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**Working Paper**

## Cross-border cooperation on CO<sub>2</sub> transport and sequestration: The case of Germany and Norway

OIES Paper: ET, No. 15

**Provided in Cooperation with:**

The Oxford Institute for Energy Studies, Oxford

*Suggested Citation:* Dickel, Ralf; Fattouh, Bassam; Muslemani, Hasan (2022) : Cross-border cooperation on CO<sub>2</sub> transport and sequestration: The case of Germany and Norway, OIES Paper: ET, No. 15, ISBN 978-1-78467-204-1, The Oxford Institute for Energy Studies, Oxford

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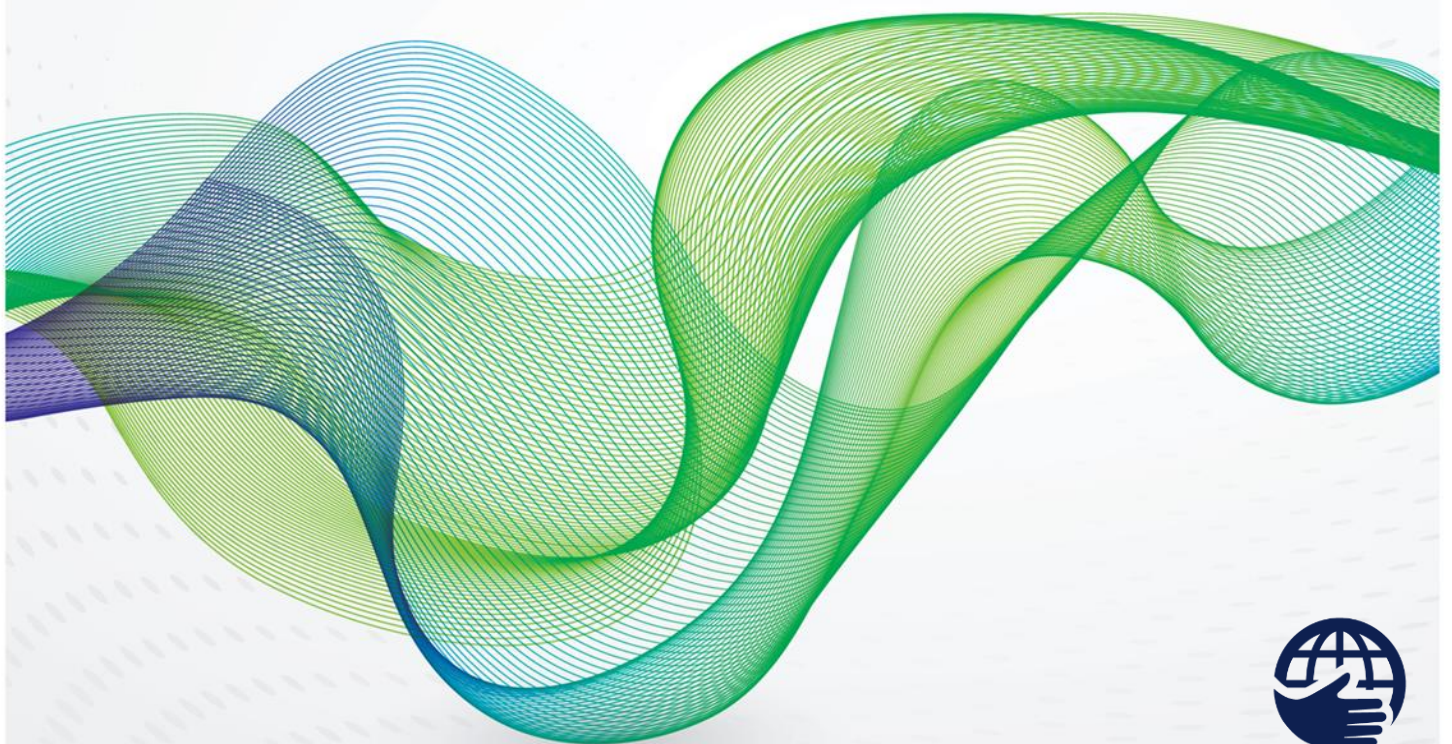
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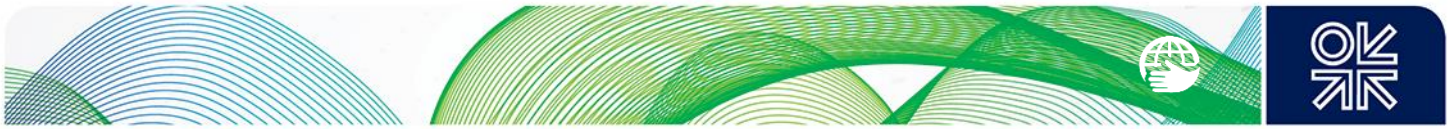
# **Cross-border cooperation on CO<sub>2</sub> transport and sequestration: The case of Germany and Norway**



Energy  
Transition

OIES Paper: ET15

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ISBN 978-1-78467-204-1



## Executive Summary

In its latest reports, the IPCC concludes that in order to remain within a global temperature increase of 1.5°C, it will be necessary to achieve ambitious energy efficiency measures and successful rolling out of renewables, but also to sequester substantial amounts of CO<sub>2</sub> in geological formations. However, many countries either only have limited geological capacity to dispose of their CO<sub>2</sub> or no suitable structures at all, while others have a potential exceeding their own immediate sequestration needs. As an example, Norway has a CO<sub>2</sub> sequestration potential which could cover large parts of the needs of the EU. On the other hand, Germany, despite its notable success and ambitious policies which support renewables deployment, will need to sequester significant CO<sub>2</sub> volumes in the order of 200-300 million tonnes of CO<sub>2</sub>/annum to meet its 2045 net-zero target. This paper provides an overview of the status of CO<sub>2</sub> sequestration as a climate solution, and the technical, economic and political obstacles which have to be overcome for CO<sub>2</sub> sequestration to work across borders, with focus on Germany-Norway as a case study.

Section 1 provides an overview of the global state of play regarding existing and planned CO<sub>2</sub> sequestration projects and the status of CO<sub>2</sub> capture and transport technologies, as well as the economics of the whole chain – from capture to sequestration. Legal issues regarding cross-border CO<sub>2</sub> transport prove to be a critical obstacle to be overcome.

Section 2 shows complementarities and potential mutual benefits between Norway and Germany and discusses if/how both countries could develop their respective contributions in time: Norway in developing an infrastructure to sequester substantial CO<sub>2</sub> volumes and Germany in rolling out of various capture technologies and building a necessary CO<sub>2</sub> collection infrastructure.

