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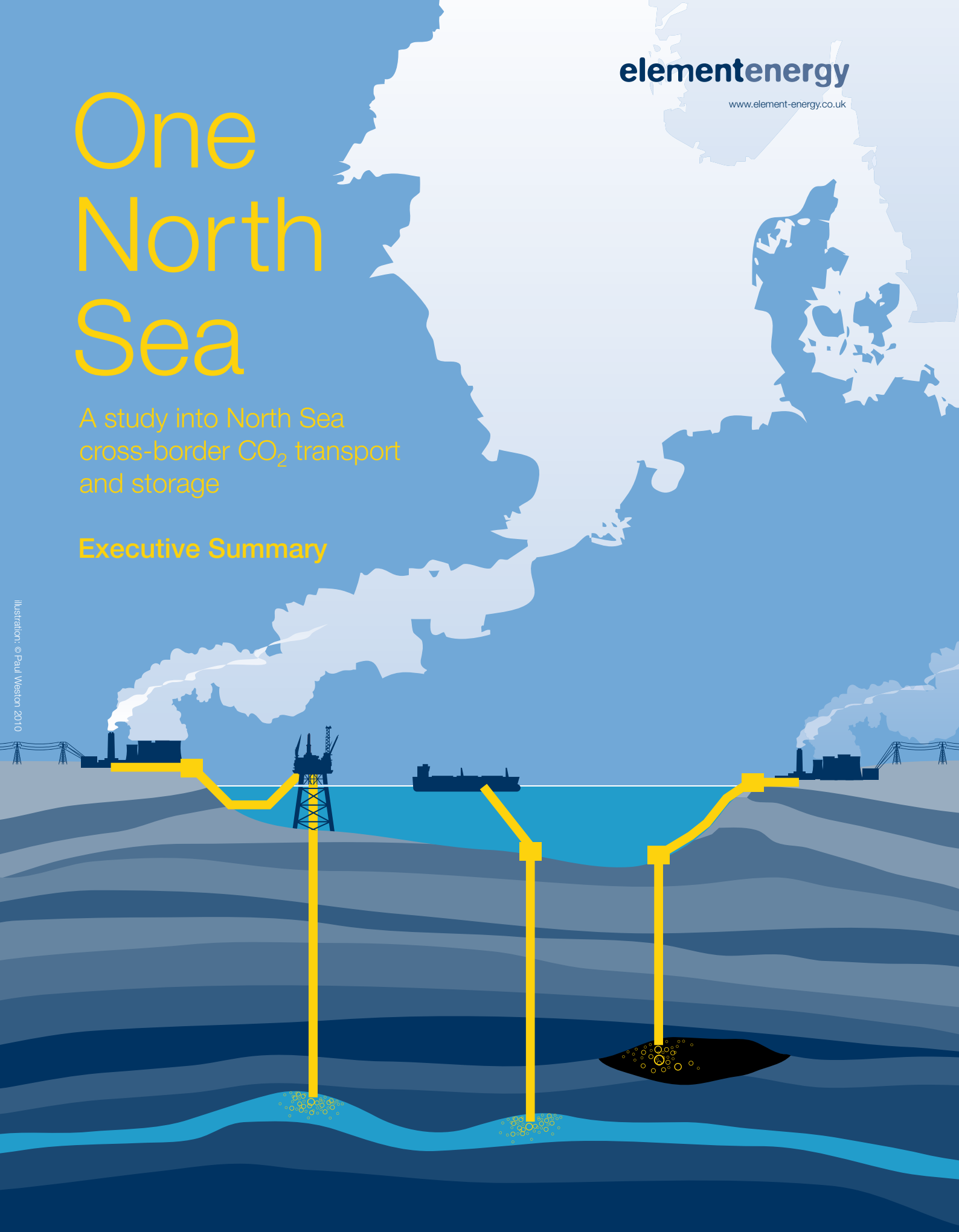
# One North Sea

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

## Executive Summary





**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

## Executive Summary

18th March 2010

Highlights and Executive Summary:

