NSBTF strategic regional plan on CO_2 transport and storage infrastructure

The North Sea Region

March 2023

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1. The North Sea Basin Task Force

The North Sea Basin Task Force (NSBTF) is composed of public authorities and private entities from countries on the rim of the North Sea, aiming to develop common principles for developing, managing, and regulating the transport, injection, and permanent storage of CO_2 in the North Sea area[1]. As of March 2023, the NSBTF includes members from Denmark, Flanders, France, Germany, The Netherlands, Norway, and the UK.

All the NSBTF members have ambitions for CCS (Carbon Capture and Storage) in their countries and wish to take a collaborative approach to develop and promote cross-border CCS in the North Sea Region. The members recognise the role of CCS to curb CO_2 emissions for their respective countries or businesses, notwithstanding the different national policies on CCS.

2. A cross-border transport and storage network

This document establishes the updated NSBTF strategic regional plan on cross-border CO_2 transport and storage infrastructure. In the previous plan, established in 2017, the NSBTF members recognised that the area of the North Sea Basin is the most logical place in Europe to start transport and storage of CO_2. To maximise this potential, the countries bordering the North Sea need to coordinate and plan together to deliver an optimised network. The sub-surface of the North Sea area has extensive CO_2 storage capacity in both depleted hydrocarbon reservoirs and saline formations of strategic importance to the development and deployment of carbon capture and storage in Europe.

The North Sea Basin Task Force has decided to come together in the spirit of regional cooperation in a shared vision to promote the development of CCS and to plan for the infrastructure required. This plan is designed to facilitate the incremental construction of a future CO_2 transport and storage network in the North Sea area and to provide a strategic regional plan for potential Projects of Common or Mutual Interest (PCI or PMI), that will form the first parts of such a future network, where relevant.

This plan also serves as a basis for examining cross-border collaboration, through for example, potential PCIs and PMIs under the EU TEN-E Regulation, in the thematic area of CO_2 transport and storage, to assess their strategic fit and their potential to provide cross-border benefits even where physical infrastructure is initially located in just one member state. The plan is in line with the role, aims and common interest of the NSBTF members.

3. The EU

The European Green Deal acknowledges the importance of CCS, CCU and carbon removals in the achievement of the 2050 EU Climate Neutrality objective. The European Commission is increasing its support to CCS and CCU as climate mitigation tools through the Innovation Fund, the TEN-E Regulation and Horizon Europe. The Commission's proposals aiming at facilitating deployment of CCS and CCU include the communication on Sustainable Carbon Cycles, the proposal for a Regulation on an EU certification framework for carbon removals, and the EU ETS Directive amendments on CO_2

[1] The term "North Sea area" includes both offshore, nearshore, and onshore storage possibilities.

transport and non-geological storage. At the second meeting of the Carbon, Capture, Utilisation and Storage Forum in October 2022 in Oslo, the Commission signalled its plans to table a communication on the strategic vision for CCS and CCU in 2023.

Developing successful demonstration and scale-up of the CCS technology requires stable funding arrangements. The TEN-E Regulation (22/869) and the Connecting Europe Facility for energy represent a possible pathway to support the development of new energy infrastructures for transport and storage of CO_2. The PCI/PMI selection process for 2023 is ongoing, with the next opportunity in 2025.

4. CCS in NSBTF member countries

The EU has an ambition to cut emissions by at least 55% by 2030 and to become climate neutral by 2050. Recent and ongoing revisions of a range of climate and energy related directives, regulations and communications address how the EU shall meet its targets and includes a significant role for CCS activities. All NSBTF members recognise the importance of CCS in meeting respective emission reduction targets, especially for hard-to-abate industries.

a) Denmark

CCS has an important role in the Danish effort to reach its climate target of 70 % reduction by 2030 and climate neutrality by 2050. In June 2020, the government and a broad majority in the Danish Parliament concluded a climate agreement for energy and industry, which included substantial investments in CCS. Approximately 37 billion DKK (5 billion EUR) has been set aside in total to achieve reductions and removals of 3.2 million tons of CO_2 per year from 2030.

Since then, political strategies for the development of all parts of the CCS value chain have been made, and R&D grants have been given to develop storage sites in depleted oil- and gas fields in the Danish part of the North Sea. Moreover, seismic investigations are going on in 2022-2024 to develop potential onshore and nearshore storage sites. The Geological Survey of Denmark and Greenland (GEUS) estimates the potential for storage in the Danish sub-surface to be between 12 and 22 billion tons of CO_2.

Given the large potential for storage, the Danish strategy emphasises the development of Denmark as a hub for storage of European CO_2. Denmark has ratified the 2009 amendment to the London Protocol, deposited a declaration of provisional application, allowing for the export of CO_2 for permanent storage in sub-seabed geological formations, and concluded the world's first bilateral arrangement with Belgium and Flanders on import and export of CO_2 with the purpose of permanent storage in sub-seabed geological formations.

A variety of project developments have taken place since 2020 and as of March 2023, Denmark has granted three exploration permits in relation to the offshore projects Greensand and Bifrost, as well as a pilot- and demonstration permit for the injection of less than 0.1 million tons of CO_2 to the Greensand project. The expected storage capacity of the Greensand project is up to 1.5 million tons of CO_2 per year from 2025-2026 and up to 8 million tons of CO_2 per year from 2030. For the Bifrost project 2-3 million tons of CO_2 per year from 2029-2030 and 10-15 million tons of CO_2 per year from 2030-2032 is expected. Other projects are emerging onshore as well such as the Danish Norne project, which expects to store 2.3 million tons of CO_2 per year by 2026 and 18.7 million tons of CO_2

per year by 2030, as well as the Ruby project which anticipates injection from 2027 with an injection capacity of 1 million tons of CO_2 per year increasing to 5-10 million tons of CO_2 per year by 2030. Lastly, a smaller onshore project in Stenlille has been announced with the purpose of gaining knowledge about the Danish onshore possibilities.

Given Denmark's approach to develop CCS on market-based terms, the above is not an extensive list of projects, but an overview of some of the known project developments. More projects who are in line with the general CCS framework in Denmark might emerge. The Bifrost and Danish Norne projects have recently applied for PCI status.

b) Flanders

The Flemish Region has established its long-term climate policies and additional measures in the Flemish Energy and Climate Plan (2021-2030) and the Flemish Climate Strategy 2050.

To achieve the necessary emission reductions, measures will be taken in several areas (energy efficiency, renewable energy etc.). The Flemish Region recognizes CO_2 capture and storage/usage (CCUS) as one of the promising avenues to reduce emissions. In this light, the Flemish Government has issued the CCUS Vision Note on the 26th of November 2021. It outlines the priorities of the Flemish Government regarding CCUS.

In the industrial port clusters of Ghent and Antwerp, a significant amount of CO_2 is emitted by chemical, steel, and process industries. The application of CCS might play an important role in reducing CO_2 emissions from these energy intensive industries. Currently, there are several projects in various stages of development, such as Ghent Carbon Hub and the project Antwerp@C. Antwerp@C is a CCS project that aims to develop a CO_2 backbone in the port of Antwerp with the potential to cut CO_2-emissions in Antwerp in half by 2030. Part of this project is Kairos@C which has also received financial support from the EU Innovation Fund.

Given the lack of available local sites in Flanders, cross-border storage in the North-Sea basin is the most realistic storage option. In that respect, The Flemish Region is actively involved in the negotiation of bilateral agreements or arrangements under the London Protocol, which will enable the cross-border transport of CO_2 for geological storage. For the transport of CO_2 on the territory of the Flemish Region, we are working on an overhaul of legislation to enable and facilitate the transport of CO_2 and therefore the development of a CCS backbone.

c) France

In France, the national low-carbon strategy ("SNBC") adopted in April 21st 2020 provides that, in order to achieve climate neutrality in 2050, the energy system should be entirely decarbonised, with the exception of international transport. For industries, CCS technologies are considered as a decarbonisation lever for the so-called "hard-to-abate" emissions of the main industrial sites with access to major storage areas. The use of bioenergy with CO_2 capture and storage can increase carbon sinks.
Achieving climate neutrality in 2050 is based on a level of 15 million tons of CO_2 per year of captured and stored CO2 emissions <u>(including industrial CCS and BECCS), that adds to the natural sink from the forest and land sector that is estimated to </u>65 million tons of CO_2 per year.