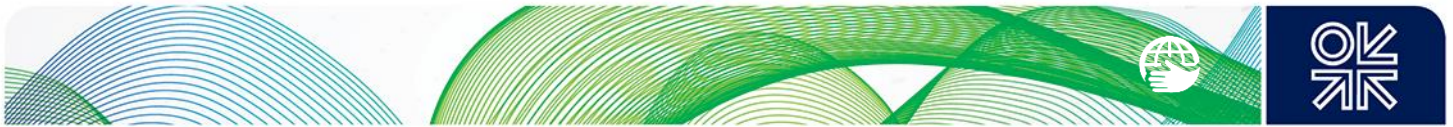
Section 3 describes the past and ongoing pioneering role that Norway has played in the CO<sub>2</sub> sequestration space. This includes technological progress and achievements, establishing an enabling licensing regime for CO<sub>2</sub> sequestration along the Norwegian Shelf and enacting a framework for research and development of pilot projects on CO<sub>2</sub> capture in cooperation with industrial players. This section highlights that while there is an increasing interest in CO<sub>2</sub> sequestration projects of up to 5 million tCO<sub>2</sub> per annum (tCO<sub>2</sub>/a), handling much larger volumes of several hundred millions tCO<sub>2</sub>/a still needs a conceptual discussion.

Section 4 focuses on the status quo in Germany. CO<sub>2</sub> sequestration in Germany itself is blocked by law, however its transport including for export purposes is not. In fact, capture and transportation technologies are available at commercial scale but have only been applied where economically viable. Rollout at a large scale needs reliable carbon pricing to render the whole chain financially feasible. Other major enablers in Germany are (i) gaining social acceptance and convincing the public that Germany needs substantial CO<sub>2</sub> sequestration to achieve its ambitious climate goals and that sequestration in Norway is handled without any leakage or hazards and (ii) creating a comprehensive and realistic plan for CO<sub>2</sub> export.

Section 5 addresses the key elements for cooperation between Norway and Germany and potential hurdles. This includes coordination of the CO<sub>2</sub> chain from its capture in Germany to sequestration in Norway, its economics as well as potential business structures and regulatory approaches. One crucial obstacle is Article 6 of the London protocol which prohibits CO<sub>2</sub> crossing borders for sequestration under the North Sea. A recent agreement between Norway and the Netherlands shows how this can be resolved, where Germany could conclude a similar agreement. Moreover, given the size of the infrastructure needed, Germany and Norway should implement procedures and install relevant institutions to cooperate on sequestration. The suggested steps and their sequencing are discussed in detail.

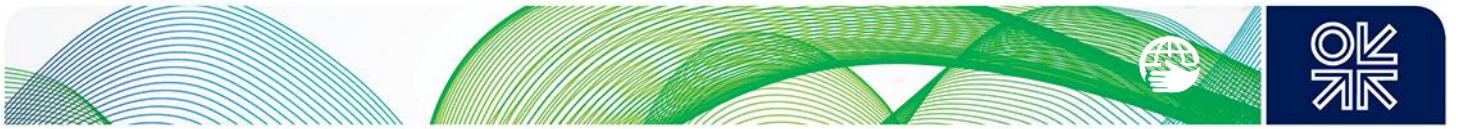
The paper concludes on an optimistic note: in the past both countries cooperated successfully on developing gas production in Norway and the infrastructure needed to develop a corresponding market in Germany and the EU, and more recently the Nordlink cable between Germany and Norway was also successfully launched. While ambitious, building the needed infrastructure to sequester CO<sub>2</sub> from Germany in Norway would be a very positive development and, as reflected in this paper, is very much achievable, considering previous successful cooperation on developing projects of similar magnitudes.





## Contents

<b>Executive Summary .....</b>	<b>ii</b>
<b>Figures .....</b>	<b>iv</b>
<b>Tables .....</b>	<b>iv</b>
<b>1. Introduction .....</b>	<b>1</b>
<b>2. Cross-border CO<sub>2</sub> transport: The case of Norway and Germany .....</b>	<b>3</b>
2.1 Can the Norwegian sequestration potential be developed in time? .....	3
2.2 Can Germany's CO <sub>2</sub> capture potential be developed in time? .....	4
<b>3. Status quo of CCS in Norway .....</b>	<b>4</b>
3.1. EOR by natural gas rather than CO <sub>2</sub> .....	5
3.2. Disposal of CO <sub>2</sub> from gas fields with high CO <sub>2</sub> content .....	5
3.3. Early investigation of CO <sub>2</sub> sequestration potential on the Norwegian shelf .....	6
3.4. Standards, legislation, and licensing .....	6
3.5. Licensing rounds .....	8
3.6. The players .....	10
3.7. Volume build-up .....	11
3.8. Economics, taxation, and handling of liability for eternity costs .....	12
<b>4. The German need for CO<sub>2</sub> export .....</b>	<b>13</b>
4.1. The need for a CO <sub>2</sub> collection system/aggregator .....	13
4.2. CO <sub>2</sub> registration, metering and certification .....	14
4.3. Status of CCS technologies in Germany .....	14
4.4 Future outlook .....	15
4.5. Germany's interface with Norway .....	16
4.6. Need for a concept for CO <sub>2</sub> handling in Germany .....	17
<b>5. Cooperation between Germany and Norway .....</b>	<b>17</b>
5.1. The CO <sub>2</sub> chain .....	18
5.2 Economics .....	19
5.3 Aspects for governments .....	19
5.4 Financing .....	19
5.5 A business model .....	20
5.6 Companies involved .....	21
5.7 Bilateral tasks between Germany and Norway .....	21
<b>6. Conclusions .....</b>	<b>22</b>
<b>Appendix: Transport Infrastructure .....</b>	<b>24</b>
CO <sub>2</sub> transportation by ships .....	24
CO <sub>2</sub> transport by pipeline .....	24
Generic rules and requirements .....	25
<b>Appendix: International Law on Cross Border Transfer of CO<sub>2</sub> .....</b>	<b>26</b>
The London Protocol (LP), Amendment, Guidelines and Guidance .....	26
Crossing third-party territory (here: crossing Denmark between the German and the Norwegian sectors) .....	27
OSPAR .....	28
EU directive and rules .....	28
Subtraction under the EU-ETS .....	28
EU delegated taxonomy regulations .....	29
EU CCS Directive .....	29
Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal .....	30

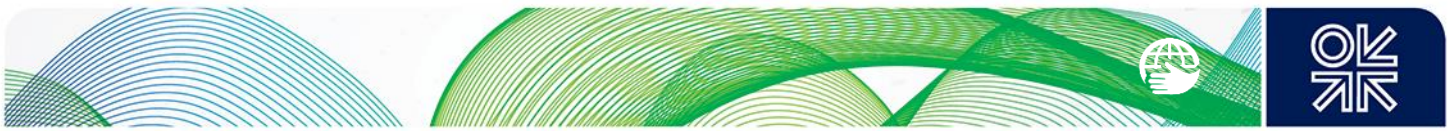


## Figures

Figure 1: Northern Lights concept building blocks. ....	8
Figure 2: CO <sub>2</sub> from potential transport and storage customers in tonnes per year. ....	12
Figure 3: CO <sub>2</sub> capture and storage value chain. ....	18

## Tables

Table 1: List of sequestration sites in Norway. ....	7
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## 1. Introduction

While improving energy efficiency and accelerating the rollout of renewable energies are key to decarbonizing economies, CO<sub>2</sub> sequestration has an essential role to play in the energy transition<sup>1</sup> and towards meeting the Paris Agreement (PA) targets<sup>2</sup>. That said, the extent of the role of CO<sub>2</sub> sequestration will vary depending on geographic and economic parameters. As such, it is necessary to understand the critical role of CO<sub>2</sub> sequestration as well as the roles of the different actors involved along its value chain.

