlands captures 40 Mt/yr, equivalent to a commitment of 1.2 Gt over 30 years. This is around half of the Dutch sink capacity recorded in the GeoCapacities database, or 80% of the sink capacity when fields below 30 Mt CO_2 capacity are excluded. This would imply the need to completely fill the larger sinks, or to connect individual sources to clusters of smaller sinks.

Given the uncertainty surrounding sink suitability and availability, an alternative strategy may be to utilise the giant gas fields or saline aquifers in the UK or Norwegian sectors of the North Sea. With the assumption that cross-border agreements are in place, the modelling predicts that 50% of CO_2 captured in the Netherlands is transported to sinks in the relatively nearby UK sector of the Southern North Sea, and the remainder stored within Dutch sinks. An alternative strategy identified by van den Broek (2009) is to transport Dutch CO_2 to Norway for storage in the Utsira formation[23]. The latter may be more attractive if the available storage potential is more certain at the time that an investment decision needs to be made.

It should be noted that the CCS demand in this scenario implies a rapid increasing of capacity between 2020 and 2030, equivalent to a ten-fold increase in the amount of CO_2 captured. This is similar to the increase in renewable electricity deployment that will be required in many European countries in order to meet EU targets by 2020. If operated at

23 Van den Broek et al. (2009) Feasibility of storing CO_2 in the Utsira formation as part of a long term Dutch CCS Strategy. International Journal of Greenhouse Gas Control, doi:10.1016/j.ijggc.2009.09.002

high load factors, a relatively limited number of large sources could make large contributions to the overall capture amounts in this scenario.

The analysis shows that there are natural clusters of industrial and power sector emissions within each country, particularly in the UK, Netherlands and Germany. As described in Section 2, many regional initiatives across the North Sea countries are already laying the foundations for the development of large CO_2 clusters in the future. The role of clusters is described in more detail in Section 5.4.

Key points from 2030 'Very High' scenario:

- Over 270 Mt/yr of CO_2 are transported and stored by NSBTF countries in 2030.
- 60% of CO_2 storage is under the North Sea itself, supplemented with onshore storage in Germany and Holland.
- Cross-border transport comprises 10-15% of overall CO_2 storage by 2030.[24]
- In the 'Very high' scenario, there are advantages to CCS projects sharing transport and storage infrastructure due to geographical aggregation of sources and sinks. Seven such clusters in the North Sea countries are responsible for 80% of CO_2 transported in this scenario.
- There is a large role for onshore storage of CO_2, particularly in Germany, where 80 Mt/yr is stored in onshore saline aquifers in Germany.
- The very high CCS demand suggests the need for a rapid ramping of capacity from demonstration volumes in 2020 to widespread, commercial-scale deployment in 2030.

4.4 Sensitivity analysis for 2030 scenarios

The results above show a large variation in the total CO_2 transported and stored in 2030, with over five times more CO_2 stored in NSBTF countries in the 'Very High' scenario than in the 'Medium' scenario. The 'Medium' scenario contains a number of plausible restrictions on overall capture investment, cross-border transport and the availability of storage. These restrictions affect the total CO_2 stored to differing degrees. Each one of these restrictions changes not only the total amount of CO_2 captured and stored, but also the geographic distribution of capture activity and the length and cost of pipelines required to connect the sources to sinks.

The figure and table below show the effect of individual changes in the input assumptions. Each sensitivity is applied to the 'Very High' scenario, holding all other assumptions constant. The 'Medium' scenario, which combines all of these restrictions, is shown last for comparison (note the effects are not additive).

24 If there is a preference to use a limited number of large offshore sinks, rather than multiple small sinks, the majority of cross-border transport would be from the Netherlands to the UK. CO_2 from the Netherlands could potentially be transported to Norway if storage economics are significantly more favourable or with pipeline re-use

Sensitivity	Cross-border transport permitted	Aquifer capacity	Onshore storage permitted	Mt/yr stored in 2030	% Cross-border flow
High scenario	Yes	High	Yes	273	10%
No cross-border transport and storage agreements	No	High	Yes	253	0%
Low aquifer capacity	Yes	Reduced by 90%	Yes	191	20%
Low hydrocarbon field availability	Yes	High	Yes	205	8%
Restricted onsgore storage	Yes	High	No	178	25%
Low capture investment	Yes	High	Yes	65	21%
Medium scenario	No	Reduced by 90%	No	46	0%

Table 11: Summary of sensitivity analysis conducted on the 'Very High' scenario

4.4.1 Cross-border transport

Cross-border transport of CO_2 is not a central feature of networks in 2030, even in a 'Very High' deployment scenario. Restricting cross-border transport in the model eliminates the transport of up to 20 $MtCO_2$/year from the Netherlands to the Southern North Sea sector of the UK continental shelf. This quantity can be stored in offshore sinks in the Netherlands, but as Dutch storage capacity comprises mainly small sinks, this may require a cluster of sinks rather than a single giant gas field as in the UK. This is likely to increase costs for both pipeline infrastructure and for detailed studies of the required sinks. In other words, restricting cross-border flows of CO_2 does not necessarily reduce the total quantity stored, but is likely to increase costs.

4.4.2 Storage restrictions

The second sensitivity shows the effect of reducing the assumed storage capacities of both on- and off-shore aquifers by 90%. This reduces the total CO_2 stored in 2030 by 30%. This is due to the loss of two large clusters in Germany, which connect to large aquifers in the 'Very High' scenario. The cluster in southern Germany, is unlikely to be feasible without these aquifers, since it would require a pipeline of 700 – 800 km to reach the nearest suitable storage sites. However, the large Ruhr cluster in north-west Germany is also dependent on large aquifers for 60 Mt/yr of storage in the High scenario, but 20 Mt/yr can be redirected to other sites. The UK and Norway are unaffected by changes to aquifer storage capacity in 2030, because the initial capacity was already very high.

Eliminating onshore storage of CO_2 has a similar effect to reducing capacities of saline aquifers in terms of total CO_2 flows. Again, it is only Germany that is seriously affected, since it relies heavily on onshore storage in the High scenario. It is worth noting that either of these restrictions could have the effect of bringing forward the demand for storage capacity under the central and northern North Sea. In other words, if economic conditions led to high CCS demand in Germany but domestic storage availability was limited, for example due to public opposition to onshore storage, then transport of CO_2 to Norway could be developed in 2030.

4.4.3 Investment in CO_2 capture

The final sensitivity shows that while transport and storage restrictions can affect the geographic distribution and cost of CCS activity, it is the overall demand for the technology from CO_2 emitters that is the main determinant of overall volumes. Switching to the 'fragile' CCS demand projection reduces total CO_2 storage by 75% in 2030. Germany shows the biggest change in CCS demand since most of its uptake in the 'Very High' Scenario was due to the mandation of CCS from 2020 onwards.

This result also shows that if the overall demand for CCS is low, then any further restrictions in transport and storage have only a small effect on the total CO_2 flows. In other words, if the overall demand for CCS is low, then detailed mapping of aquifer capacities and agreements to allow cross-border CO_2 transport are not critical to enable that demand to be met.

4.4.4 Conclusions from sensitivity analysis:

- Where there are no restrictions on domestic storage and high aquifer capacities are available, restricting cross-border transport has only a small effect on total CO_2 transported by 2030. Cross-border transport may allow access to higher quality sinks with shorter pipelines, but it is not necessary in 2030 from a capacity point of view.

- Restricting aquifer capacity reduces the total CO_2 stored by 30%. Germany is particularly affected, since it relies on aquifers for much of its onshore storage in 2030. Cross-border transport is significantly higher (up to 25% of total flows), as German CO_2 is more likely to be exported.

- Restricting onshore storage has a similar effect, because German aquifers are the main form of onshore storage.

- Despite the uncertainties regarding sink capacity, given its abundance, policies that lead to high levels of CCS in 2030 can still be pursued by NSBTF countries if required.

- If the overall demand for CCS is low, then comprehensive storage evaluation of the North Sea, with high organisation and co-operation between stakeholders including cross-border agreements are unnecessary

4.5 CCS in 2050

The Medium and Very High scenarios described above show very different paths for deployment of CCS in the North Sea region. In the Very High scenario, the industry grows rapidly between the end of the demonstration phase to become a significant contributor to CO_2 abatement by 2030, while in the Medium scenario the technology remains at a much smaller scale, and more sensitive to the economics of individual projects, for example due to opportunities for EOR or the reuse of existing infrastructure.

In addition to these medium-term projections, we investigate the longer-term potential for CCS in the North Sea region. The following scenario shows the continued development of CCS out to 2050, based on the assumptions in the 'Very High' scenario. The demand for CCS is assumed to be very high, and are in-line with 2050 projections from the IEA's 2009 CCS roadmap. In addition, transport and storage continues to be unrestricted, with transport of CO_2 across national boundaries where required or where economically preferable.

Figure 10 shows the flows of CO_2 to and from the North Sea countries in 2050. A large number of sources are available for storage in this scenario, and so regional clusters of CO_2 emitters, which could benefit from sharing transport infrastructure, are shown on the map.

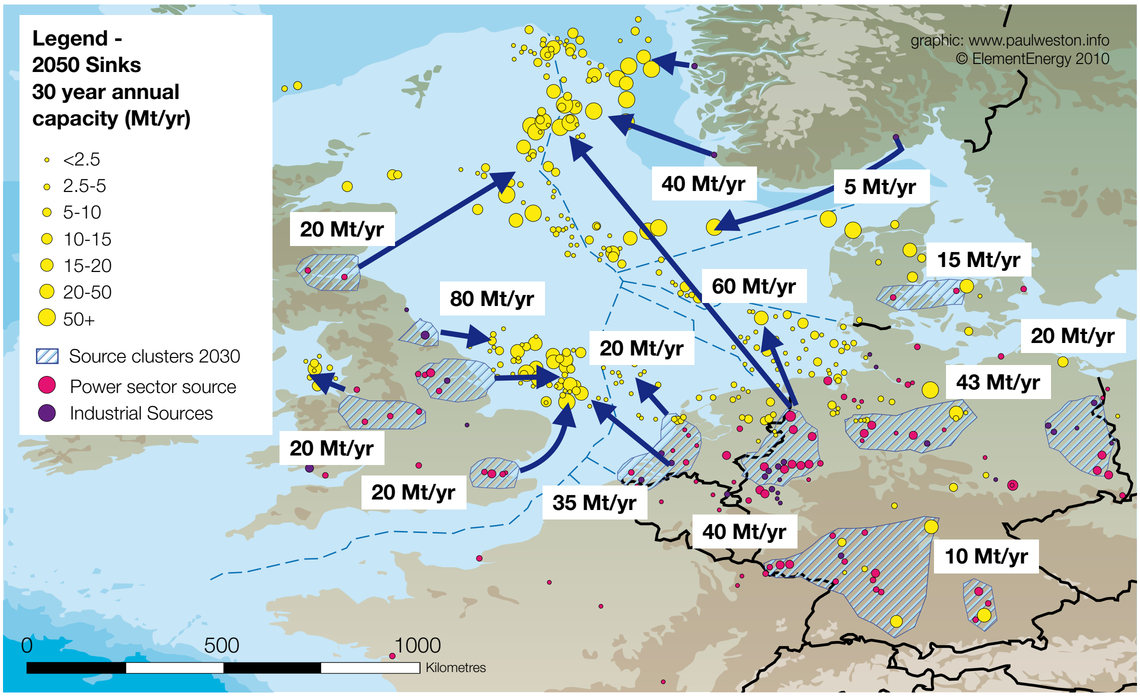


Figure 10: CO_2 transport in 2050 – Very High Scenario. (No restrictions on transport or storage)

A 2050 vision of Carbon Capture
Picture: © Bellona

The overall quantity of CO_2 stored in 2050 is 450 Mt/yr. Note that since a 30 year project lifetime has been assumed in the modelling exercise, this figure includes CO_2 from projects that began in 2030. The total CO_2 stored by all projects over their lifetimes is over 15 Gt.