In the context of the ambition raised by the EU “Fit for 55” package, the SNBC is currently revised and its latest version should be published in 2024. It should provide for the use of CCS before 2030 and in greater quantities than the current SNBC in view of the acceleration of industrial projects in France. In France between 5 and 10 million tons of CO_2 per year could be captured for geological storage by 2030. By 2050, the level of captured emissions could be higher than in the current version, due to the realisation of industrial strategies.

Two French CO_2 capture projects, near Dunkirk, have already been selected by the European Innovation Fund. These two projects plan to capture 1.2 million tons of CO_2 per year by 2027.

In addition, a major plan to finance decarbonisation was launched by the government in 2021 under the name "France 2030", with a budget of 5.6 billion of euros. Most of this budget will be dedicated to supporting the decarbonisation of industrial processes, in particular through CO_2 capture technologies.

Finally, on the 8th of November 2022, the President of the Republic asked the government to draw up a national strategy for the development of CCUS. Expected in June 2023, this strategy is currently under discussion and covers all aspects of the CO_2 chain: capture, transport, storage, use, acceptability, regulation, relations with other countries to provide France with a real climate and industrial roadmap for these technologies.

d) Germany

The Federal Government published its second evaluation report on the national CCS Act (*Kohlendioxid-Speicherungsgesetz, KSpG*) at the end of 2022. The report contains a comparison of national and international studies which shows that the prospect of achieving greenhouse gas neutrality in Germany, Europe and globally only seems realistic if CCU/S is implemented in industry and in the waste sector at the very least. In accordance with these findings, the Federal Government made suggestions to parliament for changes to the national CCS Act to enable the swift and efficient planning, approval, and construction of the necessary transport/pipeline infrastructure. It also suggests ratifying the amendment to the London Protocol to allow the export of CO_2 for the purpose of offshore storage.

The Federal Government has furthermore announced the development of a carbon management strategy, which it will present in 2023. The strategy is intended to identify potential areas of application for CCU and CCS as well as to define the legal and economic framework conditions needed for a successful ramp-up, including the creation of the necessary infrastructure. The focus is on process emissions in industry which cannot be avoided or are difficult to avoid.

Germany only shares a small portion of the North Sea as coastal waters and Exclusive Economic Zone and will therefore depend on the development of an efficient CO_2 infrastructure network with its neighbouring countries if it decides to rely on CCS to reduce GHG emissions.

e) The Netherlands

The Dutch government views CCS as a necessary technology to reach its 2030 climate targets. In 2019 it was agreed within the Dutch Climate Agreement that CCS projects in industry can apply for subsidy under the existing SDE++ support scheme. A form of contracts for difference policy, the SDE++, adjusted in 2020 to include support for CCS projects, in addition to a range of renewable power and emission reduction measures. As of 2023, the SDE++ has been successful in granting subsidy support to four CCS projects, with an additional 10 CCS projects being considered for support in 2022.

The ROAD CCS project, a planned CO_2 capture project on a coal-fired power station in Rotterdam, was cancelled in 2017. However, some of the preparations from the ROAD project with regards to the transport and storage infrastructure, have been utilized for the Porthos CCS Project. Porthos is developing a project in which CO_2 from industry in the Port of Rotterdam is transported and stored beneath the North Sea. The CO_2 will be captured from four emitters and will be transported and stored in depleted gas fields located approximately 20 km off the coast. Two of the three empty gas fields, named P18-2 and P18-4, have received irrevocable CO_2 storage permits in line with the EU Directive on the geological storage of CO_2. The Porthos CCS Project is operated by EBN, Gasunie and the Port Authority of Rotterdam. The project is scheduled to commence operation in 2026, injecting 2.5 million tons of CO_2 per year for a period of 15 years, after which the initial storage sites will have reached capacity.

Another large scale, multi-user CO_2 transport and infrastructure based in the port of Rotterdam is also currently in feasibility phase. The Aramis project involves the development of a large 200 km CO_2 pipeline from Rotterdam towards the northern part of the Dutch continental shelf where considerable CO_2 storage capacity is available in depleted gas fields. The project will be developed based on 'open access' principles and is being designed as over-dimensioned to allow for further national and international growth in the demand for CO_2 storage. The initial phase of the Aramis project, involving the storage of 5 million tons of CO_2 per year, is planned to commence operation in 2027. Outside of Rotterdam there are additional smaller CO_2 capture plants operating or planned at waste-to-energy plants. There are also feasibility studies ongoing for CO_2 transport infrastructure in the northern region of the Netherlands.

f) Norway

Norway has two commercial full-scale CCS projects, Sleipner (1996) and Snøhvit (2006) , which are both part of petroleum producing projects on the Norwegian Continental Shelf. The Norwegian government is committed to further develop CCS as stand-alone projects, and has identified financial support for the development of CCS as one of the policy instruments for enhanced climate action in the ICTU for our updated Nationally Determined Contribution to the Paris Agreement. Norway has legally binding targets of reducing emissions by 55% in 2030 compared to 1990 levels and 90-95% (excluding removals by biogenic sinks) by 2050 compared to 1990.

The Norwegian petroleum directorate has developed a CO_2 storage atlas for the Norwegian Continental Shelf, which shows a significant potential for storage of CO_2 in saline aquifers. The atlas is based on existing seismic data produced by the petroleum industry in Norway.

At present, the central element for the Norwegian Government's CCS ambitions is the full-chain CCS project called Longship. The project integrates a complete chain of individual CO_2 providers, a flexible transport solution, and third-party storage on the Norwegian Continental Shelf. Two carbon capture facilities are currently being built in Norway: At Heidelberg Material's cement plant in Brevik, and at Hafslund Oslo Celsio's waste-to-energy plant in Oslo. These facilities will each have capacity to capture 0.4 million tons of CO_2 per year. The CO_2 storage operators build the site with excess capacity to enable storage of CO_2 from other European capture projects.

The construction of the Longship project is well underway, and the first capture and storage of CO_2 planned in the beginning of 2025. Phase one of the project will have a storage capacity of up to 1.5 million tons of CO_2 per year. The transport and storage part of the project, Northern Lights, have already signalled their ambitions for a second phase, with a minimum storage capacity of five million tons per year.

There is increasing interest in developing additional CO_2 storage on the Norwegian Continental Shelf. The Norwegian authorities awarded three new exploration licenses in 2022 and will continue to announce new licenses as the market develops.

Norway has ratified the 2009 amendment to the London Protocol, under the IMO, and has deposited a declaration of provisional application allowing for the export of CO_2 for permanent storage in sub-seabed geological formations.

g) United Kingdom

The UK's Net Zero Strategy emphasised the importance of decarbonising industry using renewable technologies such as CCUS. The UK is committed to progressing CCUS as part of its Net Zero Strategy, utilising industrial "clusters" to capture and store 20-30 million tons of CO_2 per year by 2030. Industrial CCUS clusters can be the starting point for a new carbon capture industry helping to create industrial 'SuperPlaces' in the UK. The UK has potential to store more than 78 billion tons of CO_2 in its continental shelf which is one of the largest potential storage capacities in Europe.

The UK's first Track-1 clusters were announced as HyNet and East Coast Cluster (Teesside and Humberside). Following the selection of Hynet and East Coast Cluster as Track 1 CCUS clusters in November 2021, the government identified the power CCUS, industrial carbon capture (ICC), waste and CCUS-enabled hydrogen projects to proceed to the due diligence stage of the Phase-2 Cluster Sequencing process (12 August 2022). The government will be looking to confirm the ambition level of Track-1, backed by a defined funding envelope at the earliest opportunity. Track-2 will establish carbon capture and storage in two additional clusters by the end of 2030.

The UK's first carbon storage licencing round attracted 26 bids from a total of 19 companies for the 13 CO_2 storage areas on offer. The round was launched on 14 June 2022 with applications closing on 13 September 2022, and the North Sea Transition Authority (NSTA) are now evaluating the bids with a view to awarding licences in 2023.

Legislation is currently progressing through Parliament and introduces primary legislation to bring forward business models for CCUS. These provisions will provide investors with the long-term revenue certainty they need to establish the CCUS industry across the UK and will play a key role in helping to deliver the Government's decarbonisation ambitions.