The Global Status of CCS 2021 report<sup>3</sup> provides an overview of CO<sub>2</sub> sequestration projects currently in operation worldwide. Of the 29 operational projects, 23 are driven by enhanced oil recovery (EOR) (in North America), while 5 projects are driven by CO<sub>2</sub> sequestration objectives (e.g. through subsidy mechanisms or taxation). CO<sub>2</sub> sequestration in geological structures has been applied on a large scale in Sleipner (starting 1996) and Snøhvit (starting 2011) in Norway (see Section 3 for more details), in In Salah in Algeria (starting 2004) and since 2019, by Chevron in its Gorgon CCS project in Australia. In Alberta, Canada, the Shell-operated Quest project captures about one third of CO<sub>2</sub> emissions from steam reformers which produce hydrogen to upgrade the bitumen oil. In the first four cases, carbon sequestration is part of gas production projects and is triggered by the CO<sub>2</sub> content exceeding the specifications for delivered gas and a standard or a strong penalty to avoid venting CO<sub>2</sub>, while the Shell project is driven by the upgrading of bitumen oil where the CO<sub>2</sub> from the steam reformers is captured instead of being vented to the atmosphere.

A number of new projects have recently emerged globally, aiming at CO<sub>2</sub> capture from industrial processes and coupled with dedicated geological storage.<sup>4</sup> By 2030, the Global Status of CCS 2021 report shows that 58 projects will be in an advanced development stage and another 46 projects in early development. Of those, only 5 projects are driven by EOR, while 14 are under evaluation and the remainder (81) are for dedicated geological storage. Half of these projects are to be developed in the US, with the rest spread around the UK, Netherlands, Australia, Norway, Sweden, Denmark, UAE, Belgium, New Zealand, Indonesia, South Korea, Ireland, Canada and Malaysia. If anything, this evidences that CO<sub>2</sub> sequestration has become a component of GHG emissions reduction policy. The overall minimum capacity both for advanced and early development projects is about 45 million tCO<sub>2</sub>/a. Although this is notable progress, it still falls very short of what is needed to achieve climate targets.

CO<sub>2</sub> sequestration can be economically viable in special cases, for instance where the costs are covered by the sale of the additional oil extracted (in the case of EOR). However, outside such contexts, its application depends on the existence of a price on/cost savings due to CO<sub>2</sub> abatement which pays for the overall elements of the CCS chain. The price needed ranges between 15-25 \$/tCO<sub>2</sub> for capture from highly-concentrated CO<sub>2</sub> sources (e.g. natural gas processing) up to 40-120 \$/tCO<sub>2</sub> for less concentrated sources (e.g. power generation, steel and cement production)<sup>5</sup>. As such, a carbon price in the order of 100 €/tCO<sub>2</sub> would suffice in a large number of cases, where around 60-70% of the costs incurred are in the capture phase and the remainder covering transport and storage costs.<sup>6</sup> Therefore,

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<sup>1</sup> It is important to distinguish between two transitions which are frequently referred to: (i) reaching net zero targets as soon as possible (no later than 2050) within the CO<sub>2</sub> budget or with some overshoot beyond the budget with later removal through DAC, and (ii) a transition towards an all-renewable energy supply which may last until the end of the century. Here we refer to the former.

<sup>2</sup> "Carbon capture and storage (including DACCS and BECCS) is central to IPCC mitigation pathways" quoted from <https://www.catf.us/2022/04/what-does-latest-ipcc-report-say-about-carbon-capture/> on the WG III contribution to the 6<sup>th</sup> Assessment Report.

<sup>3</sup> Global CCS Institute (2021). Available at: <https://www.globalccsinstitute.com/wp-content/uploads/2021/11/Global-Status-of-CCS-2021-Global-CCS-Institute-1121.pdf>

<sup>4</sup> See page 16 and Appendix to Global status of CCS 2021.

<sup>5</sup> IEA (2021). Is carbon capture too expensive? Available at: <https://www.iea.org/commentaries/is-carbon-capture-too-expensive>

<sup>6</sup> IPCC (2018). Special Report on Carbon Dioxide Capture and Storage. Chapter 8: Cost and economic potential. Available at: [https://www.ipcc.ch/site/assets/uploads/2018/03/srccs\\_chapter8-1.pdf](https://www.ipcc.ch/site/assets/uploads/2018/03/srccs_chapter8-1.pdf)



the economics of EOR are directly correlated to whether a carbon price or a financial support mechanism exists.

In the US, the large number of projects for CO<sub>2</sub> sequestration have been supported by new tax incentives under Section 45Q of the Internal Revenue Code which provided a tax credit of 50 \$/tCO<sub>2</sub> for CO<sub>2</sub> sequestration.<sup>7</sup> Section 45Q was further enhanced by bipartisan legislation in 2018 and its application clarified in 2021. The Inflation Reduction Act signed in August by President Biden provides further support increasing the Section 45Q base tax credit by industrial facilities and power plants to 85 \$/tCO<sub>2</sub> for CO<sub>2</sub> stored in geologic formations, 60 \$/tCO<sub>2</sub> for the beneficial utilization of captured carbon emissions, and 60 \$/tCO<sub>2</sub> stored in oil and gas fields. It is also worth noting that present carbon credit prices within the EU emissions trading scheme (EU-ETS) are approaching the level needed, where it is currently set at around 96 €/tCO<sub>2</sub> (as of August 18<sup>th</sup>, 2022), with forward prices for 2025 of over 90 €/tCO<sub>2</sub>.

In addition to carbon pricing/support mechanisms, for geological CO<sub>2</sub> sequestration, a licensing system akin to that specific to hydrocarbons must be devised. Specific rules need to address the certification of CO<sub>2</sub> handling, from the CO<sub>2</sub> capture phase (how much is captured vs how much is still released to the atmosphere), to transport (pipeline or shipping), and sequestration (monitoring of CO<sub>2</sub> injected). The issues pertaining to these different phases could occur within one jurisdiction or across borders.