It is clear from Figure 10 that many of the clusters developed by 2030 play an important role in 2050. For example, total CO_2 captured from Yorkshire and Humber increases from 40 to 80 Mt/yr, while capture in North West Germany increases from 60 to 100 Mt/yr, building on infrastructure developed for the 2030 networks. In addition to existing clusters, new networks are developed in southern and eastern Germany, as well as in England.

The very high demand for CCS in 2050 can only be sustained with substantial cross-border transport of CO_2. Analysis of 2050 infrastructure requirements should obviously be treated with even greater caution that that of 2030.[25] The scenario predicts 75 Mt CO_2/year are transported from Holland and Germany to the UK and Norwegian sectors of the North Sea. The demand for storage in the North Sea from countries outside the NSBTF is not examined in this study, but would be significant in a very high CCS scenario in 2050 if storage opportunities elsewhere around Europe become restricted.

Transport of even 100 Mt CO2/yr (3Gt over 30 years) can be accommodated within the sinks in the northern and central North Sea. In the UK sector of the southern North Sea it would be important to ensure that major sinks (gasfields) are left in a condition that permits future CO_2 storage. It also highlights the benefits of infrastructure planning and capacity mapping, where large CO_2 volumes are expected. For example, if large flows are expected from continental Europe, perhaps

25 Potentially many oil and gas pipelines may have become available for re-use, and clustering or integrated transport infrastructure could significantly impact economics.
26 BERR (2007): UK Continental Shelf Oil and Gas Production and Reserves

because of restrictions on onshore storage, storage capacity in the southern North Sea could be used extensively and other capacity, such as aquifers in the Northern North Sea, could play a key storage role by 2050.

Finally, it is worth noting the scale of CCS in this scenario compared to existing hydrocarbon activity. For example, the annual storage of CO_2 in the UK is 150 Mt in 2050, equivalent to over ca. 25% of total 2007 UK emissions. For comparison the offshore oil industry in the UK peaked at 140 Mt of oil per year in 1999[26]. Whilst the analysis shows such volumes of CO_2 to be feasible, it nevertheless represents a very considerable challenge.

Key points for 2050:

- The total flow of CO_2 by 2050 reaches 450 Mt/yr in the North Sea countries. This would mean an infrastructure similar in size to the North Sea oil industry at its peak, and could imply substantial interactions with other users of the North Sea area.
- Cross-border transport of CO_2 is essential, with Germany and the Netherlands storing CO_2 in UK and Norwegian sinks.
- For large CO_2 flows to be economic, combined with the need to connect marginal sources to meet the overall CCS demand, there will be an important role for trunk pipelines and shared infrastructure, rather than ad hoc deployment of point to point networks.
- Many of the largest sinks in the southern North Sea are committed by 2030 in the Very High Scenario. Therefore large gasfields and aquifers in the central and northern North Sea are required.
- CCS plays a major role in meeting CO_2 abatement targets. For the UK, annual capture in 2050 is equivalent to 25% of current emissions.

Additional drivers for CO_2 networks

5

5 Additional drivers for CO_2 networks

The analysis in the previous chapter examined the effects of transport and storage restrictions on the quantity and distribution of CO_2 flows throughout the North Sea countries. In the modelling, source-sink matches were driven by the relative economics of transport between sources and sinks on a point-to-point basis, optimising where there is potential competition between sources for the same sink and between sinks for the same source[27]. This approach provides a convenient, simple and transparent basis to help understand many of the transport and storage issues facing the NSBTF. In practice, with capture representing the dominant cost, and storage representing the dominant uncertainty, transport economics may only influence, rather than control source-sink matching.

This chapter examines other factors which may influence the development of CCS: CO_2 Enhanced Oil Recovery (EOR), infrastructure re-use, and shipping. It also explores the issue of source and sink clustering in more detail.[28]

5.1 CO_2-enhanced oil recovery

CO_2-enhanced oil recovery is a mature technology in operation for many decades in North America. The storage capacities and incremental oil yields associated with CO_2-enhanced oil recovery (EOR) in the North Sea are highly uncertain but could provide substantial revenues to the oil industry and the relevant Governments. Previous studies have identified that CO_2-EOR could lead to storage of 10 – 100 Mt CO_2/year.[9,29]

- For the UK sector, the total incremental oil in the sinks database is up to 2 billion barrels in 37 fields - the five largest UK EOR fields could have a combined oil yield of up to 1.1 billion barrels.
- For the Norwegian sector, the total incremental oil is expected to be 1.8 billion barrels in 22 fields - the top five Norwegian EOR fields could have a combined incremental oil yield of 1.1 billion barrels.

North Sea oil production facility
Picture: iStockphoto © LandbySea

27 Element Energy et al. CO_2 pipeline infrastructure study for IEA GHG Manuscript submitted.
28 Competing uses of the subsurface, for example natural gas storage or geothermal energy, have been flagged by stakeholders as sources of uncertainty.
29 Tzimas et al. (2005) Enhanced oil recovery using carbon dioxide in the European Energy System EU JRC Report 21895 EN; Bellona (2005) CO_2 for enhanced oil recovery on the Norwegian Shelf.

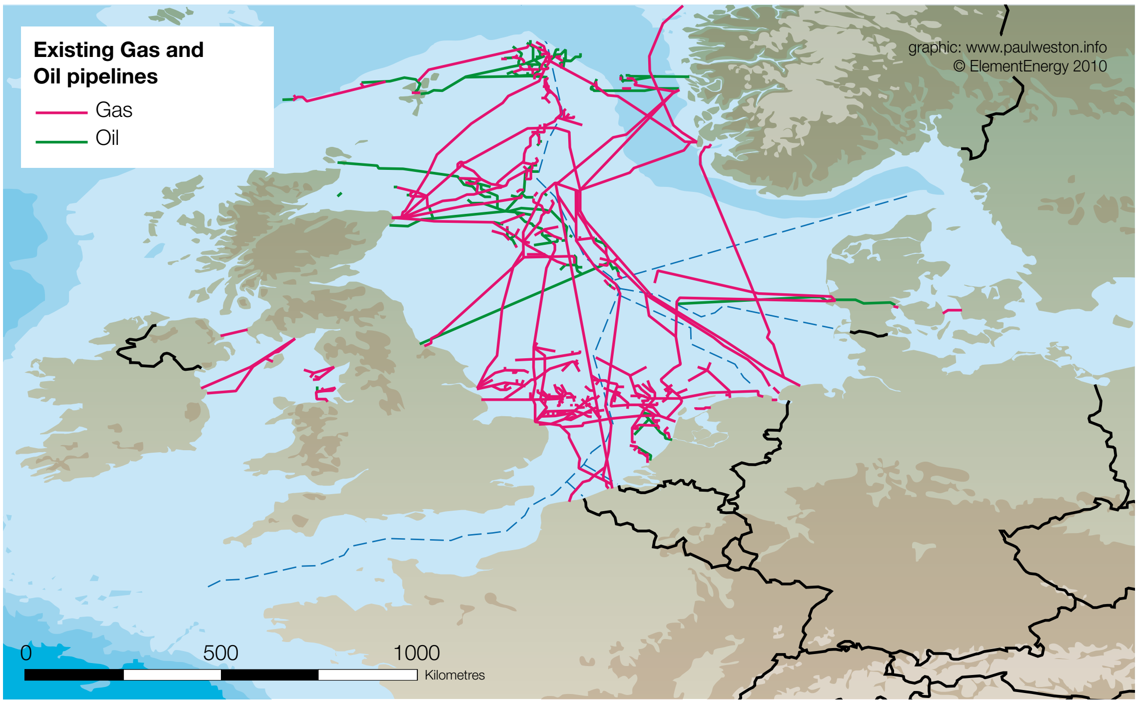
Up until 2006, there was some expectation that CO_2-enhanced oil recovery would drive CCS in the North Sea. However EOR has very different requirements from CO_2 storage. The costs of offshore CO_2 recycling facilities and additional CO_2 injection wells make CO_2-EOR substantially more expensive to carry out in the North Sea than onshore in North America where CO_2-EOR is commercially viable. Studies have typically concluded that oil prices would need to be sustained in excess of $70/bbl for CO_2-EOR in the North Sea to be cost competitive with CO_2 storage without EOR[9,16]. The economics of enhanced oil recovery will depend strongly on site specific issues and technology developments, but also on the prevailing taxation and incentive systems for tertiary oil recovery, and whether supplied CO_2 represents a cost or a revenue source. Industry stakeholders have highlighted that CO_2-EOR could be facilitated by favourable economic arrangements and increased organisation[30].

Enhanced oil recovery is not the only potential source of value for CO_2. Already in the Netherlands CO_2 is piped from a refinery to greenhouses to support plant growth as part of the Rotterdam Climate Initiative. The FP7-funded ECCO project aims to quantify in further detail the economically valuable uses for captured CO_2.

Developing a deepwater offshore field for CO_2-enhanced oil recovery is a major engineering challenge, comparable in scale to original field development, with long lead times and requiring a high degree of organisation and risk taking in the context of uncertainty. Importantly, the window of opportunity can be extremely tight, as demonstrated by the failure of the BP/SSE DF1 enhanced oil recovery project. CO_2 competes with other options for extended secondary recovery, for tertiary recovery, or for abandonment - these may better match licence owners' priorities and capabilities.

30 CO_2 entry quality specification for networks may need to take potential use in EOR into account from the outset

Figure 11: Existing gas and oil pipelines in the North Sea



5.2 Infrastructure re-use

5.2.1 Pipelines

There is an extensive network of oil and gas pipelines in and near the North Sea, which presents a significant opportunity for re-use. This includes trunklines between shore and oil- and gas-fields, as well as inter-field pipelines. Re-use of this infrastructure would substantially reduce the capital costs (and planning risks) for CO_2 transport. It would also strongly influence the matching of sources and sinks.