The UK is working to progress and overcome regulatory barriers to cross boundary CO_2 transport and storage as a key enabler for general international competitiveness. It is important that we work as partners in resolving these barriers to developing low-cost storage solutions for the benefit of everyone. The UK has ratified the 2009 amendment to the London Protocol, under the IMO, and deposited a declaration of provisional application allowing for the export of CO_2 for permanent storage in sub-seabed geological formations.

5. Delivering Trans-European CO_2 Infrastructure and Storage Facilities

On 23 June 2022, a revised TEN-E Regulation (2022/869) laying down new EU rules for cross-border energy infrastructure entered into force. The TEN-E Regulation (2022/869) identifies eleven priority corridors and three priority thematic areas for energy infrastructure to develop and interconnect. One of the thematic priorities is the development of cross-border carbon dioxide transport networks and carbon dioxide storage. This involves CO_2 crossing national borders.

Each member country in the NSBTF has or will develop plans and encourage investors to develop national CCS infrastructure. The NSBTF and this regional plan creates a national platform for transboundary collaboration and is intended to facilitate timely investment and optimised infrastructure and storage capacity to the benefit of involved countries.

6. Introduction to the NSBTF plan

The NSBTF expects that a network delivering CO_2 from multiple countries around the North Sea will build up in a stepwise manner, and that planning can lead to efficient and coordinated infrastructure expansion. This strategic regional plan sets the context for future projects of common interest (PCIs) and projects of mutual interest (PMIs). The plan itself is project-neutral and flexible.

This plan contains a brief introduction on the general CCS process chain (sources, transport, and sinks) and on elements of combined CCS process chains (clusters and hubs).

7. General Elements of a CCS/CO_2 process chain: CO_2 sources, transport facilities, sinks

CCS consists of three elements: source (capture) – transport – sink (storage). The term “sink” is synonymous with “store or storage site”.

a) CO_2 sources

Stationary sources of CO_2 streams include both power stations and/or heat production, industrial facilities, biogenic emitters and direct air capture. Large sources emitting tens to hundred million tons of CO_2 in their lifetime, can consider “single source-several storage sites” type infrastructure. For smaller sources, “several sources-single storage site” type infrastructures may be appropriate. A different network design and management would result from various sources of CO_2 (Figure 1). Clusters of sources connected by PCIs or PMIs may evolve into larger regional interconnected networks encompassing a variety of sources and sinks. There may be substantial benefits from the interconnection of such clusters from the outset.

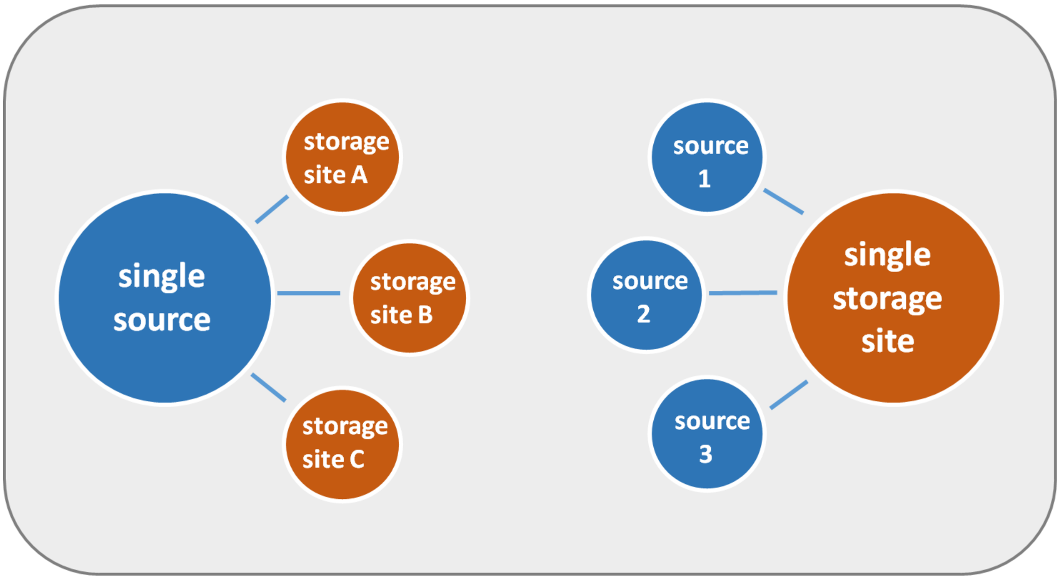


Figure 1: Schematic diagram illustrating CCS clusters involving a single source, e.g., large power plants in contrast to smaller industrial CO_2 sources. (Source: BGR).

b) Transport facilities

i. Pipelines

The main options for the transport of large volumes of liquids or gases in continental areas and shelf seas are pipelines. The existing (oil and gas) pipeline corridors could serve as additional CO_2 pipelines in the future. Suspended production pipelines from depleted hydrocarbon fields may also be repurposed for CO_2 transport.

ii. Ships, rail and trucks

Transport of liquid CO_2 in ships to storage sites is another option as onshore industrial areas are often linked to the sea by inland waterways of suitable width and depth. Larger ports can often provide intermodality between shipping and other means of transportation.

CO_2 can be transported by rail or trucks for more limited volumes of CO_2 (than for example pipelines). This mode of transport can also be combined with pipelines and ships. Trains and trucks can be available for CO_2 transport in a narrow time frame and much earlier as, for example, pipelines. Also, both transport modes may become necessary to connect more remote CO_2 sources (and sinks) to larger transport infrastructures (i.e. pipeline networks). These modes of transport are not eligible under the TEN-E regulation.

iii. Buffer storage

As ship, trucks and rail transport is intermittent, loading and unloading of CO_2 may require buffer storage, either in salt caverns or over the ground in tanks (liquid form).

c) Sinks

Geological features considered for storage infrastructure are hydrocarbon fields (i.e., depleted oilfields and depleted natural gas fields) and saline aquifers. Other niche options like coal seams or basalt are available, with limited local potential only and not considered for infrastructure development.

i. Depleted natural gas and oil fields in the North Sea Area

Natural oil and gas fields are frequent in the North Sea, and onshore in the Netherlands, and in Germany. As an initial assumption, the known gas production volumes are considered proportional to the CO_2 that could fill the pore space previously occupied by natural gas. As abandoned fields eventually must be closed, the time window when infrastructure is still available on fields that have gone out of production is limited. Re-opening of abandoned fields would be much more costly than shifting directly from natural gas production to CO_2 storage.

Offshore oil fields are frequent in the sub-surface reservoirs of the North Sea, and depleted oilfields offer another option for permanent storage of CO_2.

ii. Saline aquifers in the North Sea Area

Saline aquifers are the most wide-spread storage option in the North Sea area with the highest potential for CO_2 storage. The existence of formations may be known, and each new site require quantification by site-specific exploration (i.e., drilling, logging, and sampling of deep wells) and proper risk assessment prior to decisions about CO_2 storage development and licencing.

8. Existing and potential infrastructure in the North Sea region

A map of large emitters, ports, pipelines, and storage sites, compiled before the summer 2023, will serve as information base for developing CO_2 transport infrastructure. The map should include:

a) CO_2 Sources

b) CO_2 Transport

c) CO_2 Sinks

Geological features considered for storage infrastructure are hydrocarbon fields and saline aquifers. Despite the possible presence of sufficient onshore storage capacity to meet storage requirements from national CCS projects, trans-boundary offshore transport solutions are also necessary. The main reason is lack of public acceptance to onshore storage in countries, such as the Netherlands and Germany.

Figure 2 provides an overview of sedimentary basins in offshore areas across Europe being potentially suitable for storing CO_2. The largest basins are in Northern Europe. A considerable proportion of Europe's CO_2 emissions are adjacent to the basins in the North Sea and the Baltic Sea regions.