**The Norwegian Ministry of Petroleum and Energy**
and
**The UK Foreign and Commonwealth Office**

On behalf of:
**The North Sea Basin Task Force**

Authors:

elementenergy

# 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.

Picture: iStockphoto © Kris Hanke

# 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.

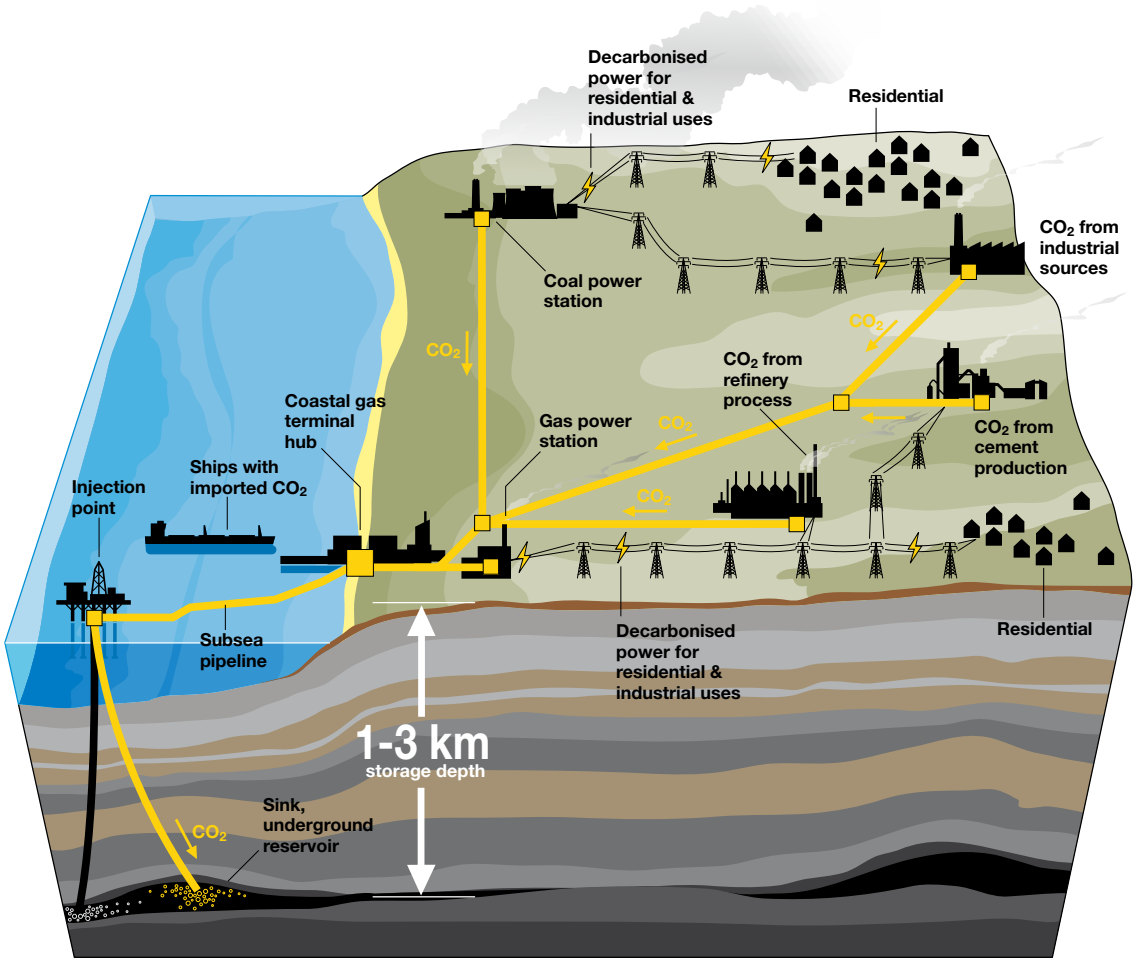
Around fifty per cent of European $CO_2$ storage potential is located under the North Sea. A large amount of predicted CCS demand is located within Germany, the Netherlands, Norway and the UK, the countries of the North Sea Basin Task Force. The geographical clustering of sources and/or sinks gives opportunities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