When CO<sub>2</sub> is sequestered within the same jurisdiction where it is captured there may still be some legal and regulatory obstacles, in particular a lack of or unclarity to the rules for transport and handling of CO<sub>2</sub>, or a lack of or unclarity of technical standards, and procedures for pipeline building and safety, amongst others. Lacking or unclear economic regulations can also block projects, even without principal legal obstacles.<sup>8</sup> The detailed requirements of CO<sub>2</sub> transport and sequestration – while tested on a commercial basis in specific cases – are yet to be defined for rollout on a large scale, even in the US. Moreover, within one jurisdiction any rent or costs stay within the one country, so the exact split may only have limited effects for the national economy.

If two different jurisdictions are involved in the CCS chain, CO<sub>2</sub> handling needs to be harmonized across borders and interface issues should be resolved (e.g. technical and operational standards, certification, transfer of ownership and risk, etc.). Similar to the imbalance which exists between the demand for fossil fuels between importing and exporting countries, suitable geological formations for CO<sub>2</sub> storage may not exist in the highest-emitting countries, which calls for a need to export CO<sub>2</sub> to countries with more suitable storage sites.

It may also be in the interest of fossil fuel exporting countries to help their customers to dispose of CO<sub>2</sub> stemming from imported hydrocarbons, as importing countries may have no other option due to the lack of sequestration potential (e.g. Japan). This will involve exporting and importing of CO<sub>2</sub> across borders, relying on offshore transport by ships or via pipelines in most cases. Thus far, such examples include the transport of CO<sub>2</sub> by a 320 km onshore pipeline from Beulah in North Dakota to the Weyburn project in Saskatchewan, and the upcoming Longship project which envisages cross-border transport of CO<sub>2</sub> via shipping from the UK and EU countries to Norway. All other projects so far have been within one jurisdiction. However, most recently (August 2022), Northern Lights signed a first-of-its-kind commercial agreement for cross-border CO<sub>2</sub> capture and transport, where, from 2025, CO<sub>2</sub> will be captured, compressed and liquified in the Netherlands, to be transported and stored in Norway.<sup>9</sup> It is expected that other similar ventures will be established, making the publication of this study all the more timely.

In what follows, this paper appraises a specific case study of cross-border CO<sub>2</sub> transport from Germany to Norway.

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<sup>7</sup> As opposed to 35 \$/tCO<sub>2</sub> for a tonne of CO<sub>2</sub> utilised for EOR.

<sup>8</sup> Please refer to the Appendix for a list and details on laws relevant to cross-border CO<sub>2</sub> transport and sequestration.

<sup>9</sup> Dragan (2022). Norway to launch Europe's first cross-border carbon transport and storage project. Available at: <https://www.autoevolution.com/news/norway-to-launch-europes-first-cross-border-carbon-transport-and-storage-project-197254.html>





## 2. Cross-border CO<sub>2</sub> transport: The case of Norway and Germany

There are many global decarbonisation policies underway which include CCS, including in the US, UK, Netherlands and Denmark, amongst others. However, these policies revolve around and address CCS implementation within one jurisdiction and may be part of an integrated climate and energy policy within the same country. This is mainly because these countries have the appropriate geology for large-scale sequestration of CO<sub>2</sub> emissions which cannot be avoided on the national level by energy efficiency measures and/or by relying on renewable resources.

In contrast, Norway and Germany represent interesting cross-border cases to study as Norway is the front-runner in CO<sub>2</sub> sequestration while Germany plays a pioneering role in developing renewables, with less reliance on CO<sub>2</sub> sequestration as a solution. Despite Germany's need to substantially reduce its unabated CO<sub>2</sub> emissions, its national policies place strong emphasis on promoting energy efficiency and renewables alone. Germany's rollout of renewables has been reasonably successful so far (to the extent that it can and has reduced power generation from fossil fuels), however the country cannot meet its net-zero target by 2045 nor achieve a reliable energy supply without including CO<sub>2</sub> sequestration.<sup>10</sup>

In this regard, Germany and Norway are in complementary positions regarding sourcing of CO<sub>2</sub> (in the order of 0.2-0.3 Gt CO<sub>2</sub>/annum) for sequestration outside of Germany. This will last until fossil fuels (with sequestration) can be fully replaced by renewables, depending on progress with electricity storage systems and conversion of electricity to molecular energy. While other North Sea states (UK, Denmark, Netherlands) have high potential for sequestration under their own territorial waters compared to their needs, France, Belgium and Poland, much like Germany, cannot sequester their CO<sub>2</sub> under their corresponding shelves.

As such, it is possible that CO<sub>2</sub> export into Norway could mirror the successful experience seen in the 1980s and 1990s in the development of gas resources, with Germany as the largest CH<sub>4</sub> importer. Norway has an interest to continue utilizing the resources of its shelf compatible with its commitments under the Paris Agreement. Beyond its hydrocarbon resources, the Norwegian shelf offers a substantial potential for CO<sub>2</sub> sequestration. Having rich hydro-resources, complemented with strong wind resources in the north and broad electrification of industry, households and transport, Norway would only need a fraction of its CO<sub>2</sub> sequestration potential for its own use. So far Norway has chosen a pioneering stepwise approach to CO<sub>2</sub> sequestration which, with engagement and support from the Government, aims to attract CCS projects to gain more experience and to broaden the number of industrial players. How to fully utilise the potential of Norway within the time restrictions of a 2050 net-zero target remains to be discussed.

For reference, the combustion of present Norwegian oil and gas production/export of around 4 million b/d oil equivalent results in around 400 million tCO<sub>2</sub>/a. Offering CO<sub>2</sub> sequestration in that amount (e.g. 70 years at 0.4 GtCO<sub>2</sub>/a = 28 Gt CO<sub>2</sub>) is well below the 70 Gt sequestration potential in the Norwegian North Sea.<sup>11</sup>

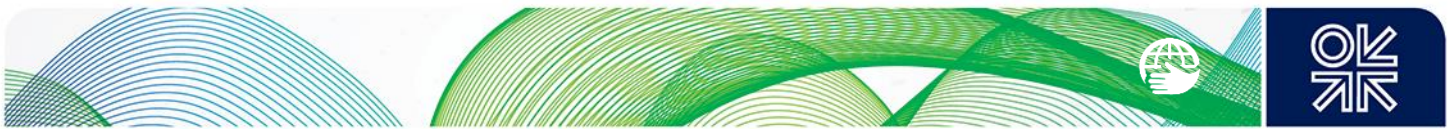
### 2.1 Can the Norwegian sequestration potential be developed in time?