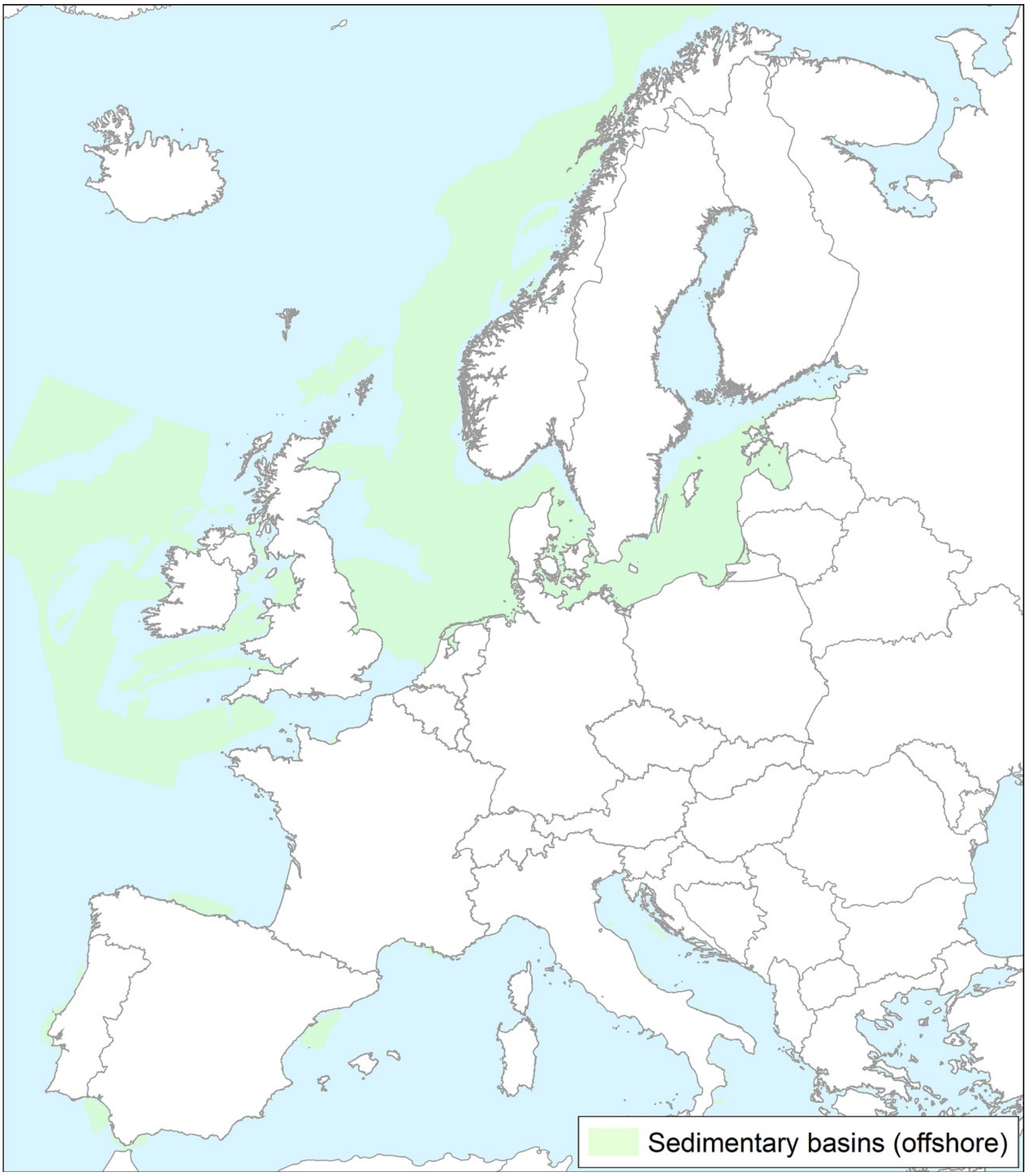


Figure 2: Sedimentary basins in offshore areas of Europe potentially suitable for CO_2 storage. Most basins are in Northern Europe. From a European infrastructure network point of view the North Sea and the Baltic Sea are of greatest interest. (Source of data: GeoCapacity, NORDICCS)

Table 1 shows currently available information on storage capacity in the various sectors of the North Sea area, from public sources. The numbers demonstrate that there is significant opportunity to permanently store future European CO_2 emissions in the North Sea area.

North Sea Sector	Information on storage capacity in the North Sea	Remarks	Source
British	Saline aquifers NonChalk Aquifers: 60 Gt Chalk Aquifers: 8 Gt	P50 values of estimated capacity range	Bentham et al. (2014)
	Hydrocarbon fields: 8 Gt	P50 values of estimated capacity range	Bentham et al. (2014)
	Saline aquifers and hydrocarbon fields: Central North Sea: 40 Gt Southern North Sea: 15 Gt Northern North Sea: 14 Gt East Irish Sea: 6 Gt Storage units with less than 20 Mt of storage capacity are not included in these figures	P50 values of estimated capacity range	Bentham et al. (2014)
Danish	Saline aquifers: 12 Gt (14 selected targets on-/nearshore), at least additional 10 Gt estimated for identified structures, open aquifers and volcanoclastic deposits	Unrisked mean values of estimated capacity range on selected structures. Full potential evaluation ongoing	Hjelm et al. (2022) + ongoing evaluation
	Hydrocarbon fields: 0.9-1.3 Gt (only chalk fields) 0.15-0.5 Gt (Siri Canyon complex)	Mean Value of estimated capacity range	Hjelm et al. (2022)
Dutch	Aquifer structures: 0.225 Gt (database estimate)	Selection of 53 'aquifer injection points' in GIS map	GeoCapacity GIS (2008)
	Storage capacity offshore gas fields: 2.25 Gt (theoretical storage capacity of 222 fields), Storage capacity onshore gas fields: 1.39 Gt (theoretical storage capacity of 172 fields)	Practical storage capacity is estimated to be 75% of theoretical storage capacity for offshore fields, and 76% of theoretical storage capacity for onshore fields.	EBN (2018)
German	Aquifer structures: 2.9 Gt (conservative estimate), 6.3 Gt (database estimate)	P50 values of estimated capacity range	Vangkilde-Pedersen et al. (2009a)
	Hydrocarbon fields: Mittelplate: 43-48 Mt A6/B4: 25 Mt	Estimation based on predicted ultimate oil recovery	DEA (2016) Reichetseder & Reinicke (2018)

Norwegian	Aquifers: 45.35 Gt	Sum of 11 evaluated aquifers	Norwegian Petroleum Directorate (2011)
	Hydrocarbon fields: Abandoned fields: 3 Gt, Close of production within 2030: 4 Gt, Close of production within 2050: 6 Gt, Sognefjord delta including Troll field: 14 Gt		Norwegian Petroleum Directorate (2011)

Table 1: Estimations of available storage (offshore and onshore) capacity of NSBTF member countries (France and Flanders do not have estimates for storage capacity in the North Sea area).

9. Combining elements of the process chain: Clusters and Hubs

The terms "clusters" and "hubs" are used in many ways in the literature. Therefore, a distinction appears appropriate for the promotion of a collective understanding of various components of a CCS infrastructure, schematically illustrated in Figure 4.

a) Cluster of sources

Clusters of CO_2 sources often occur in industrial areas. Pipelines can be used for connecting the sources to the collecting hub. CO_2 sources depending on the availability of local resources, such as lignite or limestone, which may be located in-land, may be distinguished from industrial sites having easy access to bulk goods supply from global markets, close to major ports. Sources need not always be clustered: some single sources produce such large amounts of CO_2 that they can supply a CO_2 transport infrastructure alone or serve as a collecting hub for other nearby sources of CO_2.