The full report and appendix can be found at **www.element-energy.co.uk**

# Executive Summary

# 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.

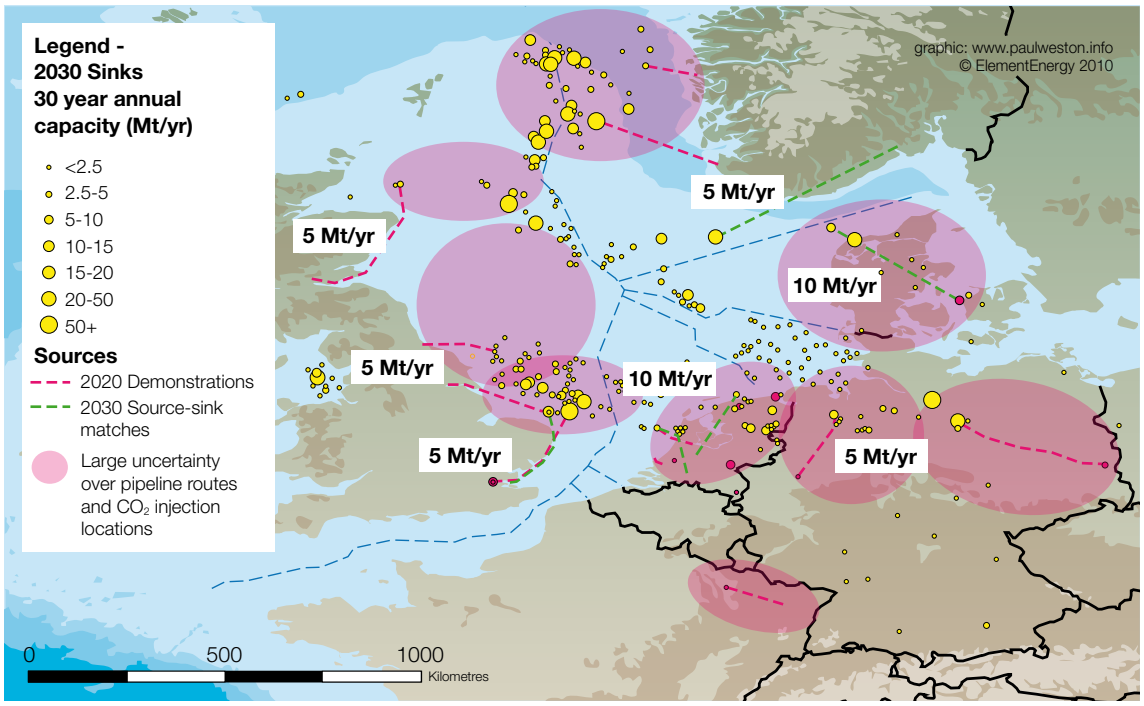



**Figure 1**: CCS activity in the 'Medium' scenario 2030

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.