Existing pipelines are mostly carbon steel, and so metallurgically suitable to carry CO_2 provided that any impurities, especially water, are maintained at a sufficiently low level. However there will be requirements to modify operation and maintenance processes to permit re-use with CO_2.

There is substantial theoretical capacity in existing pipelines. For example, 28 pipelines in the UK sector alone each have theoretical capacities in the range 10-50 Mt CO_2/year if operated in dense phase. In addition there are many smaller in-field and inter-field pipelines which connect into trunklines offshore from various contributing fields, which could also be considered for CO_2 transportation if the connected fields are selected as storage sinks. However, it is not clear where capacities and availabilities match source demand or sink capacity.

Although the economic benefits could be high, the challenges to pipeline re-use are substantial:

1) Design pressure could be a limitation. Maximum allowable operating pressures

are often reduced with age and may be particularly reduced for re-use with CO_2.[31] This effectively reduces transportation capacity compared to a purpose-built new line (typically 200 – 300 bar).

2) Remaining service life for CO_2 operation can only be assessed on a case-by-case basis, based on data on internal corrosion, historic use and maintenance records. Even when there appear to be no technical barriers to re-use, it is possible that owners/operators may not wish to take risks of committing pipelines that have been in long-term use for hydrocarbon transport.

3) Timing will be a major limitation. The date at which pipelines become available is inherently uncertain and is commercially sensitive information. Even if information can be shared, it may be very difficult to match decommissioning timelines with those for CCS demand and sink availability – mothballing may be necessary.

Gassco has identified that the 40" diameter offshore 600 km Europipe1 could support a transport capacity of ca. 40 Mt CO_2/year if made available for CO_2 transport[32]. The exact capacity will depend on pressures used. The pipeline runs from Draupner E platform to Dornum in Germany. The impact of this availability could be substantial – allowing sources in north Netherlands and north-west Germany to connect to central North Sea sinks (especially Norwegian sinks) at much lower costs than would be associated with new pipelines. However the timing of pipeline availability is unclear – as the need for capacity depends on shippers' requirements.

The BP/SSE DF1 project at Peterhead had proposed to re-use a pipeline connecting St. Fergus gas terminal with the Miller oilfield. Scottish Power and National Grid are proposing to re-use an onshore 36" 300 km gas pipeline for gas-phase CO_2 transport from Avonbridge (close to the Longannet power station) to St. Fergus gas terminal for onward transport.

5.2.2 Platforms and wells

The potential to re-use offshore physical infrastructure[33] such as existing platforms and wells requires site-specific analysis of technical feasibility, economic benefits such as delayed decommissioning, and contractual barriers. The window of opportunity to adapt existing above ground infrastructure may be very narrow, as current North Sea legislation which typically requires infrastructure to be removed after hydrocarbon production has ceased.

The potential to improve storage-readiness through choices of equipment, materials, and processes through low-cost actions is poorly understood. An example is well abandonment procedure, where some approaches may be more compatible with future use for CO_2 than others. Without clear guidance on choices, and further incentives to cover additional costs, it is unlikely that the market will deliver interventions that improve storage readiness. The oil and gas industry representatives on the NSBTF are well placed to lead on this issue.

5.3 Shipping

Ship transport of oil and gas is routine worldwide and already plays an important role in the North Sea. Four CO_2 ships are in commercial service on behalf of the food and drinks industry and other industrial users.

Shipping can be cost competitive with pipelines for smaller volumes (such as those corresponding to demonstration projects), or

31 For example, the MAOP for National Grid's feeder pipeline in Scotland is 75-85 barg, but re-use for CO_2 is expected to occur only at much lower pressures, where the CO_2 will be in gaseous phase
32 Sigve Apeland (2009) Personal Communication
33 There may be benefits in re-using existing hydrocarbon reservoir models in accelerating the understanding of sinks. Generally these are proprietary data, however some arguments have been made that data could be made available at a reasonable cost and subject to indemnities once hydrocarbon production has ceased to accelerate understanding of CO_2 storage potential. I. Phillips, Personal Communication

CO2 ships and hubs can potentially handle throughputs of up to 20 Mt CO2/year
Picture: © Anthony Veder

with longer distances (over 1,000 km).

Shipping could be a key enabler for specific CCS projects, and thereby facilitate the transition to large scale infrastructure, where:

- No economic pipeline route can be identified, because distances or terrains are too challenging, or volumes or lifetimes are too small.
- The timescale and success of pipeline consenting are difficult to predict or incompatible with demand.
- There is a high risk associated with the locations of sources or sinks, or the rate of growth in capacity, which challenges the business case for high capital investment in pipelines that are sized for future capacity.
- The ability to handle variations in capacity over time is essential.

CO_2 ships and hubs can potentially handle throughputs of up to 20 Mt CO_2/year with high flexibility, relatively low capital costs, and reduced risks from planning delays or of stranded assets. With lead times for CO_2 ships expected to be two to three years, individual ships can be ordered to meet demand, which means capacity and utilisation can be matched more carefully than for pipelines. Scaling down the ship capacity is unlikely to be a problem as ships could be redeployed, elsewhere in the world for CO_2 transport or modified for use in the LPG trade.

Transport network topologies

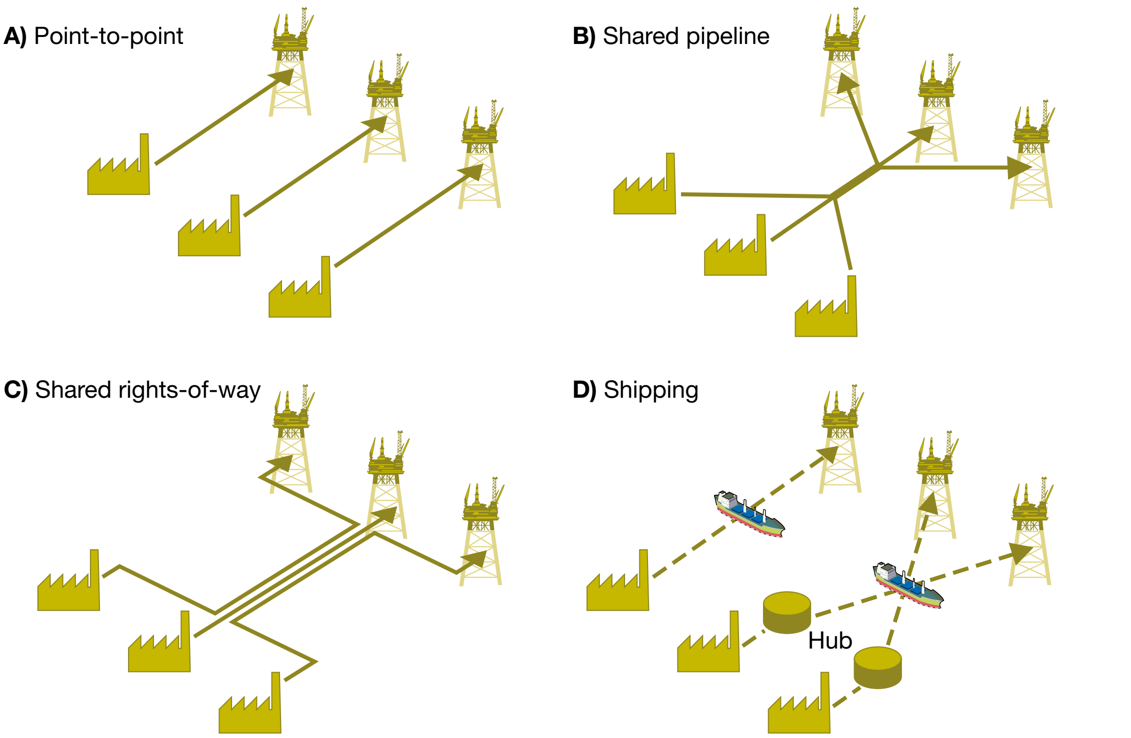


Figure 12: Schematic of options for transport network topologies. A) Point-to-point; B) 'Oversized' Pipeline; C) Rights-of-way for pipelines; D) Shipping and shipping hub concept.

CO_2 shipping is formally proposed for at least two European CCS demonstration projects, which their proponents expect to commence before 2020, namely:

- The Fortum/TVO project intends to transport CO_2 from the Meri Pori coal-fired power plant in Finland to the North Sea by ship.
- The use of a hub with CO_2 transport by barge or ship is highlighted by Anthony Veder and Vopak within the Rotterdam Climate Initiative.

5.4 Source clustering

The source-sink matching exercise above identifies natural geographic clusters of sources and sinks. Where CCS demand is high and many sources within a cluster are expected to invest in capture technology, there are opportunities to share transport and storage infrastructure. Shared infrastructure features strongly in the 'Very High' scenario, where a smaller number of source clusters are responsible for the majority of capture activity. In the 'Medium' scenario, the CCS demand is much lower in 2030, suggesting a larger role for simple point-to-point connections.

Transport and storage infrastructure for CCS could develop in four dominant ways schematized in **Figure 12**.

In **Figure 12**, Option A presents point-to-point pipelines which are developed independently of each other. Option B presents an integrated pipeline infrastructure, whereby multiple sources (or sinks) are connected to a trunkline which may be oversized at the outset. Option C is an intermediate option, where new pipelines are built as needed, but sharing an existing right of way. Option D shows a shipping option, whereby source and sink connect directly or via a hub. **Table 12** compares the main advantages and disadvantages of the four topology options, emphasised as important in discussions with stakeholders.

Table 12: Comparison of transport network topology options

Topology	Advantages	Disadvantages
A point-to-point	• Low up-front capex • Does not require estimation of future demand • Does not require co-ordination between multiple stakeholders • Reduces risk of low pipeline utilisation	• Average cost per tonne across all networks is higher than with shared infrastructure. • Multiple pipelines across different routes means large planning hurdles and disruption to those affected. • No flexibility to accommodate additional sources at low cost. • Could be higher capex in long term.
B Shared pipeline	• Low transport cost when operating at full capacity. • Enables connection of marginal sources. Could attract new sources e.g. industry to the region. • Lower planning hurdles and disruption since multiple sources share one trunk pipeline.	• High initial cost. May require public sector funding initially. • Risk of low utilisation if demand is lower than forecast. • Requires common entry specification for CO_2. • Complex business models. • Requires higher up-front confidence in storage availability
C Shared rights of way	• Robust and flexible • Lower planning hurdles as new pipelines are built on shared rights of way. • Capacity matched to demand.	• Transport costs are higher than for shared pipelines with same throughput. • Does not significantly reduce costs for smaller, marginal sources.
D Shipping	• Lower upfront costs than pipelines. • Flexible in the event of sink failure CO_2 can be routed to other storage sites. • Suitable for projects where multiple, small sinks may be required, or where project lifetimes are small. • Capacity matched to demand	• Very high transport costs compared to mature pipelines. • Large number of ships required to meet high demand.