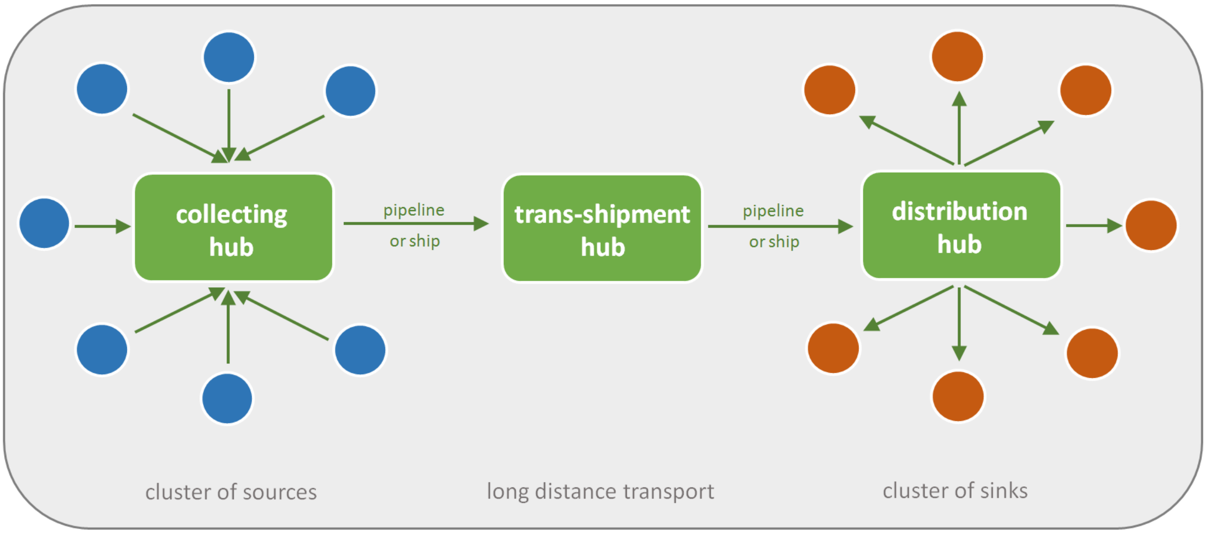


Figure 3: Schematic illustration of a CCS infrastructure. (Source: BGR).

b) Collecting hubs

The hubs collecting CO_2 from a variety of sources could comprise manifolds, measuring and monitoring stations, compressors, coolers, heat exchangers, ports for pipeline inspection and maintenance (pigging). Depending on the requirements of the subsequent transport, installations for gas conditioning, e.g., drying or liquefaction of CO_2 might be part of the collecting hub.

c) Trans-shipment hubs

Trans-shipment hubs are typically needed when the mode of transport changes from pipeline to ship or vice versa. Also, nodes of out-going (CO_2) and in-coming (hydrogen and hydrocarbons) pipelines could be trans-shipment hubs, usually located close to the seashore. The combination of continuous pipeline transport and discontinuous ship transport would require buffer storage. Cooling of the gas stream and pumps for CO_2 of high density and low compressibility ("liquid") needed for vessel transport, and re-heating for unloading CO_2 from tanks into pipelines or injection wells.

d) Distribution hubs

Distribution hubs could simply consist of a manifold connecting pipelines for the distribution into the reservoirs of a cluster of stores to a larger pipeline delivering CO_2 from land. Ships unloading CO_2 offshore, require a more complex hub, which allows ships to moor and unload, while CO_2 is heated and injected.

e) Clusters of storage sites (sinks)

Clusters of storage sites could be saline aquifers and depleted oil and gas fields in the North Sea. Extended aquifers of high storage capacity may serve as a single sink for CO_2 supplied by a network fed by multiple sources. However, due to technical and economic reasons and risk management, large rates of CO_2 would probably be injected by an array drilled at one or more sites.

We should consider the future evolution of infrastructure while developing individual projects, to avoid over-investments and lock-ins, as the future expansion of transport infrastructure moves forward. We should also consider the CO_2 production lifetime and load cycles, especially seasonal variations, or longer downtimes for maintenance of facilities.

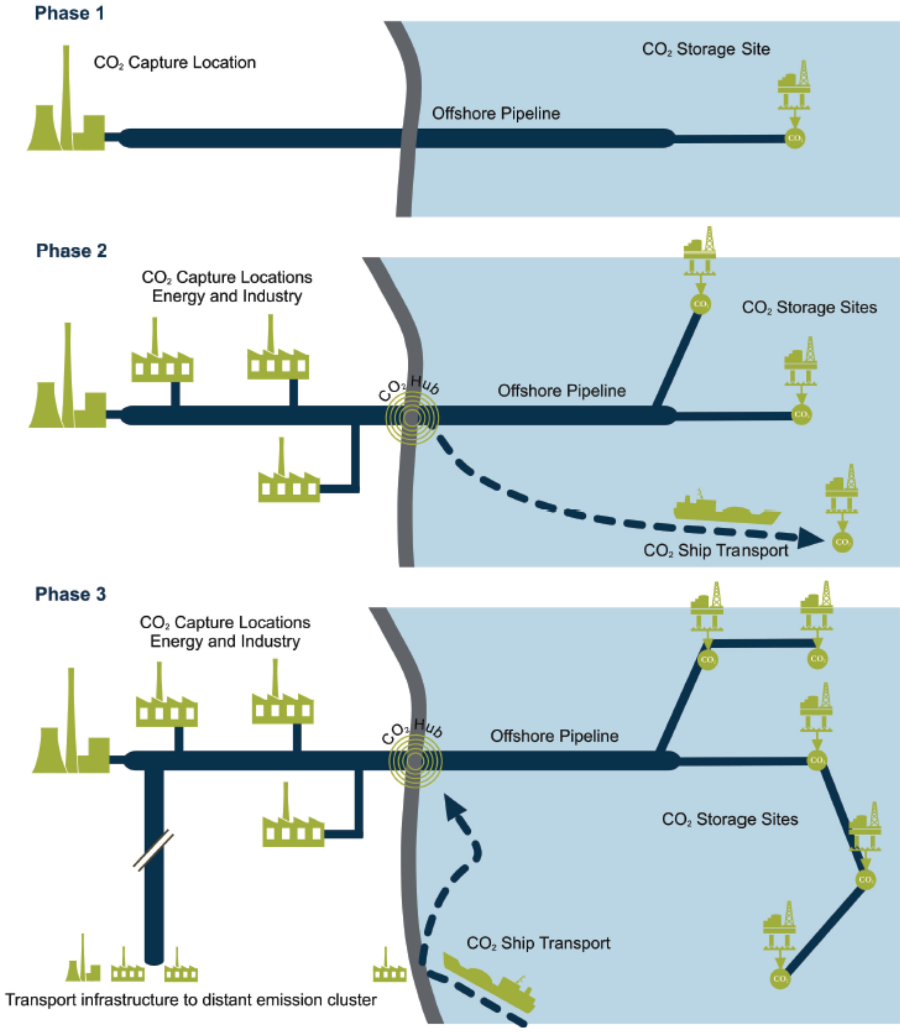


Figure 4: Schematic sketch of a stepwise CCS infrastructure development. (Source of figure: Bellona (2015), ZEP (2015)).

10. Infrastructure concepts for the North Sea Area

The members of the North Sea Basin Task Force agree that in the long-term a network of sources and sinks with connecting transport infrastructure in and around the North Sea area should be developed. This will happen in a stepwise manner, building on initial starting points based on promising source clusters and storage sites. The first commercial infrastructure projects may require public funding, for instance through selection of European Projects of Common Interest and access to funding from the Connecting Europe Facility.

The first infrastructure should be expandable; more local sources can connect to the first infrastructure; the pipeline and cluster/hub store upgraded; ship loading and unloading added, and more sinks connected to the first infrastructure as it expands.

Infrastructure concepts for the North Sea include maps that propose connections between CO_2 sources and storage sites. The term hub is defined in a consistent way. Most earlier studies include ship transport in their assessments, indicating that ship transport may become important in the development of a CCS infrastructure (at least in its early phase). For onshore storage other transport modes, such as rail can become increasingly important.

This plan does not attempt to set out the long-term development pathway of North Sea area CO_2 infrastructure in detail, but to point to sensible locations for initial infrastructure investment and how these might contribute to future development of a broader network.

a. Danish CCS Infrastructure concept

The annual long-term CO_2 capture potential from Danish point sources is estimated to be 5.4-10.8 million tons of CO_2 divided between industrial, waste incineration, power production and biogas plants. It is estimated that more than half of the long-term potential stems from biogenic sources. GEUS estimates the total storage capacity of a number of identified saline aquifer at 12 billion tons and at least additionally 10 billion tons are estimated for other identified structures, open aquifers and volcaniclastic deposits. The potential storage capacity of hydrocarbon fields is also considerable.

Options for storage are situated offshore, nearshore, and onshore. As of March 2023, three exploration permits have been given for offshore storage in the North-western part of the North Sea, two of which are located in depleted oil- and gas fields, and one concerning a saline aquifer.