These are significant figures and many doubt that this potential can be developed by 2045-2050. However, the skills and the industrial equipment needed for CO<sub>2</sub> sequestration are similar to those applied in hydrocarbon development. Injecting 1Gt CO<sub>2</sub>/a would require drilling of a total of 1000-3000 wells drilled. This compares with 4000 wells which have already been drilled on the Norwegian shelf

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<sup>10</sup> As shown in Dickel, R. (2022). Achieving net zero plus reliable energy supply in Germany by 2045: The essential role of CO<sub>2</sub> sequestration. Oxford Institute for Energy Studies. OIES Paper: ET13.

<sup>11</sup> As an illustration: If Norway were to make full use of its CO<sub>2</sub> sequestration potential by the end of the century, this potential may be used between 2030 and 2100 with 20 years build up and build down => 50 years plateau use. A plateau of 1 GtCO<sub>2</sub>/a would require a sequestration volume of 50 GT CO<sub>2</sub> (Potential is given by the NPD with 70 Gt CO<sub>2</sub> for the Norwegian North Sea plus 10 Gt CO<sub>2</sub> in the 2 areas north. Deducting 30 Gt as a margin leaves 50 GtCO<sub>2</sub> for full use of the CO<sub>2</sub> sequestration potential => plateau of 1 Gt CO<sub>2</sub>/a).



during the past 20 years. Wells are increasingly drilled from subsea formations which may be linked to central platforms or handling facilities onshore, and less so from fixed platforms.

For comparison, and related to pipeline infrastructure, new gas projects to the Continent were established in 1981 (Statpipe) and 1986 (Troll, with Europipe I and II, Zeepipe, Franpipe). These five pipelines have a total capacity of around 100 bcm CH<sub>4</sub>/a which, when combusted, produce around 200 million tCO<sub>2</sub>/a. The last pipeline (Europipe II) was completed in 1999 – during the same period 35 (oil and gas) fields were developed. This shows that infrastructure of dimensions similar to that for CO<sub>2</sub> sequestration can be built within two decades.

Assuming that Norway is willing to utilise its CO<sub>2</sub> sequestration potential to compensate for the CO<sub>2</sub> stemming from the combustion of its oil and gas, or that of other countries, then it should develop a concept for the transport (import) and sequestration of such large volumes which would amount to a hundredfold of the total volumes of present projects. This would necessitate creating economic mechanisms to compensate for future long-term risks incurred by offering its geological formation for CO<sub>2</sub> sequestration by others (e.g. by charging [inverse] royalty on CO<sub>2</sub> sequestration). This could be a percentage of the CO<sub>2</sub> emission price as a royalty or as an element for taxation.

## 2.2 Can Germany's CO<sub>2</sub> capture potential be developed in time?

Germany needs to sequester large volumes of CO<sub>2</sub> (circa 200-300 million tCO<sub>2</sub>/a) – outside the country under current legislation: this includes CO<sub>2</sub> from chemical, steel and cement production and from post-combustion decarbonisation in fossil power plants. While CCS is available at industrial scale, its rollout so far has not been economically viable due to the low CO<sub>2</sub> price, which is now approaching the level needed to pay for the whole chain of CO<sub>2</sub> abatement. For comparison with major changes in industrial infrastructure in the past in Germany, one can refer to (i) the desulfurization of coal/lignite fired power plants between the 1970s and late 1990s and (ii) the rollout of renewables (PV/wind) from 2000 to 2020:

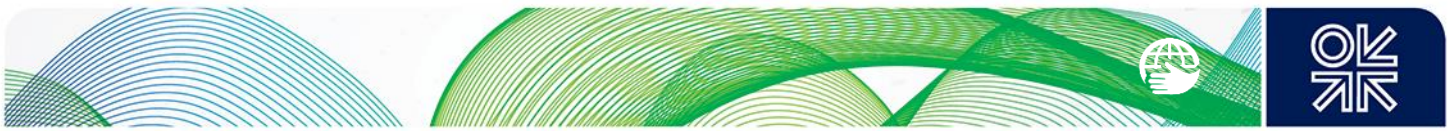
- Desulfurization of all new and existing coal and lignite power plants in Germany: Since 1974 new plants had to be desulfurized, and under the GFAVO issued in 1983 (German ordinance on desulfurization of large combustion plants) all existing plants had to also be retrofitted or shut down within 10 years. As a result, by 2000, some 20 GW of lignite (partially new build, especially in the East) and around 30 GW of hard coal were equipped with desulfurization. The marginal – price setting – power plants were either gas-fired plants or coal/lignite-fired plants equipped with desulfurization, so that it was possible to earn the prices needed to recoup the costs of desulfurization (with additional government support for the first desulfurization plants).
- Between 2000 and 2020, around 50 GW each of PV and onshore wind and 7.5 GW of offshore wind were built, supported by a surcharge on the power price which so far amount to around 250 billion € with further commitments for the future. At 100 €/tCO<sub>2</sub> for decarbonisation of the whole chain from capture to sequestration, 200 million tCO<sub>2</sub>/a would amount to extra costs of 20 billion €/a. In view of the successful rollout of renewables, CO<sub>2</sub> capture and transport to a transfer point to Norway by 2045 looks like a feasible change of industry structure.

An issue for competitiveness for German/EU energy consuming industry – vis-à-vis the US – is not so much that US industries do not decarbonize, but rather that decarbonising the US industry through CO<sub>2</sub> sequestration is paid for via tax credits, while the incentive for EU industry is avoiding carbon taxes.

## 3. Status quo of CCS in Norway

Norway is arguably Europe's leading country with experience and ambitions to sequester CO<sub>2</sub> at present, evidenced by the facts that:

- The country has long experience with capture and injection of CO<sub>2</sub> streams from gas production with high CO<sub>2</sub> content (Sleipner and Snøhvit) and is gaining additional experience on the handling of anthropogenic CO<sub>2</sub> from the ongoing Northern Lights/Longship projects;



- Legislation and rules for CO<sub>2</sub> transportation and sequestration on the Norwegian shelf are already in place (Regulation of 5 December 2014 no. 1517)<sup>12</sup>;
- The geology of the Norwegian shelf is well understood: in the last 20 years, around 4000 wells had been drilled on the Norwegian shelf; and
- The large potential for CO<sub>2</sub> sequestration was evaluated and published early on (i.e. in the CO<sub>2</sub> Atlas), estimated at 70 Gt for the North Sea part.<sup>13</sup>

Indeed, Norway has an interest to continue utilizing the natural resource of the Norwegian shelf and maintaining its geological and offshore industry-related skills by developing CO<sub>2</sub> sequestration on a large scale. This not only involves using existing hard infrastructure, but also soft infrastructure such as knowledge of geology, offshore technologies and related management skills. Developing a large-scale CO<sub>2</sub> import and injection infrastructure is certainly within the competence of the Norwegian offshore industry given its past performance in developing large-scale gas production and the related gas pipeline infrastructure in the 1980s and 1990s (e.g. Statpipe, Zeepipe, Europipe 1 and 2 and Franpipe to the Continent and Langeled and Vesterled to UK).