CASE STUDY

The role of government intervention in major infrastructure decisions: The Beauly-Denny transmission line upgrade

A proposal to upgrade the Beauly-Denny transmission line in Scotland by installing 400 kV cables in place of the existing 132 kV lines was put forward by the electricity grid operator in 2005. The proposal would provide an additional 6 GW of capacity for new projects, mostly wind energy, and is critical in meeting the UK's renewable energy targets. The upgrade will require the construction of new pylons, which will run parallel to the existing system, and the existing system will be decommissioned once construction is completed.

The proposal has been subject to substantial public opposition, with over 18,000 objections from individuals and lobby groups. A public enquiry ended at the end of 2007, but it was not until January 2010 that the proposal was approved by the Scottish Executive, despite opposition from all local councils through which the proposed line passes.

The experience of the Beauly-Denny upgrade has implications for the development of CCS infrastructure:

- Planning is likely to be a major hurdle for new pipelines, causing long delays and creating uncertainty for emitters considering investing in capture technology.
- An approach based on shared trunk pipelines reduces the number of planning applications, compared to separate point to point pipelines, decreasing the risks of rejection.
- For strategically important pipelines, intervention by national governments may be required to secure planning permission where there is strong local opposition.

The relative merits of each topology depend not only on the locations, timings and capacities of sources and sinks which clearly differ between countries of the NSBTF, but also on cultures and the regulatory and planning systems of each country. A recent analysis by NERA examined the regulatory framework for CCS transportation in the UK, and considered the rationale for government intervention in CO_2 pipeline investment, for example to fund over-sizing pipelines in anticipation of future demand[34]. Their main conclusion was that given a strong enough incentive for CO_2 abatement, a market-driven system will promote economically efficient investment in the construction of CO_2 pipelines.

5.4.1 Timescales for major transport infrastructure development.

The results in this study suggest that a plausible 'very high' uptake scenario will require major integrated transport and infrastructure that could match the capacity of the North Sea oil and gas infrastructure as early as 2030, substantially overtaking it by 2050. The existing oil and gas infrastructure in and around the North Sea developed over at least five decades, and has left the region with excellent supply chain skills, and an intimate knowledge of working safely and legally in and around the North Sea and its

34 NERA Economic Consulting (2009) Developing a Regulatory Framework for CCS Transportation Infrastructure, prepared for DECC, available as part of the DECC Consultation "A Framework for the development of clean coal http://www.decc.gov.uk/en/content/cms/consultations/clean_coal/clean_coal.aspx

subsurface. These supply chains and know-how can be leveraged to support the growth of CO_2 transport and storage infrastructure in 2020 to 2030, preparing industry if CCS is rolled out globally after 2030.

Immediate action is required to enable these high levels of CCS infrastructure to be operational by 2030. This is because of:

(i) Long lead times associated with major infrastructure development.

(ii) The ability to unlock significant investment in infrastructure at a reasonable cost will require substantial de-risking for all parties.

Both public and private investment has been required for oil and gas infrastructure development, within the North Sea and elsewhere, the exact mix reflecting national and commercial priorities and timing. Regardless of the source of funding however, the development of the oil and gas infrastructure could be justified by a history of clear demand, as well as surplus value that ensures profitability of the overall supply chain.

Even with strategic drivers and robust economic benefits, cross-border infrastructure has long lead times, as shown by the Nord Stream Pipeline[35].

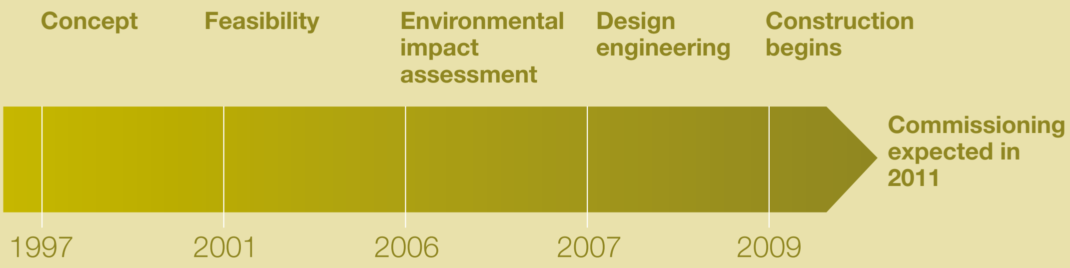
CASE STUDY

The Nord Stream Pipeline

The Nord Stream pipeline, which is to transport natural gas from Russia to Northern Germany across the Baltic Sea was conceived in 1997.

- A feasibility study was commenced in 2001.
- An environmental impact assessment was carried out in 2006.
- Design engineering commenced in 2007.
- Construction commenced in 2009.
- Gas delivery is not expected to commence before late 2011.

Timeline



35 The Economist (2008) Russia's pipeline hits a snag; available at http://www.economist.com/world/europe/displaystory.cfm?story_id=11376692


Picture: iStockphoto © Csaba Peterdi

Legal and regulatory issues

6

Picture: iStockphoto © William Mahar

6 Legal and regulatory issues

6.1 General challenges

The NSBTF countries are at very different stages in the development of legislative arrangements to facilitate CCS. The UK and Norway have transposed elements of the recent EU CCS Directive into national law, but ratification in other jurisdictions is proceeding more slowly. Depending on how they are implemented, elements of the Directive could make economic deployment of CCS less likely. Therefore it will be important to engage industry and where possible implement coherently in the North Sea region. In any case, further work is necessary in all countries to permit the development of CO_2 storage and eventual handover of stores to national governments.

Since energy companies and supply chains are predominantly international businesses, stakeholders confirmed that a harmonised regulatory landscape would be strongly preferred. Any divergence in policies could delay deployment of the technology, and contribute to increased costs.

However the economic potential for CCS, worldwide but particularly across Europe, is heterogeneous; there is wide variation in storage volumes, source clustering, and commercial organisations who would be involved in delivery. This may make it challenging to obtain the required harmonisation of regulations at UN or EU levels. Given their common interests, the governments of the NSBTF could coordinate the licensing regimes and regulatory requirements, providing leadership for other regions.

If utilities/developers are to become comfortable with the risk profile of projects, and proceed to implementation, there is an urgent priority to develop regulations for risk acceptance, site qualification, monitoring, verification, accounting, reporting, decommissioning, monitoring and legal liabilities that are acceptable to stakeholders.

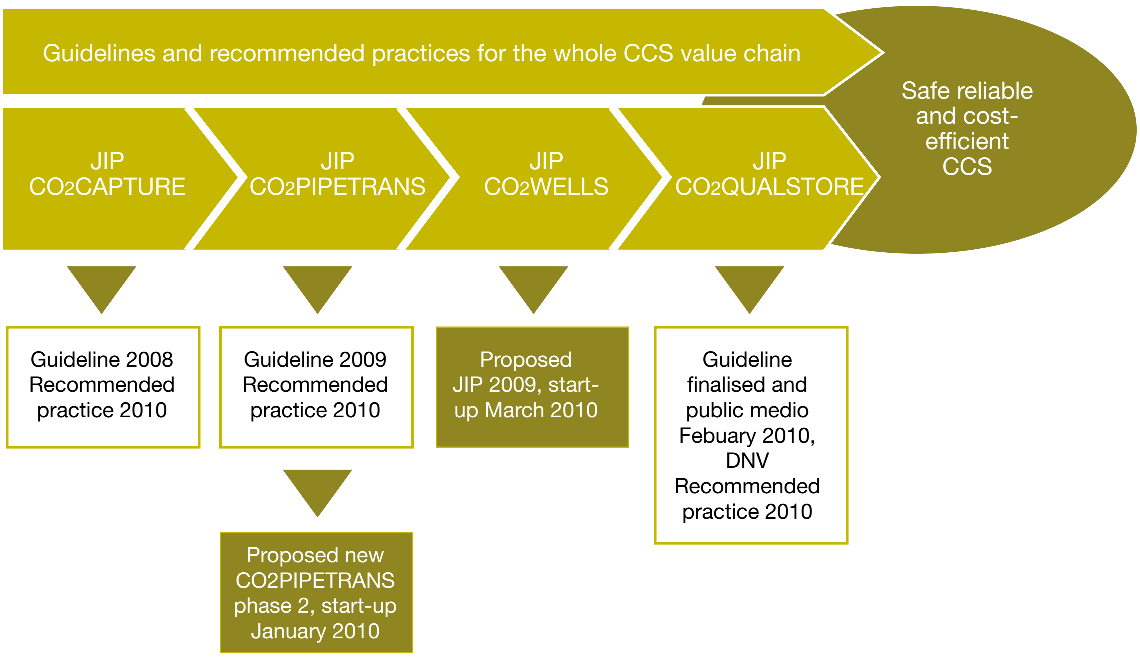
The jurisdictions of existing regulators for CO_2 transport and storage are unclear. Therefore the speed and attitude of regulators in developing fit-for-purpose uncomplicated regimes will influence the pace of deployment and potentially industry structures (i.e. vertically integrated systems vs. independent transport and/or storage businesses).

The recent amendments to the London and OSPAR Conventions should permit transport of ‘overwhelmingly pure’ CO_2 for disposal into geological formations below the seabed. However both amendments require two-thirds of signatories to ratify the amendment. Until this occurs, legality of injecting CO_2 under the North Sea from new purpose-built platforms will theoretically remain open to challenge.

If CCS is to play its part in the transition to a low carbon economy, knowledge and support from the oil and gas sector will be critical.

Access to existing infrastructure and reservoirs could expedite development, but would need to be available on reasonable terms. However, there is difficulty in estimating cessation dates of hydrocarbon production. While there are needs to respect the basis on which existing contractual commitments have been entered into, and also a need to preserve the potential for future oil and gas production, there is a risk that hypersensitivity to these issues could reduce options for low cost storage, and thereby the development of a large CCS industry.

Figure 13: Overview of the DNV co-ordinated Joint Industry Projects (JIP) to develop CCS guidelines. (Image courtesy DNV)



To accelerate the deployment of CCS in a safe and sustainable way, there is a need for authoritative and readily available guidelines that contribute to:

- Proper selection and qualification of well-suited storage sites according to recognised procedures.
- Efficient and harmonised implementation of legal and regulatory frameworks for CCS.
- Predictable conditions for operators, regulators and other stakeholders.
- A swift transition from R&D and demonstration scale projects to large scale CCS by acceptance for a learning-by-doing approach where data is gathered during operation to validate storage performance, and where uncertainties are controlled through a risk-based verification and qualification process.
- Use of concurrent best engineering practice, best available technology (BAT) and proper management of risks and uncertainties throughout the life of a CCS project.

Furthermore, to build confidence in CCS as a trustworthy option to mitigate global warming, it is important that CCS projects are implemented in a clear and transparent way, with benefits and risks balanced and well communicated.