Preliminary seismic investigations are ongoing at a number of onshore and nearshore geological formation and strategic environmental assessment for the sites are being undertaken. The completion of the activities and an evaluation of the results will likely result in a tender for further exploration applications end of 2023 or beginning of 2024.

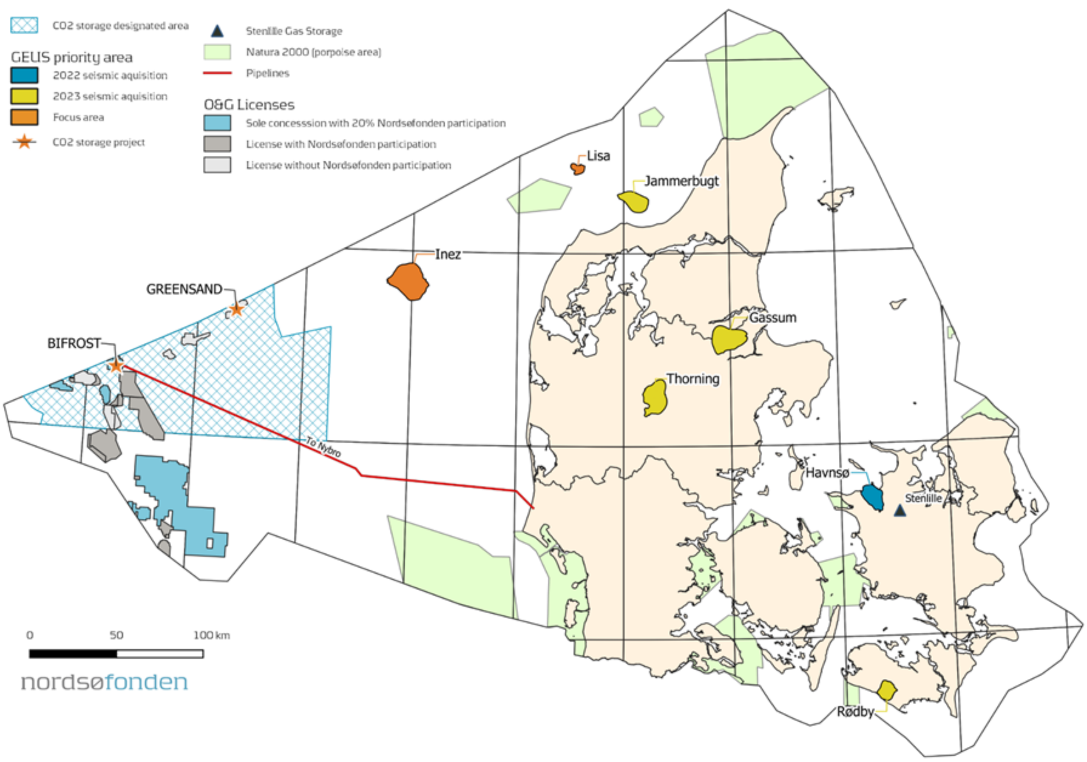
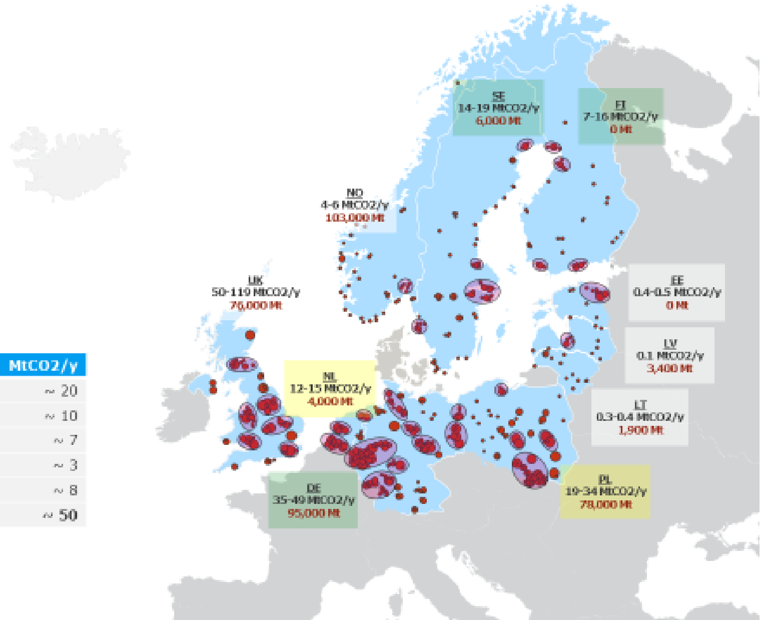


Figure 5: A selection of potential Danish CO_2 storage sites. (Source: Nordsøfonden, 2023)

A study from 2021 commissioned by the Danish Energy Agency estimates[i] the indicative CO_2 volumes relevant for storage in Denmark (including domestic CO_2 volumes) at up to ~50 million tons of CO_2 per year. According to the study, import of CO_2 for storage in Denmark is mainly relevant from

Germany, Sweden and Finland. However, lower and more uncertain potential for CO_2 import is also assessed from Poland and Netherlands.

Country	MtCO2/y
Germany	~ 20
Sweden + Finland	~ 10
Poland	~ 7
The Netherlands	~ 3
Denmark (domestic CO_2)	~ 8
Total	**~ 50**



<u>Figure 6:</u> Overview of Northern European CO_2 point sources which could be relevant for storage in Denmark. The delineation is based on closeness to Denmark. Point sources outside of these countries could also be relevant for storage in Denmark. (Source: Study commissioned by the Danish Energy Agency, 2021)

Available options for transport between sources of CO_2 and Danish storage facilities are pipelines, shuttle tankers, sea vessels, and other modes of transport. Based on the 2021 study of the potential Danish market for CO_2 storage an illustration of a possible set-up for a storage and transport network is given in the figure below. The figure is for illustrational purposes, and more storage sites and projects have been announced since then, for instance the Danish Norne and the Bifrost projects, which have recently applied for PCI status. They anticipate different combinations of transport modes to connect sources with storage facilities. These include national and transnational shipping, on- and off-loading facilities and pipelines. Other projects under development in Denmark expect similar set-ups.

Figure 7: Illustration of possible components for different options for set ups of transport and storage of CO2 in Denmark. (Source: Study commissioned by the Danish Energy Agency, 2021)

b. Possible CCS Infrastructure in France

France does not have any significant onshore storage project in its North part now and has less storage capacity than other North Sea countries. Large European cooperative projects between States, but also inter-regional and multi-actors' projects are therefore key for the storage of emissions captured. Also, the need for port infrastructures to export CO_2 to the North Sea area appears necessary in all scenarios, especially as French industrial emissions are highly concentrated in Le Havre and Dunkirk.

Indeed, according to the ADEME[2] 2020 report, out of a total of 51 million tons of CO2 that could theoretically be captured on the whole national territory, 21 million tons of CO_2 concern the Hauts-de-France and Normandy regions. The main export hubs will be Dunkirk and Le Havre (where gross industrial CO_2 emissions are currently 16.5 million tons of CO_2 eq/year for Dunkirk and 10.7 million tons of CO_2 eq/year for the Seine Valley), but other ports will also be able to collect regional emissions, such as Saint-Nazaire or Ambès/Bordeaux, for shipping to the North Sea area.

[2] ADEME = Agence de l'environnement et de la maîtrise de l'énergie (environment and energy management agency).