### 3.1. EOR by natural gas rather than CO<sub>2</sub>

Lacking natural CO<sub>2</sub> resources, pressure maintenance in oil and gas condensate fields on the Norwegian shelf is handled by injection of natural gas – around 35 bcm CH<sub>4</sub>/a.<sup>14</sup> The North Sea is an oil province in decline, and many fields stand to benefit from EOR. The CO<sub>2</sub> Atlas of the Norwegian Petroleum Directorate (NPD) discusses in detail, in its Chapter 8, the potential for CO<sub>2</sub>-EOR, referring to a former study by the NPD on the Norwegian shelf which was updated in 2012 and which “shows an increased oil recovery of more than 370 Mt from 19 fields in the North Sea with an injection of 80 Mt/a CO<sub>2</sub>”. This compares with 55 million tCO<sub>2</sub>/a emitted by the German steel industry in 2017.<sup>15,16</sup> A major concern here, however, is if a CO<sub>2</sub>/water mixture can break through to the production wells and reach production facilities as this may cause corrosion in well and process equipment if not protected. Technological solutions must be improved before this can be a viable method for EOR. For the time being, EOR using CO<sub>2</sub> seems to not be a priority in Norway.

### 3.2. Disposal of CO<sub>2</sub> from gas fields with high CO<sub>2</sub> content

Norway now has longstanding experience with CO<sub>2</sub> injection from Sleipner in the North Sea part of the Norwegian shelf and from Snøhvit<sup>17</sup> in the North.<sup>18</sup> Substantial differences exist between the structures regarding depth, temperature, reservoir rock, etc.<sup>19</sup> While CO<sub>2</sub> injection requires tailor-made approaches, it is well understood and can be closely monitored.

#### *Sleipner*

Disposal of CO<sub>2</sub> from the Sleipner West field (which has an in-situ CO<sub>2</sub> content of around 10% compared to a transport specification of about 2.5%) was organized by separating the CO<sub>2</sub> by amine scrubbing

<sup>12</sup> See [https://lovdata.no/dokument/SF/forskrift/2014-12-05-1517#KAPITTEL\\_9](https://lovdata.no/dokument/SF/forskrift/2014-12-05-1517#KAPITTEL_9).

<sup>13</sup> Norwegian Petroleum Directorate (2019). CO<sub>2</sub> storage Atlas Norwegian North Sea.

<sup>14</sup> See page 345 of the H21 North of England (2018) (H21 NoE) Report (2018). Available at: <https://www.h21.green/wp-content/uploads/2019/01/H21-NoE-PRINT-PDF-FINAL-1.pdf>

<sup>15</sup> Umwelt Bundesamt (2019): “Top 10 emissions of air pollutants from pig iron and steel production in 2017”, 17 June 2019 (in German) [https://www.umweltbundesamt.de/sites/default/files/medien/384/bilder/dateien/5\\_tab\\_top10-luftschadstoffe-roheisen-stahlerzeug\\_2019-06-17.pdf](https://www.umweltbundesamt.de/sites/default/files/medien/384/bilder/dateien/5_tab_top10-luftschadstoffe-roheisen-stahlerzeug_2019-06-17.pdf)

<sup>16</sup> Taken from OIES NG 159

<sup>17</sup> <https://reader.elsevier.com/reader/sd/pii/S187661021300492X?token=2B4980EFC2B7F313BFEEB3C0B042EC144D5119CECBF369CE677AD29FD5983A61303F431DF0C9DD30A674CCB3E8306A06&originRegion=eu-west-1&originCreation=20220519185521>

<sup>18</sup> <https://www.equinor.com/news/archive/20220405-awarded-smeaheia-polaris-co2-licenses>

<sup>19</sup> [https://www.spe-aberdeen.org/wp-content/uploads/2020/11/Mon\\_Equinor\\_SPE-CCUS-Insights-from-Sleipner-and-Sn%C2%A2hvit-26Oct2020.pdf](https://www.spe-aberdeen.org/wp-content/uploads/2020/11/Mon_Equinor_SPE-CCUS-Insights-from-Sleipner-and-Sn%C2%A2hvit-26Oct2020.pdf), page 3





offshore on Sleipner Platform T, to be injected from the Sleipner A platform using a 3 km long horizontal well into the bottom of the Utsira aquifer formation, at a rate of around 1 million tCO<sub>2</sub> per year. Here, injecting CO<sub>2</sub> is economically attractive due to the tax imposed by the Norwegian state on offshore CO<sub>2</sub> emissions: “The monitoring programme at Sleipner is generally perceived to be a great success and is commonly cited as a good example of how to monitor an industrial-scale storage site. The key monitoring tool is 4D seismic which has proved spectacularly effective in tracking the plume, but other techniques have also been tested with varying degrees of success”.<sup>20</sup>

### **Snøhvit**

The Snøhvit CCS project, which started in 2008, is part of the Snøhvit gas field development in the Barents Sea. In this project, CO<sub>2</sub> is removed from the gas at the onshore gas processing plant (Melkøya) and then transported via a 150 km long pipeline to a subsea injection template. By the end of 2017, almost 5 Mt CO<sub>2</sub> had been injected into the subsurface. Initially, the CO<sub>2</sub> was injected into the Tubåen Formation, a saline aquifer below the gas-bearing Stø Formation. However, during the first 3 years of injection, a gradual rise in pressure was observed mainly due to geological barriers which limited the access to the available pore space. This led to the decision to perform a well intervention in 2011 leading to a modified injection plan with the CO<sub>2</sub> injected into the aquifer of the Stø Formation. Injection has continued since then with a stable pressure trend. Crucial to this evaluation was the use of seismic 4D data, downhole gauges and reservoir modelling which allowed optimization of the CO<sub>2</sub> injection plan.<sup>21</sup>

### **3.3. Early investigation of CO<sub>2</sub> sequestration potential on the Norwegian shelf**

The NPD has regularly published comprehensive CO<sub>2</sub> atlases of the main parts of the Norwegian shelf<sup>22</sup>. As noted earlier, the highest potential for sequestration exists in the North Sea<sup>23</sup>, with a potential of 70 Gt CO<sub>2</sub> out of a total of 80 Gt CO<sub>2</sub> (see Table 1 for an overview of the different existing sequestration sites).