It is unlikely that there will be substantive additional barriers to purely commercial CO_2-EOR within or between the NSBTF countries – these will likely operate under existing frameworks.

6.2 Cross-border challenges

We have identified five main classes of cross-border issue:

1) CO_2 is transported from a source in country A to a storage site in country B so that the transport (pipeline or ship) crosses a boundary. This could include when a network of sources and sinks includes one or more sources, or one or more sinks, from different countries. Transport could use new or existing pipelines.

2) Where CO_2 injection occurs in one state but there are potential impacts from planned or unplanned CO_2 migration or pressure changes in a neighbouring state.

3) Where the storage unit itself spans one or more national boundaries.

4) Transport (by ship[36] or pipeline) proceeds from a source in country A to a sink in country B proceeds via country C, where there may or may not be planned temporary storage in country C. The EU storage directive requires member states to facilitate such transport where possible.

5) As above but where there is a value for CO_2, e.g. where enhanced oil recovery plays an important role – in general this would fall under existing legislation e.g. for petroleum production.

Obviously there must be appropriate regimes for capture, transport and storage in the countries where these occur to provide legal certainty. Cross-border projects face additional potential legal and regulatory challenges, above and beyond the requirements to satisfy national legal and regulatory requirements. These issues could be mitigated by the NSBTF or similar organisation, for example by the following:

- Where CO_2 transport across borders may be challenged under international treaties which restrict the transport of wastes or hazards across borders, these should be amended to explicitly enable CO_2 transport and storage.
- Liabilities for fugitive CO_2 emissions from cross-border CCS networks should be limited and clear.
- Liabilities in respect of storage complexes that span national borders should be limited and clear either on a case by case basis or generally.
- In general, where there is a need to satisfy at least two sets of regulators – adding expense, uncertainty and costs – such regulators should commit to being consistent in their approaches, requirements and timelines. Developers would need to consider the regulatory and permitting regimes for pipeline construction and routing, for authorising CO_2 transportation and/or storage, and the relevant environmental and health and safety regimes.
- Incentives, such as emissions accounting systems or national policies, should consider and support cross-border projects.

6.2.1 Legal rights to transport CO_2 across borders

CO_2 used solely for enhanced oil recovery would be treated as a commodity, and not a waste product. However, the classification of 'captured CO_2' in national or regional legislation (e.g. if it becomes classed as a waste with some hazardous, dangerous properties), will subsequently determine which international

36 International maritime law will apply to cross-border ship transport. A. Soroko, Personal Communication

treaties might apply. Even if CO_2 is not considered hazardous, legal restrictions will apply if:

- impurities in the CO_2 stream are considered hazardous by their presence, or are present in significantly high levels in terms of total mass flow[37], or
- supercritical CO2 were to be considered a dangerous substance requiring stricter regulation that other condensed gases.

In cases of trans-boundary transport of CO_2, trans-boundary storage sites or, trans-boundary storage complexes, the EU's CCS directive requires the competent authorities of the Member States to meet jointly the requirements of this Directive and of other relevant Community legislation. Where more than one Member State covers the CO_2 network or the storage site, the Member States concerned must consult with a view to ensuring that the provisions of the Directive are applied consistently. These two provisions require states to cooperate in respect of cross-jurisdictional matters. The CCS Directive does not provide for situations where a site has been receiving CO_2 from more than one Member State. This could constitute a barrier which could be addressed at EU or North Sea Basin Task Force level.

In October 2009, Article 6 of the 1996 London Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter was amended. The 2009 amendment allows the export of carbon dioxide streams for disposal in secure geological stores, provided that an agreement has been entered into by the countries concerned. Such an agreement must include confirmation and allocation of permitting responsibilities between the exporting and receiving countries, consistent with the provisions of this Protocol and other applicable international law; and in the case of export to non-Contracting Parties. A Contracting Party entering into such an agreement or arrangement shall notify it to the Organisation. The amendment requires ratification.

6.2.2 Simplifying regulation of cross-border transport of captured CO_2

Having to comply with two or more regimes both in pre-project development and on an ongoing basis will inevitably increase costs and gives rise to the risk of inconsistencies between those regimes. This may impact more marginal projects in particular. Costs and inconsistencies could be reduced if the authorities in the respective states consulted with each other and tried to ensure that, so far as possible, their regimes were similar and aligned. The transporter will need authorisations under each regulatory regime.

A good example of how these issues have been addressed as between UK and Norway in the oil and gas context can be found in the UK/Norway framework agreement of 2005 available at https://www.og.decc.gov.uk/upstream/infrastructure/index.htm (pertinent extracts are included below). Prior to the 2005 Framework, individual treaties for cross-border pipelines and reservoirs were negotiated, which in some cases was difficult and took several years. This is still the case for electricity interconnectors. Much more rapid development of cross-border reservoir projects has been observed since the Framework has been implemented[39]. Importantly these include marginal projects that otherwise would not have been developed.

The UK-Norway agreement addresses principles with respect to co-ordination including:

1) Scope
2) Jurisdiction

37 The mass flow of impurities may need to be below a threshold value to avoid triggering these concerns.
38 Element Energy et al., on behalf of the IEA Greenhouse Gas R&D Programme (Manuscript in Preparation). These treaties are supplemented with multilateral or bilateral treaties.

3) Definitions

4) Health, Safety and Environmental Standards, Physical Access and Inspection

5) Metering and Inspection

6) Taxation

7) Exchange of information (including a prohibition on rules which would prevent necessary information flowing from one state to another and so on)

8) Approval procedures

9) Expert procedures for apportioning reserves across boundaries and resolving disputes

10) Consultation and exchange of information

11) Authorisations

12) Construction and operation of cross-boundary pipelines

13) Decommissioning

14) Access terms and conditions

15) Emergency situations

16) Entry and exit points and tariffs

17) Dispute settlement mechanisms

18) Use of infrastructure across the delimitation line

19) Selection of additional transport capacity

Insight from other sectors is also useful, for example the recent commitment to co-operation to develop an offshore electricity grid amongst North Sea countries[40].

6.2.3 Storage complex spanning national boundaries

Where a storage unit or complex spans a national boundary (median line), agreement will be necessary on the terms for its exploitation. This may involve the use of expert opinions to apportion opportunities and impacts for interested parties. Realistically, this could be a longer term issue for the NSBTF (i.e. well beyond 2020), as enthusiasm for the use of trans-boundary storage units would most likely develop on the back of successful operation of storage units within a single country.

The principles for how this is dealt with for trans-boundary hydrocarbon reservoirs in the UK and Norway 2005 Framework Agreement are shown in the box below. The agreement also covers terms for infrastructure on one side of the median line to access a reservoir on the other side of the median line.

39 P. Kershaw, DECC (2009) Personal Communication
40 See for example, http://www.businessgreen.com/business-green/news/2254540/uk-signs-north-sea-super-grid, which is itself based on an earlier agreement available at http://www.benelux.be/pdf/pdf_nl/dos/dos14_PentalateralMoUMarketCouplingAndSecurityOfSupply.pdf

CASE STUDY

UK Norway Ministerial Statement on a new framework agreement for transboundary hydrocarbon reservoirs

JOINT EXPLOITATION OF TRANSBOUNDARY (MEDIAN LINE FIELD) RESERVOIRS AS A UNIT

Where the two Governments and their respective licensees agree that a petroleum reservoir extends across the delimitation line and is to be exploited, both Governments shall agree on:

- the licensees' agreement;
- the approval of the development plan and any amendments to the plan;
- the establishment of the total amount of reserves, the apportionment of the reserves and the procedures for carrying out and applying the outcome of redeterminations;
- the appointment of a unit operator and any change of operator;
- the use of infrastructure for third party development; and
- the timing of the cessation of production from the reservoir.

6.2.4 Cross-border impacts from storage operations

More complex legally and politically, is where storage could have potential impacts in an adjacent state due to fluid migration and pressure increases that in principle could result in damage to life, health, physical infrastructure, or compromise the use of oil and gas reservoirs (including those yet to be discovered).

Although no cross-border impacts are currently foreseen from existing CO_2 injection in the Utsira Formation, or planned CO_2 storage projects within the NSBTF countries, early agreement on how to manage impacts would reduce uncertainties of possible future legal challenges.

A legal framework could improve investor and government confidence that these issues could be dealt with in an appropriate manner, reducing the likelihood of need for recourse to broader agreements that do not consider CCS specifically[41]. Therefore this study recommends that the NSBTF examine how to deal with this issue.

The primary requirement would be for the treatment in the country where the damage occurs to be the same as the treatment that would arise if the injection had also occurred in that country so that there is no discrimination between domestic and foreign reservoirs or storage complexes. If there is any protection under local law for the injection company in this situation it would extend to injections outside the jurisdiction. The secondary requirement would be that for major risks, treatment on both sides of the border should ideally be the same to encourage optimal development of networks not driven by legal concerns.

Theoretical damage to life, health property is only likely to arise if there is an explosive or sudden large scale leakage. Subject to actuarial evidence being available, this may be insurable and could be dealt with in the same way as other health and safety risks.

In the event of compromised oil and gas production, in areas already licensed, licensees could claim loss. For those areas not yet licensed, the state would presumably be the loser. Therefore states might need to be prepared to agree to indemnify each other

41 For example, the Espoo United Nations Economic Commission for Europe Convention on Environmental Impact Assessment in a Transboundary Context

against this latter type of damage (effectively sign a waiver), although there are no obvious precedents for this, so could be challenging to agree.

6.2.5 Emissions accounting

CO_2 emission accounting systems (e.g. for targets, taxes, penalties, credits or ETS allowances) have an influence on (i) priorities for government activities and (ii) where value is recouped within the CCS chain, and thereby industry priorities. Two regimes are particularly noteworthy here – the EU Emissions Trading Scheme and the UN Framework Convention on Climate Change.

The EU has recently proposed draft guidelines on the treatment of emissions accounting for CCS, which impose monitoring obligations on operators, and liability to purchase allowances (emission rights) equal to any emission recorded. The proposed draft guidelines do not provide guidance on how any unintentional emissions from pipelines might be allocated in National Greenhouse Gas Inventories in cases where the pipeline crosses national boundaries, and the precise location of the fugitive release is uncertain.

6.2.6 Mechanisms to facilitate cross-border project development

With respect to the development of CCS in the North Sea, stakeholders will need to consider how they foresee the development of the industry and the extent of cooperation between North Sea countries. The regulatory framework put into place will differ according to the option that is chosen.

There are a number of ways in which parties interested in co-operating in the development of CCS in the North Sea can formalize arrangements including by way of a Memorandum of Understanding (MOU), a Treaty or a Framework Agreement.