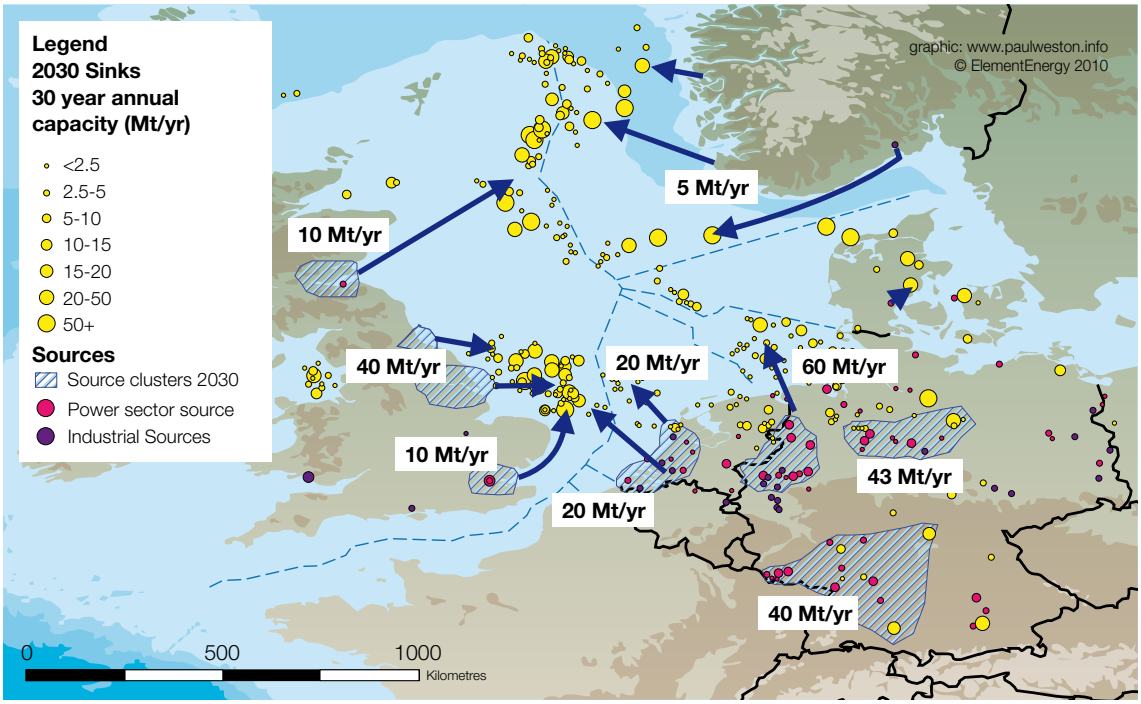



**Figure 2**: CCS activity in the 'Very High' scenario in 2030

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.