### **3.4. Standards, legislation, and licensing**

Sequestering CO<sub>2</sub> in geological structures can be organised similar to oil and gas production, with a licensing regime for qualified companies under the supervision of a public authority such as the NPD in Norway. The difference is that so far there is no global market for CO<sub>2</sub> as there is for oil or gas, and income from CO<sub>2</sub> sequestration is derived from a public good, not from a global market. In the cases of Sleipner and Snøhvit, the economic benefits stem from avoiding a substantial tax on CO<sub>2</sub> emissions which become part of the overall costs of gas production.

Early on, the NPD developed standards for CO<sub>2</sub> handling, injection and sequestration as a basis for licensing under an open regime for sequestration of anthropogenic CO<sub>2</sub>.<sup>24,25</sup> In addition, a ‘CO<sub>2</sub> Safety’ regulation was issued in 2020.<sup>26</sup> More recently, further development of CCS was discussed in an addendum (on April 8, 2022) noting that:

- The Longship Project will be an important part of the Government’s CO<sub>2</sub> handling and Norway’s contribution to developing necessary climate technologies;

<sup>20</sup> Page 8, file:///C:/Users/Ralf/Desktop/OIES%20and%20Decarbon%20gas/Sleipner\_Chapter\_V5\_withFigs\_singlespace.pdf

<sup>21</sup> Page 167: The CCS hub in Norway: some insights from 22 years of saline aquifer storage

Philip S. Ringrose

<sup>22</sup> Most recent version: <https://www.npd.no/en/facts/publications/co2-atlases/co2-atlas-for-the-norwegian-continental-shelf/>

<sup>23</sup> <https://www.npd.no/en/facts/publications/co2-atlases/co2-atlas-for-the-norwegian-continental-shelf/1-introduction/>

<sup>24</sup> <https://lovdata.no/dokument/SF/forskrift/2014-12-05-1517?q=Forskrift+om+utnyttelse+av+undersj%C3%B8iske>

<sup>25</sup> <https://www.npd.no/en/regulations/regulations/exploitation-of-subsea-reservoirs-on-the-continental-shelf-for-storage-of-and-transportation-of-co/>

<sup>26</sup> [https://www.ptil.no/contentassets/f18375b7184d4cd68fc1c733b318b3dc/co2-sikkerhetsforskriften\\_veiledning\\_e.pdf](https://www.ptil.no/contentassets/f18375b7184d4cd68fc1c733b318b3dc/co2-sikkerhetsforskriften_veiledning_e.pdf)





- The Government will arrange for commercial carbon storage on the Norwegian shelf;
- The Government will continue to facilitate CO<sub>2</sub> handling as a contribution towards reaching the goals of the Paris Agreement, including through arranging for a green industrial effort;
- The Ministry of Petroleum and Energy (MPE) will review the proposed solution to finance the Fortum Oslo Varme CCS project at Klemetsrud; and
- A storage site for injection of CO<sub>2</sub> located between the oil fields Brage, Troll and Oseberg was announced in accordance with the CO<sub>2</sub> Storage Regulations, with the deadline for applications having closed on July 1, 2022.

**Table 1: List of sequestration sites in Norway.<sup>27</sup>**

Aquifer	Capacity Gt	Injectivity	Seal	Maturity	Data quality
<b>North Sea aquifers</b>					
Utsira and Skade Formations	15,8	3	2		
Bryne and Sandnes Formations	13,6	2	2/3		
Sognefjord Delta East	4,1	3	2/3		
Statfjord Group East	3,6	2	3		
Gassum Formation	2,9	3	2/3		
Farsund Basin	2,3	2	2/3		
Johansen and Cook Formations	1,8	2	3		
Fiskebank Formation	1	3	3		
<b>Norwegian Sea aquifers</b>					
Garn and Ile Formations	0,4	3	3		
Tilje and Åre Formations	4	2	2/3		
<b>Barents Sea aquifers</b>					
Realgrunnen Subgroup, Bjarmeland Platform	4,8	3	2		
Realgrunnen Subgroup, Hammerfest Basin	2,5	3	2		
<b>Evaluated prospects</b>					
North Sea	0,44				
Norwegian Sea	0,17				
Barents Sea	0,52				
<b>Abandoned fields</b>					
<b>North Sea</b>	3				
<b>Producing Fields_2050</b>					
North Sea 2050	10				
North Sea_Troll aquifer	14				
Norwegian Sea	1,1				
Barents Sea	0,2				

Source: Norwegian Petroleum Directorate (n.d.)

<sup>27</sup> <https://www.npd.no/en/facts/publications/co2-atlases/co2-atlas-for-the-norwegian-continental-shelf/7-summary-storage-capacities-of-the-norwegian-continental-shelf/>

### 3.5. Licensing rounds

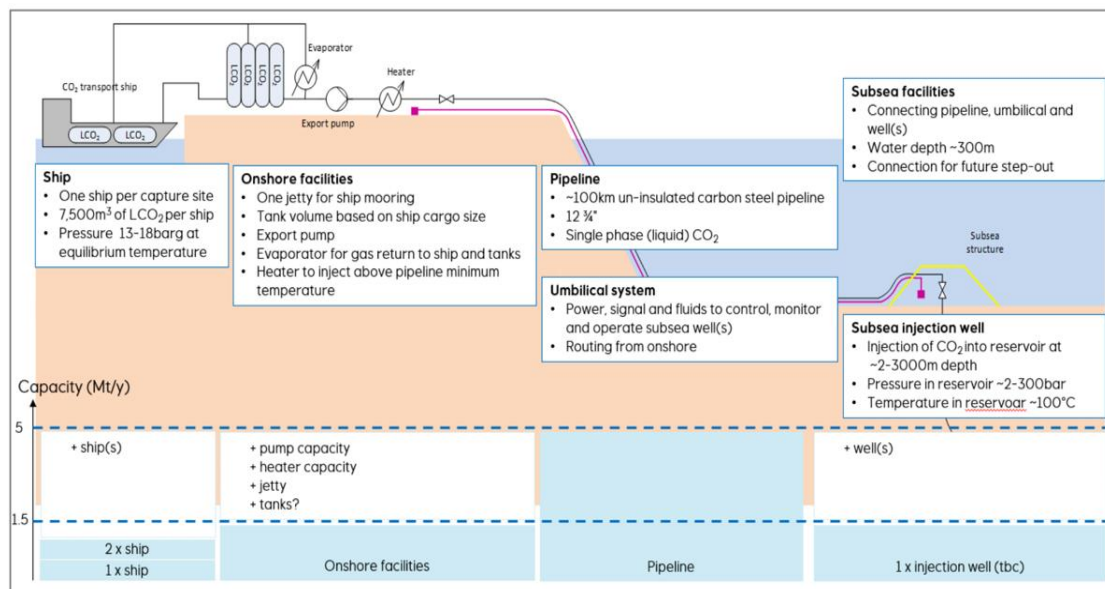
The Norwegian Government has issued a number of licensing rounds.