There are several examples where MOUs have been used by states wishing to cooperate on energy matters. Two recent examples in Europe are the MOUs signed in respect of the Single Electricity Market in Northern Ireland and Ireland ("SEM") and Market Coupling and Security of Supply in Central Western Europe. The MOUs are fairly short, high-level documents that provide a map to be followed by signatories in achieving the desired aims. An MOU records international "commitments", but in a form and with wording which expresses an intention that it is not to be legally binding. An MOU can be used where it is considered preferable to avoid the formalities of a treaty, for example, where there are detailed provisions that change frequently or the matters dealt with are essentially of a technical or administrative character. The formalities which surround treaty-making do not apply to a MOU and therefore it may be a faster process:

- In December 2006, the UK and Ireland signed a MOU arranging the establishment and operation of a single wholesale electricity market (SEM) in Northern Ireland and Ireland. The MOU set out the goals of the governments and provided the broad framework within which both would enact legislation to enable the implementation of the SEM.

- In June 2007, the governments of Belgium, France, Germany, Luxembourg and the Netherlands signed a MOU on market coupling and security of supply in Central Western Europe to promote a more efficiently functioning cross-border electricity market in the five countries and as a step towards further European integration. The MOU set out the objective of the analysis, the design and implementation of the market coupling between the five countries, as well as the objectives to be achieved in security of electricity supply.

The US Interstate Oil and Gas Compact Commission Task Force on Carbon Capture and Geological Storage also provides a valuable example of cross-border co-operation[42].

6.2.7 Conclusions on cross-border issues

This section has identified diverse barriers to cross-border transport, cross-border storage, and impacts from CO_2 stored in one country on a second country.

The experience from the development of oil and gas reservoirs, pipelines and electricity interconnects across national boundaries provides valuable lessons for how cross-border transport and cross-border storage should be managed. This knowledge should be leveraged for CO_2 storage projects.

The technical analysis indicates significant potential for cross-border CCS issues to increase in importance for the countries of the North Sea Basin Task Force in the period up to and beyond 2020. As the pre-eminent forum for deliberating on CO_2 transport and storage issues in the North Sea, the North Sea Basin Task Force is in a leading position to tackle, if necessary:

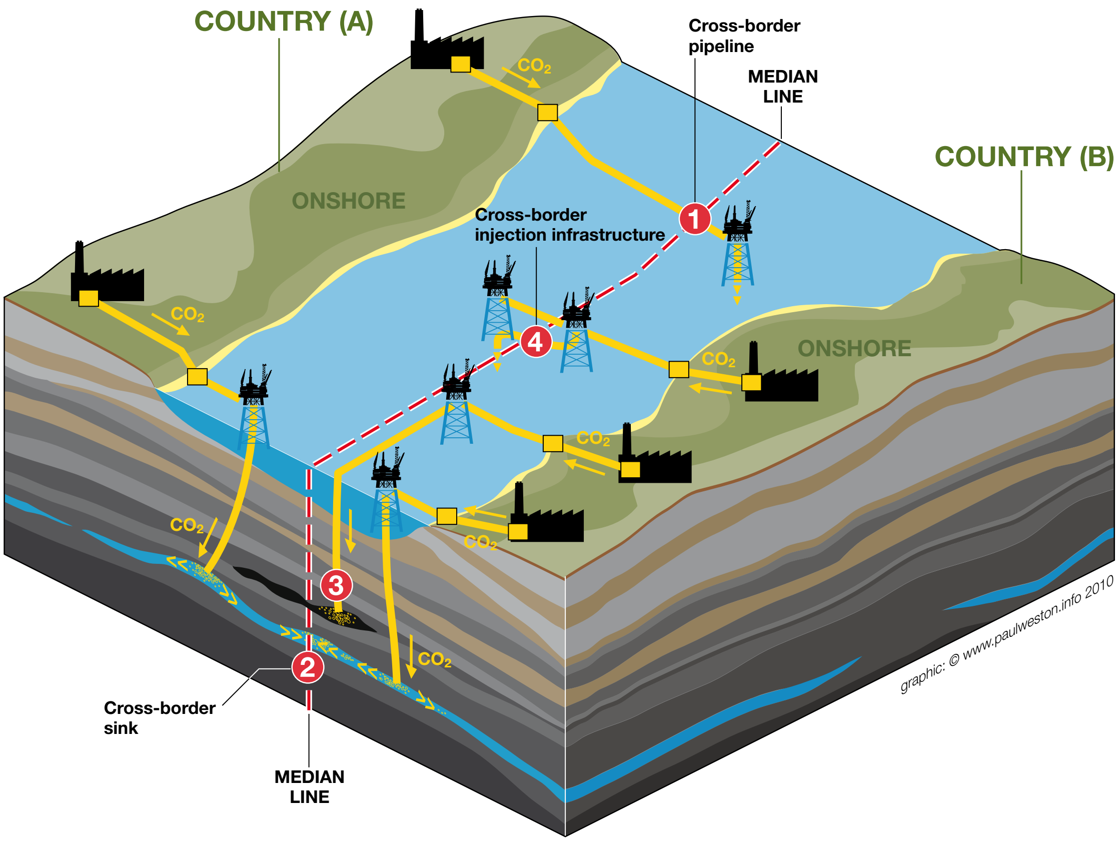
- Potential impacts from CO_2 storage project developed in one country on a second country.
- The management of liabilities for CO_2 transported from one country and stored in a second country.
- The management of CO_2 storage complexes that span national borders, for example exploration, leasing and licensing of pore spaces, short and long-term monitoring and liabilities.
- Co-ordination of the permitting, construction, operation, decommissioning and liability issues for physical CCS infrastructure such as pipelines and injection facilities that span borders.

Despite experience with several project-specific transboundary agreements, the UK Norway framework agreement for transboundary hydrocarbon reservoirs and infrastructure took three years to agree. The development of CO_2 storage agreements may be more time consuming. Therefore a commitment by the North Sea Basin Task Force to start to address these issues through working groups or studies in the period 2012 to 2015 will increase the likelihood that legal clarity is available to CCS developers in advance of any major infrastructure decisions in the late 2010s or early 2020s if required.

42 http://www.iogcc.state.ok.us/carbon-sequestration

Figure 14:

Cross-border issues



1. Cross-border pipeline	2. Cross-border sink	3. Cross-border impacts	4. Cross-border injection infrastructure
ISSUES • Long term liability impact • Pipeline management	ISSUES • CO_2 migration • Pressure changes • Allocation rights	ISSUES • Possible compromise of nearby hydrocarbon reservoir	ISSUES • Infrastructure management

A ‘One North Sea’ Vision

7

7 A ‘One North Sea’ Vision

The main conclusions from the technical analysis and stakeholder consultation in this report are:

- Subject to proving its technical and commercial viability in the period up to 2020, CCS will be an essential technology for significant carbon abatement in the NSBTF countries and globally by 2030.
- Although there are many uncertainties, the growth of CCS deployment amongst the North Sea countries could be significant, particularly in the period 2020 – 2030.
- This high level of deployment amongst NSBTF countries is sustained by the combination of:
    - Abundant and diverse CO_2 storage sites; over half the CO_2 storage in Europe is within the borders of the four NSBTF member countries.
    - Highly clustered CO_2 sources, which will facilitate the development of efficient transport networks.
- There is significant research, development and demonstration within the NSBTF countries, with considerable activity through all levels of the supply chain from capture, transport and storage.

We conclude that the member states and commercial partners of the NSBTF are in a natural leadership position on CCS, due to:

- Abundant sink capacity and source clustering, reducing costs for CCS deployment,
- The opportunity to capitalise on commercial activity within NSBTF member states, to act as a supplier of CCS technologies and expertise, which, once proven, can be exported worldwide.

We propose the following vision for CCS within the North Sea region:

Near term (period to 2020)

A coordinated set of demonstration and pre-commercial projects proving key elements of the technology, thereby establishing the North Sea countries as world leaders of CCS technology development.

- There will be efforts by the governments and stakeholders of the NSBTF, to coordinate the development of appropriate CCS incentives at European and global level.
- Stakeholders within the North Sea region will be seen as vital in proving the technical and economic potential of CCS.
- A much more accurate picture of the true storage capacity in the North Sea region will have been developed, increasing confidence for policymakers and commercial stakeholders alike.
- The demonstration projects within North Sea member countries will be coordinated to ensure the necessary learning is achieved efficiently. This extends to sharing best practice on capture technologies, transport routing, and sink mapping and maturation techniques.
- During this time, the NSBTF members will show leadership on the exploitation of storage sites, both hydrocarbon fields and aquifers, including sharing data and expanding mapping, characterisation, injection and monitoring activities.
- Leadership will also be shown on the deployment and safe operation of sub-sea

CO_2 transport and storage facilities.

- Appropriate legislation will be in place to facilitate the large scale commercial storage of CO_2 under the North Sea, and its transfer between member states.

Mid-term (period from 2020 to 2030)

Assuming successful CCS demonstration and subject to need, there will be a ramping up of commercial CCS deployment so that by 2030 the technology is making a significant contribution to CO_2 abatement within Europe.

- Incentives for CCS will be sufficient and long-term so as to encourage a growing number of large scale commercial projects.
- The legislation developed in the near term, will support an increasing volume of cross-border flows. This mutual support will help to reduce risk and costs amongst North Sea member states.
- By the end of this period, the CCS flow in the North Sea and the industry required to develop it, is approaching the size of the oil and gas industry in the North Sea.
- The North Sea countries will be exploiting the knowledge gained through this and the previous period by exporting technologies and services to a worldwide market.

Long term (2030 to 2050)

Assuming successful CCS deployment and subject to progress with alternative energy technologies and prevailing global CO_2 mitigation requirements.