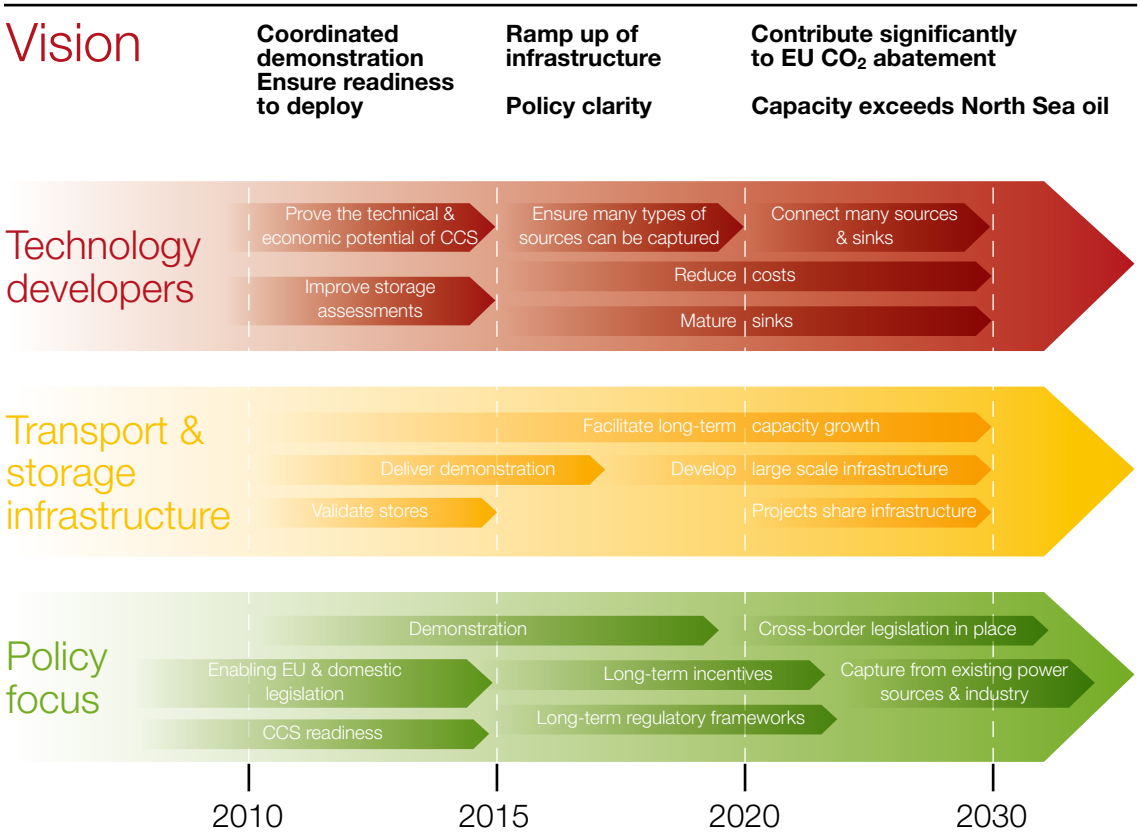
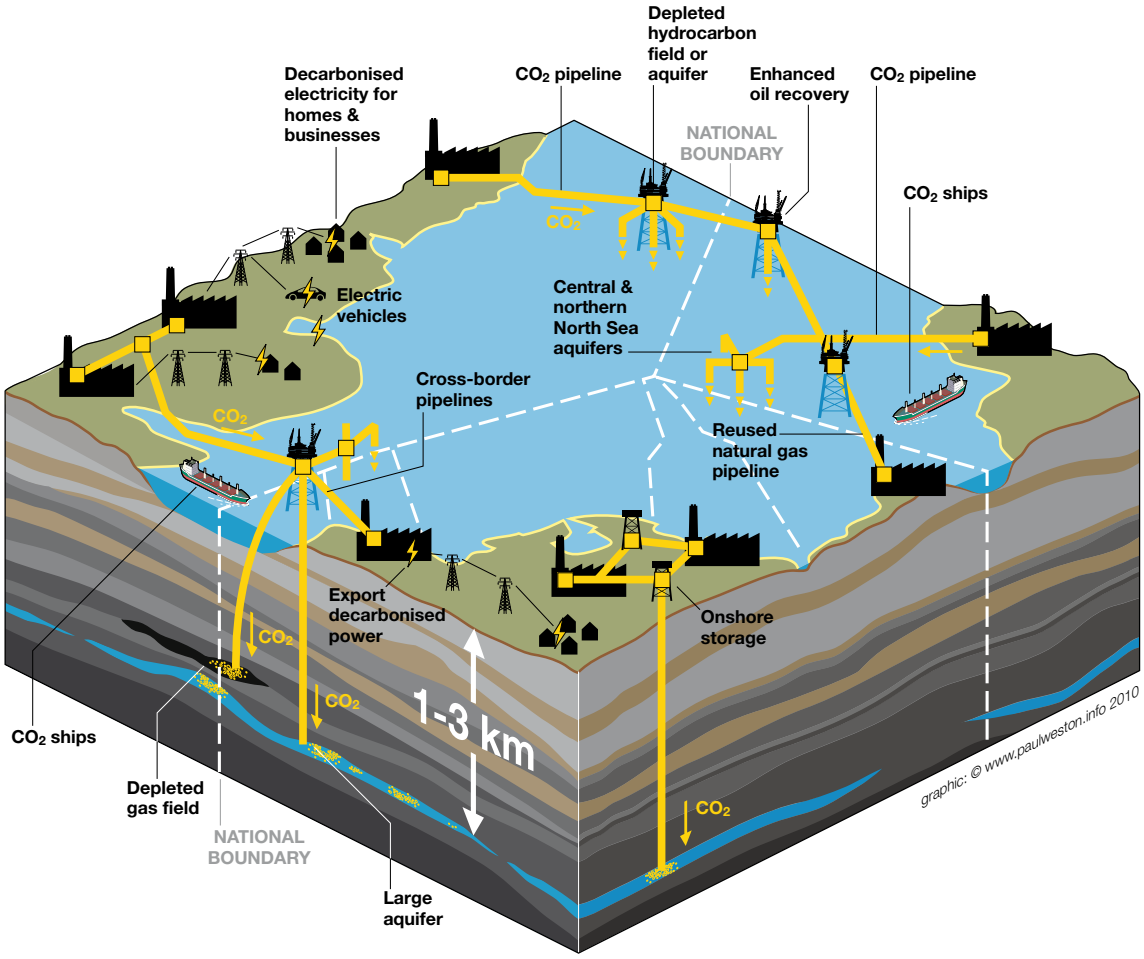



**Figure 3**: Timeline reflecting the focus of CCS stakeholders in the North Sea region (assumes 'Very High' scenario).

# A ‘One North Sea’ vision



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Carbon capture plant, courtesy of Vattenfall

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