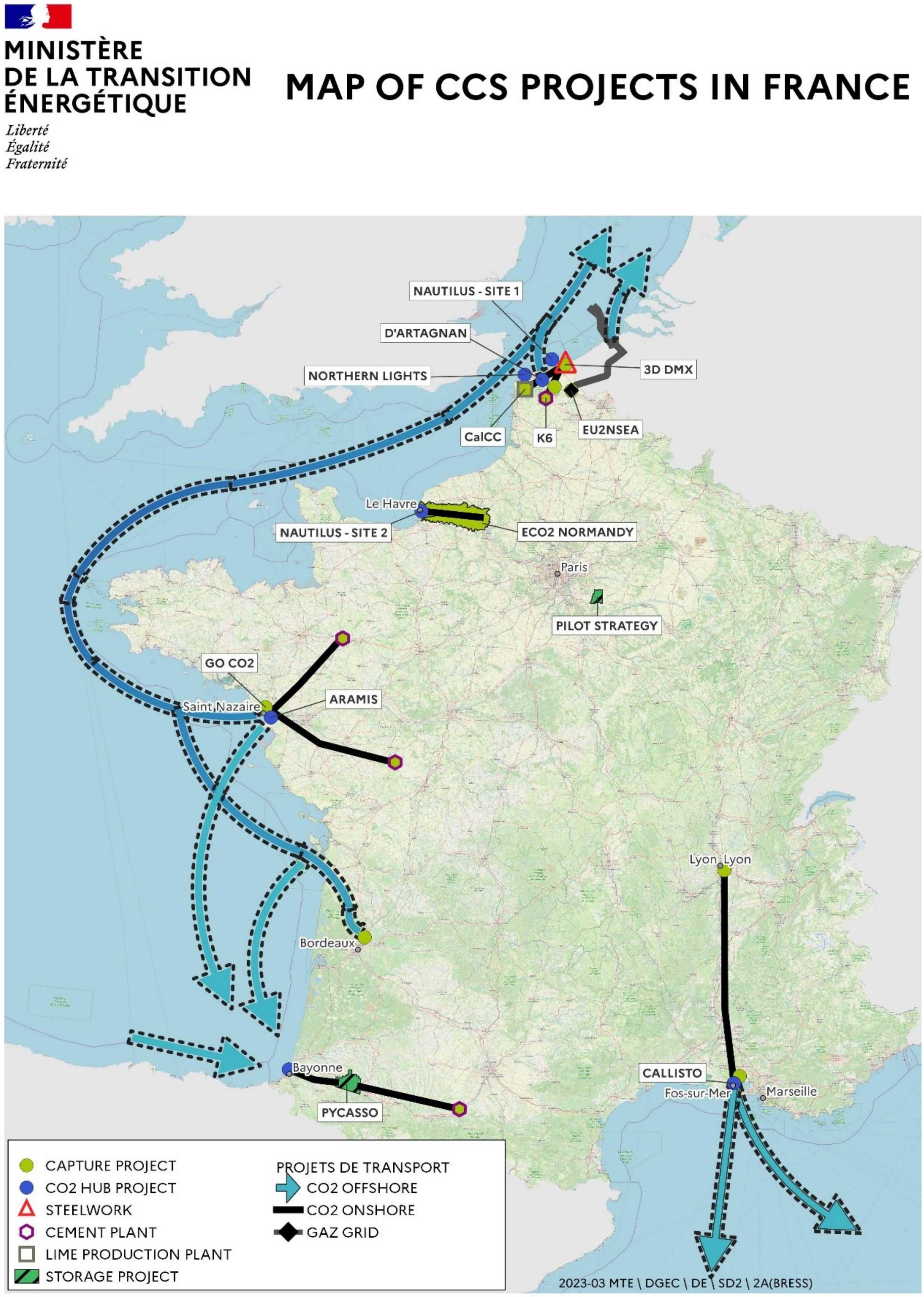


Figure 8: CCS projects in France (Source: Ministry of Energy Transition, 2023)

c. CO_2 Infrastructure developments and Plans in the Netherlands

Given the emission reduction potential, existing infrastructure connections, and access to the North Sea, the industrialised harbour of Rotterdam has been the focus of many CCS developments in recent years. The Porthos CCS Project, the Aramis CCS Project and the CO2Next liquid CO_2 terminal are planned for development in the harbour of Rotterdam. Although demand for CO_2 transport and storage is expected to emerge regionally, the open-access nature of these projects mean that they could potentially serve cross-border projects in neighbouring countries and beyond. As well as storing CO_2 on the Dutch continental shelf, the CO_2 handling facilities planned in Rotterdam can facilitate the collection and further transportation of CO_2 to other countries around the North Sea. A conceptual image of potential developments is presented below in Figure 9.

Figure 9: Planned and possible CO_2 transport and storage infrastructure in the Netherlands with links to neighbouring countries (courtesy of Energie Beheer Nederland)

Despite the majority of CCS developments emerging around Rotterdam, there is relatively limited CO_2 storage space immediately off the coast of Rotterdam. The majority of the CO_2 storage space in depleted hydrocarbon stores are located in the more northern segments of the Dutch continental shelf. Therefore the planned CO_2 pipeline as part of the Aramis project (delineated by the green line on Figure 9), has the potential to unlock a large potential of CO_2 storage capacity in the North Sea. The approximate locations of offshore gas fields for which practical CO_2 storage potential is assumed is provided in Figure 10. There is also expected to be CO_2 storage potential in offshore saline aquifers, however this will need to be investigated through exploration activities.

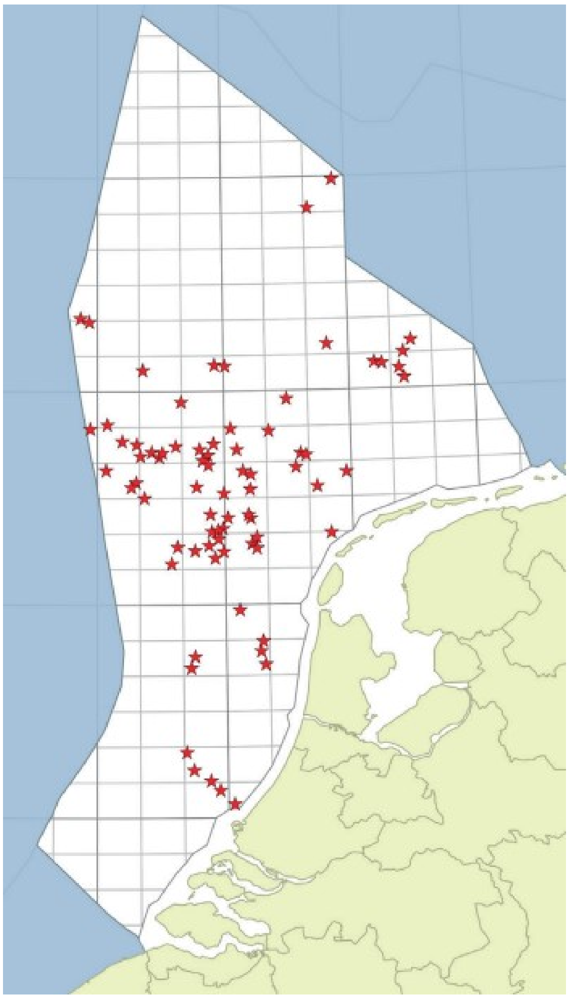


Figure 10: Approximate locations of gas fields for which practical storage capacity is present on the Dutch continental shelf (EBN, 2018)

Next to CO_2 transport and storage developments in Rotterdam region, there are also planned CO_2 transport and storage activities in the north of the Netherlands, specifically in the Eemshaven seaport. These initiatives could enable the decarbonisation of industrial and fossil-based power assets in this region, with the transport infrastructure potentially linking up to planned transport and storage infrastructure from the Rotterdam region, as depicted in Figure 11.