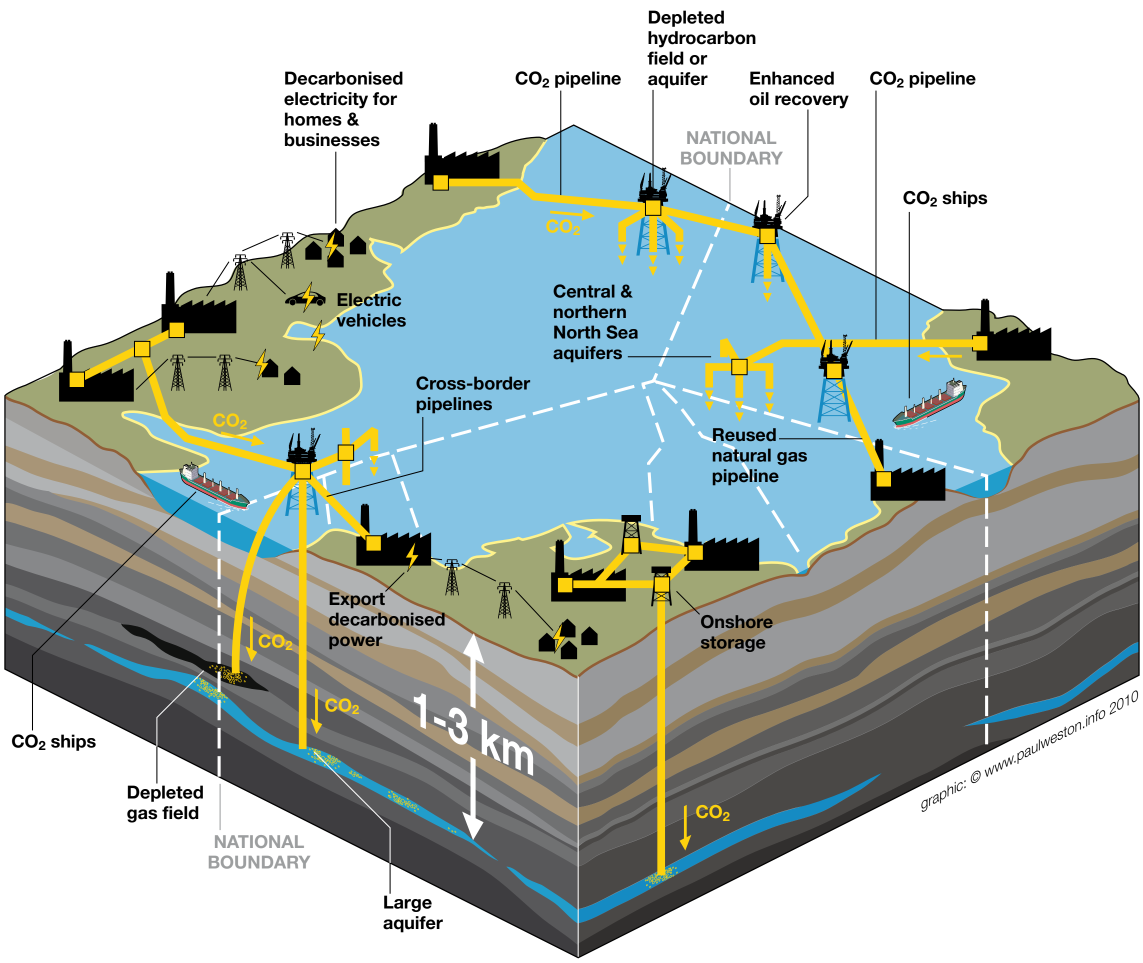
- A greater number of CO_2 sources will be captured. Many projects will be integrated to form source clusters, making use of shared CO_2 trunk lines and sinks.
- A well-established transport and storage infrastructure will allow the region to attract and retain high emitting and energy-intensive industries, allowing them to operate cost-effectively within a low carbon economy.
- Some North Sea countries will develop CCS capacity beyond their own needs, and become a net exporter of low carbon electricity to other European nations.

Whilst the above vision is considered technically realistic, there are diverse obstacles to delivering CCS deployment at a scale consistent with the ‘Very High’ scenario. The next chapters summarise the key barriers and identify possible actions to deliver the vision.

See One North Sea graphic,
next page **Figure 15**

Figure 15:

A 'One North Sea' vision



Barriers to achieving the vision

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8 Barriers to achieving the vision

Stakeholders consulted during the preparation of this report suggested that the large scale deployment of CCS infrastructure by 2030, with substantial contribution from cross-border projects is technically feasible. However the stakeholder and literature review, and the technical, legal and regulatory analysis within this study identified numerous barriers to CCS deployment.

8.1 Global barriers to CCS deployment

In addition to weak incentives generally for CO_2 reduction, systemic barriers to commercial CCS deployment worldwide identified in the stakeholder and literature review for this study include:

1. The eventual capacities, locations and timings for CCS deployment are highly uncertain. This makes planning for CCS difficult for both governments and industry.

2. There has been limited operational experience in large scale CO_2 injection – consequently there are no well calibrated or fully accepted criteria for CO_2 storage capacity and suitability determination.

3. The technical and economic viability of CCS at large scale remains to be demonstrated.

4. Weak economic or regulatory incentives for power or industrial sources to justify the higher capital and operating costs associated with CCS operation.

5. Uncertainty over the development of legal and regulatory frameworks for CCS generally and CO_2 storage in particular, hampers investment.

8.2 Barriers to CCS deployment for the North Sea region

In addition to the barriers above, there are specific issues affecting CCS in the North Sea region. In the absence of concerted efforts by North Sea Governments, industry and wider stakeholders to develop CCS technologies, infrastructure, policies and regulations CCS activity is likely to limited to a handful of medium-scale demonstration projects.

1. Insufficient financial or regulatory incentives for CO_2 capture remain the biggest barriers to widespread CCS deployment in Europe. The locations and amount of demand in 2030 are highly sensitive to policy and market influences.

2. If there are sufficient incentives to support a very high CCS demand, our modelling suggests that restrictions in transport and storage availability can dramatically change the level and distribution of CO_2 emissions abatement through CCS activity within the North Sea region.

3. Whilst overall theoretical capacity estimates are high, storage opportunities for CO_2 are highly site-specific. Information on the locations, capacities, suitability and availability of individual sinks are too limited to develop Europe-wide policies and investments that would result in significant CCS activity.

4. A vicious circle comprising uncertainty over the demand for CCS, investment in

integrated infrastructure, sink suitability and availability, technology development and public policy across Europe creates a real risk that investments in CCS infrastructure will not proceed quickly enough to enable a large-scale roll-out of CCS in the period 2020 to 2030.

5. There is limited legal and regulatory clarity for CO_2 storage development, creating challenging business models for storage.

6. The modelling work suggests that onshore storage and aquifers play a large role in CO_2 storage in very high uptake scenarios, particularly in Germany. If domestic storage was not viable, cross-border storage could be accessed if suitable cross-border transport infrastructure was in place.

8.3 Barriers to cross-border projects in and around the North Sea

The technical analysis identifies that cross-border flows of CO_2 between countries represented on the North Sea Basin Task Force are unlikely to be significant until after 2020. However the stakeholder review identified that cross-border projects involving countries not currently represented on the Task Force may be developed. Tackling cross-border issues early could increase the potential for favourable CCS policies in countries around the North Sea and in Europe generally, promote investor confidence and choice, and provide a blueprint for other regions in managing cross-border CO_2 flows.

The legal analysis identifies the following challenges:

1. Governments will need to agree terms for accepting long-term CO_2 liabilities from cross-border projects.

2. Governments will need to agree terms for the permitting, construction, operation and decommissioning of any physical infrastructure that crosses the national boundaries.

3. Governments will need to agree how to develop storage units which cross national boundaries directly.

4. Governments will need to agree how to manage any potential impacts from CO_2 storage projects across national boundaries.

5. CCS project developers will need robust signals for capture demand and storage availability and regulation, and information on existing or future infrastructure plans in different countries.

6. CCS project developers will need to satisfy legal and regulatory requirements from two or more sets of regulators, potentially adding risks, raising costs and/or introducing delays.

Barriers to cross-border projects

Picture: iStockphoto © Erna Vader

Delivering the vision

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9 Delivering the vision

Activities to remove the barriers outlined above and deliver the vision need to occur at a number of levels, and involve diverse organisations. It is neither necessary nor appropriate for the responsibility for all of these activities to formally lie as actions for the NSBTF itself. Indeed members of the NSBTF already individually contribute to a number of other CCS related forums.

Action at global level is necessary, because challenging caps on CO_2 emissions can only be achieved through global agreements, because CCS will draw on existing supply chains that operate and innovate globally, and because stimulating a global market for CCS will create opportunities for CCS businesses that develop in Europe. In the short term one half of the proposals for CCS demonstrations worldwide are outside of Europe, meaning that it will be important to tap into experience gained worldwide.

The analysis within this report demonstrates that organisation and engagement of the members of the NSBTF at European level is also essential, because it is primarily through influencing EU energy and climate policy that the largest and most sustainable CCS deployment scenarios may develop.

With access to large amounts of offshore CO_2 storage, North Sea countries benefit strongly from economic opportunities connected to CCS, and may have a compelling incentive to be early adopters of CCS technology, and therefore display leadership on issues such as transport and storage, including managing CO_2 flows across borders. This is consistent with the stakeholder analysis which identified that proposals for CCS projects in North Sea countries are developing well.

9.1 Near-term actions at global level

Substantially more progress is required worldwide in:

- Gathering operational experience with both CO_2 capture and storage
- Developing lower cost 'next generation' capture technologies
- Developing better guidelines on determining the capacity and suitability of potential storage sites.
- Delivering large scale and safe CCS demonstration projects in a timely manner.
- Sharing knowledge from demonstrations between governments, industry and the public.
- Supporting measures that could reduce the costs of capture, transport and storage.
- Committing to strengthening economic and regulatory incentives for CCS.
- Providing as much clarity as possible on long-term policies and initiatives.
- Engaging with the public and NGOs to gain support for CCS.
- Removing legal obstacles to cross-border CO_2 transport or storage.

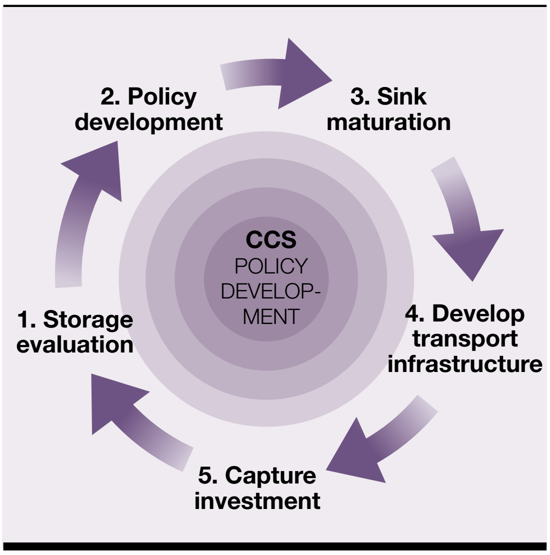
Existing institutions such as the Carbon Sequestration Leadership Forum, the International Energy Agency, the Global CCS Institute, and United Nations are well placed to tackle these issues.

9.2 Near-term actions at European level

This report recommends that the governments of the North Sea Basin Task Force work together, and with the European Union, to deliver a supportive policy environment, for example by:

- Introducing measures that promote CCS deployment in Europe beyond a first wave of CCS demonstration, for example capture readiness and incentives for capture, transport and storage.
- Facilitating implementation of the EU CCS Directive and developing supportive structures for exploration, licensing and leasing arrangements for storage.
- Substantially improving the quality, consistency and availability of information on potential geological storage locations under the North Sea and across Europe. Ideally this should identify potential conflicts of interest and other economic issues. This would reduce risks and create a virtuous circle for policy development, sink maturation, transport infrastructure development, and capture investment.

Figure 16: Virtuous circle of CCS policy development and investment in capture, transport and storage infrastructure.