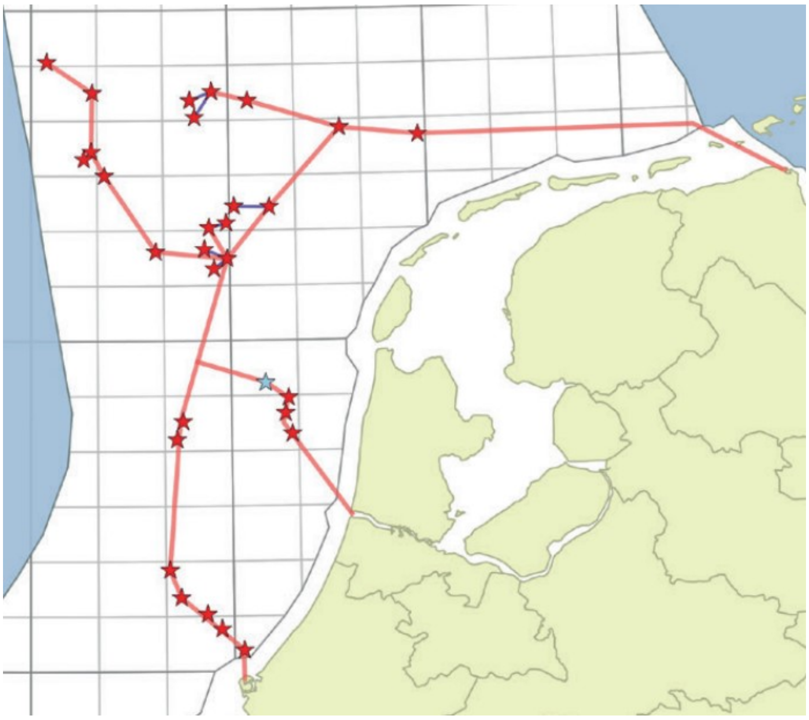


Figure 11. Possible infrastructure developments and interconnections between CCS initiatives in the northern and southern regions of the Netherlands (EBN, 2018).

d. Central North Sea concept

The Central North Sea is Europe's largest CO_2 storage resource and is both extremely well characterised and easily accessible due to extensive existing hydrocarbon extraction activity and infrastructures. The focus of the Central North Sea hub concept is on delivering CO_2 to offshore depleted oil and gas fields for storage or CO_2-EOR with subsequent expansion to large regional saline aquifer stores. CO_2 infrastructure development could enable CO_2 import from sources around the North Sea and inland continental Europe by pipeline and/or shipping.

e. Transport and storage sites in Norwegian North Sea

The Norwegian Longship project is a full-chain project which includes CO_2 capture, a flexible transport solution and an offshore storage facility. The Norwegian Government has also provided significant funding for the Longship project. The first phase of the project will be operational in 2026, with a storage capacity of 1.5 million tons of CO_2 per year. The Northern Lights project is the transport and storage part of the Longship project, and the construction is well underway. Northern Lights are working towards a second phase with a storage capacity of 5 million tons CO_2 per year.

There is commercial interest in developing additional CO_2 storage on the Norwegian Continental Shelf. The Ministry of Petroleum and Energy awarded three new exploration licences to different operators in 2022 and more exploration licences are set to be awarded during 2023.

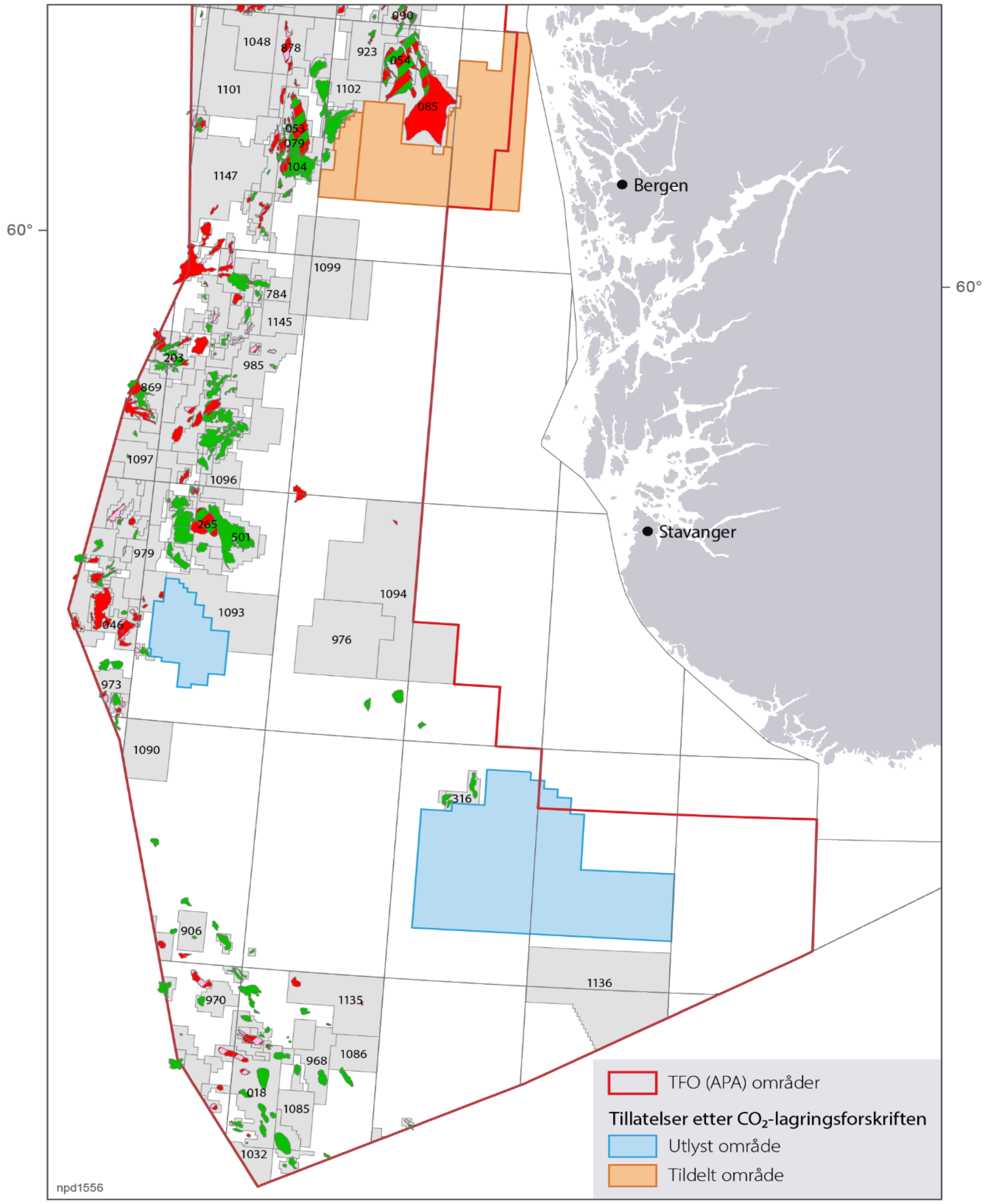


Figure 12: Permitting processes under the CO_2 storage regulation, Norway. (Source: The Norwegian Petroleum Directorate, 2023)

Figure 13: Possible combination of ship and pipeline transport of CO_2 to an offshore storage site. (Source: Haines (2015)).

11. Towards Projects of Common and Mutual Interest

From the examples shown above the NSBTF members conclude that they need to collaborate on CO_2 transport and storage infrastructure. CO_2 transport between the countries will be indispensable to match relevant emission sites with storage sites in the North Sea area. The procedure to develop Projects of Common or Mutual Interest are a suitable vehicle to realise the collaboration.

Although more commonly considered as infrastructure that physically connects two countries and crosses a border, PCIs can be located on the territory of one member and have a significant cross-border impact e.g., leading to enhanced capacity or removed bottlenecks for other country/countries.

A full chain CCS project involves a range of technical, regulatory, and commercial challenges. Schemes brought forward as PCI projects can help establish the necessary learning on how to address these additional challenges and obtain any necessary associated Government approvals. In turn, this can inform the structure of subsequent trans-boundary projects brought forward on a more commercial basis.

NSBTF members promote cross-border infrastructure and will work to facilitate projects related to this, with consideration of the prevalent political situation. NSBTF members will also move forward on the route of establishing PCIs and PMIs. Also, establishing and maintaining more detailed national transport and storage plans and storage atlases including cross-border aspects will be important.

12. Conclusion

The NSBTF Strategic Regional Plan may serve as the plan foreseen in the TEN-E Regulation for the PCI and PMI selection process. The listed concepts are examples of infrastructure and storage development proposals around the North Sea area. Planning, developing, and deploying CO_2 transport and storage infrastructure concerns the whole CCS chain, including relevant capture sites.

The NSBTF members recognise that the development of CO_2 transport and storage infrastructure in the North Sea area is of European common interest. NSBTF expects that a network delivering CO_2 from multiple countries around the North Sea area will develop in a stepwise manner, and that joint planning can lead to a more efficient and coordinated infrastructure expansion.

Annex 1: North Sea Basin Task Force Members

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Alex Blades, Department for Energy Security and Net Zero

[i] markedsanalyse_af_co2-lagring_i_danmark.pdf (ens.dk)