- Continuing to fund research, development and demonstration activities that may reduce the costs of CCS.
- Agreeing to collectively influence European policy development related to CCS.
- Reducing the risk of projects being blocked or unnecessarily delayed through responsible public engagement on issues around climate, energy, economics and CCS.
- Developing common guidelines for CO_2 transport and storage to provide clarity and simplicity for participants.

9.3 Actions for the NSBTF (or other similar consortia)

Recommendation 1

Recognising the limitations of existing data on sink capacity, availability, and suitability, and long lead times for storage assessment and validation, the NSBTF (or others) should, by 2012, consider a shared CO_2 storage assessment to improve the consistency, quality and credibility of North Sea storage capacity estimation, mapping, suitability assessment, and/or validation.

Recommendation 2

Recognising the potential for information to reduce uncertainties and optimise the development of CO_2 transport and storage infrastructure, the NSBTF (or others) should continue to assess and publish biennial long-range reviews of opportunities and challenges for CCS-related activity in and around the North Sea region.

The next review should include:

i. Updated assessments of the economic potentials, timing, organisation and implementation of capture, transport, storage, enhanced oil recovery, and infrastructure re-use.

ii. Updates on relevant national and European policies and guidelines, and comparison of technical, legal, regulatory or commercial barriers for CCS in the North Sea region with other regions of the world.

iii. Identification of low cost near term measures that could substantially reduce the long-term costs of CCS, for instance data sharing, future-proofing specific sites or infrastructure, or increased organisation.

iv. Case Studies providing as much detail as possible on site-specific opportunities and challenges for capture, transport and storage.

Recommendation 3

Recognising that depleted hydrocarbon reservoirs under the North Sea are promising early storage sites, in the period 2010 – 2015 the NSBTF (or others) should share experience and thereby develop guidelines on how stewardship should be transferred between hydrocarbon extraction, Government and CO_2 storage.

Recommendation 4

Recognising that influencing policy development and sharing information at global and particularly European levels will be critical in developing CCS around the North Sea, the governments and members of the NSBTF (or others) must continue to show leadership and co-operation in the development of legislation, and in sharing information where appropriate, to support CCS, in their own countries, at European level and in global forums.

9.4 Actions for Governments to facilitate cross-border CO_2 flows

The analysis in this report identifies that cross-border CO_2 transport and storage could play a useful role by 2030. The governments of NSBTF member states (or other similar grouping) are best placed to address these cross-border issues directly, and we recommend the following actions:

Recommendation 5

Before 2014 the NSBTF Government Members should review progress on cross-border issues and expected demand, and if necessary publish a formal statement of intent to agree terms where required in respect of the management of cross-border flows or potential impacts, infrastructure and storage complexes.

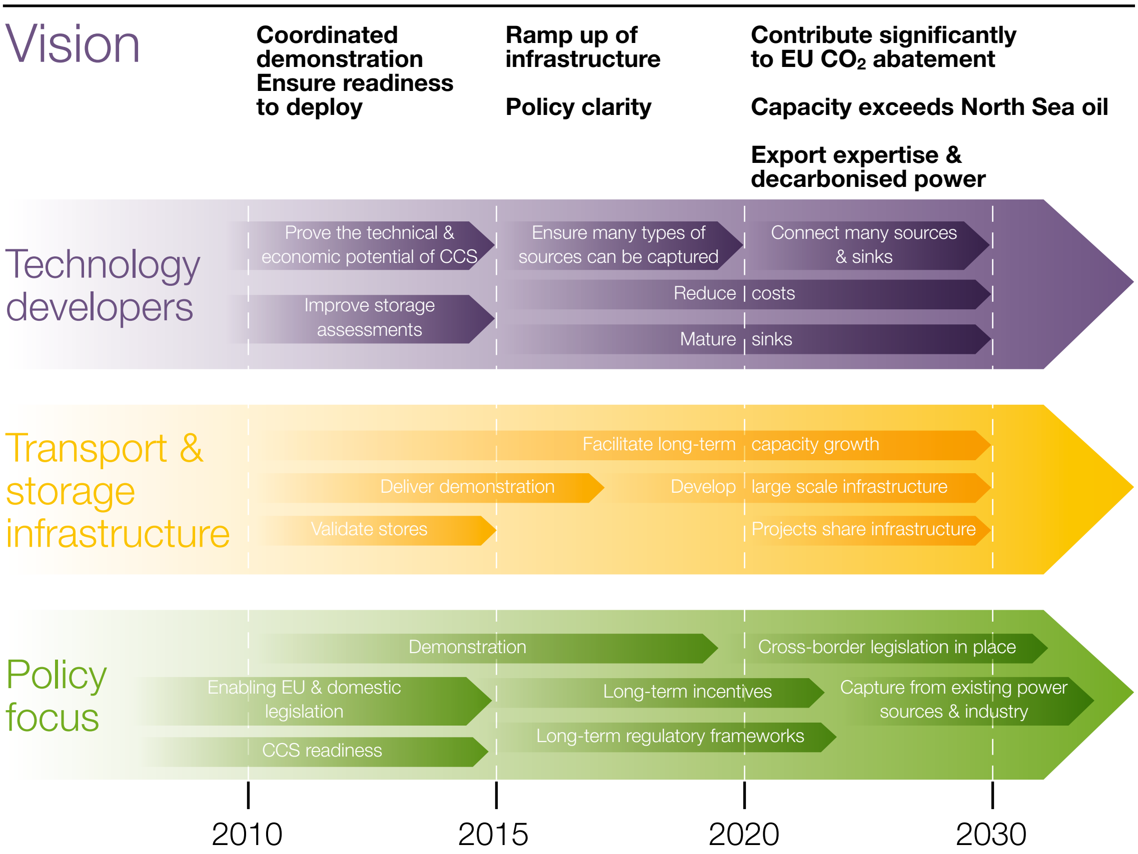
Whilst the exact timing and focus will depend on the outcome of this review and expected lead times, Governments should consider developing frameworks in the period 2015 – 2020 for:

- The management of potential impacts of CO_2 storage projects developed in one country on a second country.
- The management of liabilities for CO_2 transported from one country and stored in a second country.
- The management of CO_2 storage complexes that span national borders, for

example exploration, leasing and licensing of pore spaces, short and long-term monitoring and liabilities.

- The permitting, construction, operation, decommissioning and liability issues for physical CCS infrastructure such as pipelines and injection facilities that span borders.

Figure 17: Timeline reflecting the focus of CCS stakeholders in the North Sea region (assumes 'Very High' scenario).



Acknowledgements

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DCMR

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DNV

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ECN

EEEGR

Electricity Policy Research Group (University of Cambridge)

E.On

Gassco

Gassnova

GEUS (Geological Survey of Denmark)

IEA Greenhouse Gas R&D Programme

IGME

Imperial College

IM Skaugen

Kema

National Grid

North West Regional Development Agency

Norwegian Ministry of Petroleum and Energy

One North East

Panaware

Polish National Centre for Research and Development

Polish Academy of Sciences

Powerfuel

Progressive Energy/COOTS

Rotterdam Climate Initiative

Risavika Gas Centre

Sargas

Schlumberger

Scottish Centre for Carbon Storage

Scottish Power

Senior CCS

Shell

SINTEF

SLR Consulting

Statoil

Teekay Shipping

The Crown Estate

TNO

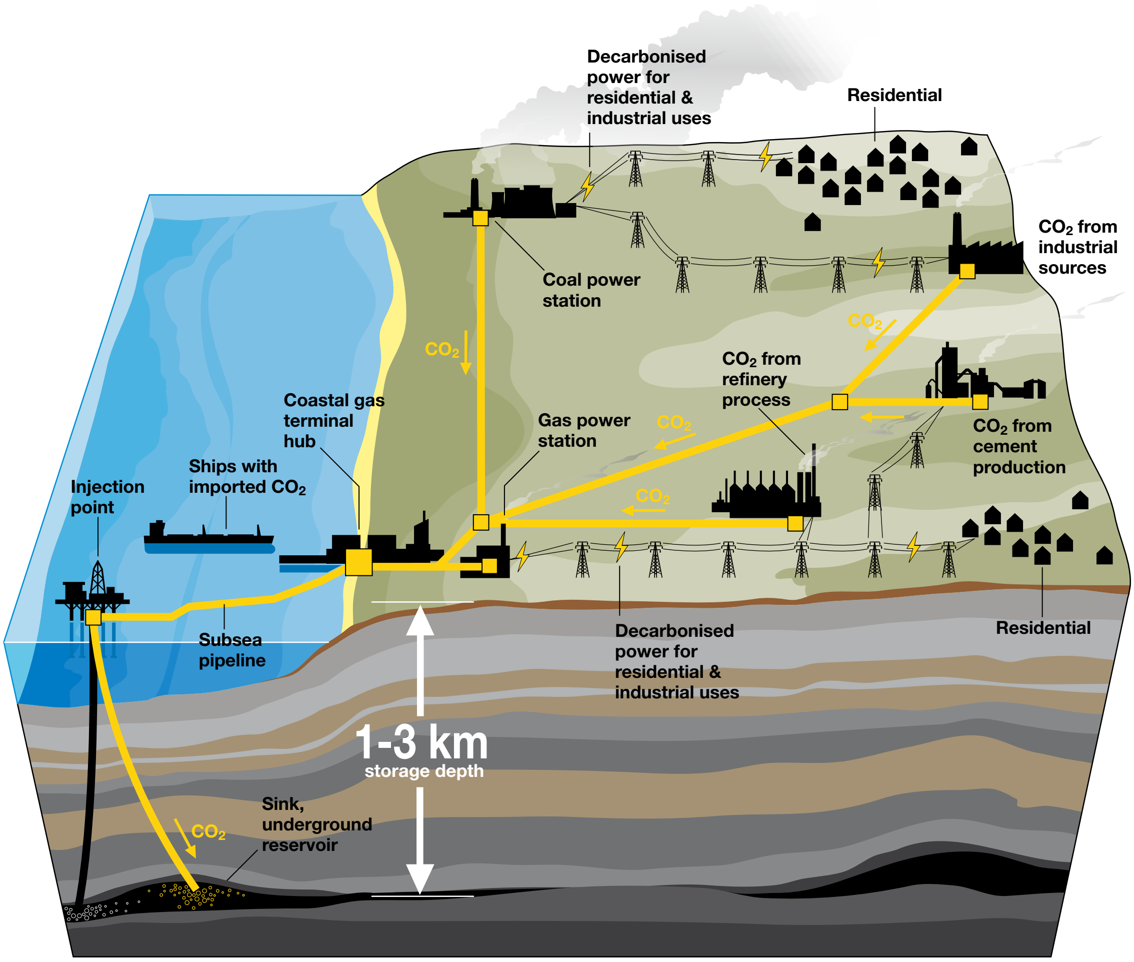
UK Coal

Vattenfall

VOPAK

Figure 18: Carbon Capture and Storage

CCS



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