#### Northern Lights

The first license was issued to the group of Equinor, Shell and Total in 2019 (the Northern Lights Project). The project, currently under development, is dedicated directly to CO<sub>2</sub> sequestration with a projected rate of 1.5 and 5 million tCO<sub>2</sub>/a in its first and second phase, respectively. The project is driven by the need to dispose of the CO<sub>2</sub> from all kinds of sources fed by CO<sub>2</sub> from the Longship project, collecting CO<sub>2</sub> by ship from Norway and projects in North West Europe.<sup>28</sup> In a first phase, as of 2024, 1.5 million tCO<sub>2</sub>/a would be collected by special CO<sub>2</sub>-carrying ships and then injected from the shore via a 150 km long pipeline into the Dunlin formation. Thereafter, volumes could be increased to 5 million tCO<sub>2</sub>/a.<sup>29</sup>

The Northern Lights project uses technology similar to Sleipner's.<sup>30</sup> The difference is that it is based on injecting CO<sub>2</sub> sourced from pre- or post-combustion of fossil fuels or from processes such as cement production. As such, the project's economic driver is not oil or gas production but avoiding CO<sub>2</sub> emissions by sequestration. Exploitation license EL001 for CO<sub>2</sub> storage was awarded to the partners in January 2019. The 31/5-7 confirmation well (Eos) within EL001 licence was drilled and successfully tested from 2nd December 2019 to 7th March 2020. The Eos well targeted the Dunlin Group Geological formation as the primary storage, where the sandstone-bearing Cook and Johansen formations both can serve as storage units for the injected CO<sub>2</sub>. The cap rock consists of impermeable claystones called Drake Formation, which prevents the CO<sub>2</sub> from migrating out of the Dunlin Group.<sup>31</sup>

**Figure 1: Northern Lights concept building blocks.<sup>32</sup>**



Source: Equinor (2019)

<sup>28</sup> <https://www.equinor.com/news/archive/20201215-northern-lights-go-ahead>

<sup>29</sup> <https://ccsnorway.com/app/uploads/sites/6/2020/05/Northern-Lights-Project-Concept-report.pdf>

<sup>30</sup> In Sleipner, CO<sub>2</sub> is a by-product specific to a single reservoir with a high CO<sub>2</sub> content, which should not be released into the atmosphere.

<sup>31</sup> <https://www.equinor.com/news/archive/20201019-sharing-data-northern-lights>

<sup>32</sup> <https://norlights.com/wp-content/uploads/2021/03/Northern-Lights-Project-Concept-report.pdf>



In 2021 two more licenses were issued: one to Equinor ASA in the North Sea, whilst the other was awarded to a group including Equinor ASA, Horisont Energi AS and Vår Energi AS in the Barents Sea.<sup>33,34</sup> In 2022, the NPD invited applications for a new round of licenses in the Norwegian Shelf of the North Sea (deadline of June 1, 2022). The companies that applied for a permit were TotalEnergies EP Norge, Wintershall Dea Norge, and CapeOmega.<sup>35</sup> As of the time of writing, no results have been announced.

### ***The Longship project***

The Longship project collects CO<sub>2</sub> from various industrial projects under contractual arrangements with the Northern Lights project. So far there are two firm projects aiming to collect CO<sub>2</sub> in Norway: (i) Fortum Oslo Varme (waste incineration plant) with 400,000 tCO<sub>2</sub>/a, and (ii) Norcem cement plant, also with 400,000 tCO<sub>2</sub> capacity per year. Both projects have high load factors and have received substantial financial support from the Norwegian Government. Further projects from outside Norway are under development.

So far two tankers of 7,500m<sup>3</sup>, in addition to 12 tanks at the transfer point with a total volume of 9,150m<sup>3</sup> are planned by Longship. The project includes two capture plants loading 5,400m<sup>3</sup> of CO<sub>2</sub> every 4 days. In order to bring down the cost of ships from the initially proposed special designs, the selected strategy was to adopt ship designs that closely resemble existing designs, namely fully pressurised LPG type ships.<sup>36</sup>

The first is the Fortum Oslo Varme<sup>37</sup>. This waste-to-energy plant treats 400,000 tonnes of waste per year that cannot be reused or recycled. The project has successfully conducted its FEED (front-end engineering and design) studies, operated a pilot plant for 5,500 hours and achieved a stable capture rate of 90-95%.<sup>38</sup> It is projected that it will produce circa 400,000 tCO<sub>2</sub> per year. The project in Oslo is considered the most mature waste-to-energy with CCS project in the world. When completed, it will be a state-of-the-art facility providing circular waste handling, district heating and negative emissions, and a model plant for around 500 similar WtE plants for European cities aiming to reduce emissions and solve their waste problems.<sup>39,40</sup>

The second is the Norcem Cement plant which will be the first cement plant globally to reduce its CO<sub>2</sub> emissions by capturing CO<sub>2</sub>, and a successful pilot project had already been undertaken. Around 400,000 tCO<sub>2</sub> will be handed to CO<sub>2</sub>-carrying ships (of Longship) to be transported to the collection point and handed over to Northern Lights. Equinor reports that the Norcem plant is the larger of the two cement plants in Norway. Yearly production volume is 1.3 million tonnes of cement mainly delivered to the Norwegian market, but a part of the production is exported within Scandinavia and the northern part of Europe. CO<sub>2</sub> emissions are an unavoidable part of current cement production processes. Total emissions from the Brevik cement plant are approximately 0.8 Mtpa. Norcem plans to capture 50% of the emissions (0.4 Mtpa) based on the amine solvent technology developed by Aker Solutions. There is a potential to increase the capture rate and volume. Norcem Brevik has been involved in CCS since 2010 and have executed several studies.

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<sup>33</sup> <https://www.npd.no/en/facts/news/general-news/2022/awards-three-companies-offered-acreage-to-store-co2/>

<sup>34</sup> For the relevant work programmes and a map, see NPD (2021).

<sup>35</sup> <https://www.offshore-energy.biz/three-companies-apply-for-co2-storage-permit-off-norway/>

<sup>36</sup> <https://ccsnorway.com/app/uploads/sites/6/2020/05/Northern-Lights-Project-Concept-report.pdf> (page 109)

<sup>37</sup> <https://www.fortum.com/about-us/newsroom/press-kits/carbon-removal/fortum-oslo-varme-and-our-carbon-capture-project>

<sup>38</sup> <https://ccsnorway.com/app/uploads/sites/6/2020/12/Pilot-Plant-Test-Report-Extended-Phase.pdf>

<sup>39</sup> The members of the German association operating WtE plants (ITAD) operate 80 WtE plants with 25 million tonne of waste per year.

<sup>40</sup> Cory, London's Waste management and recycling company signed a MoU on 13 May 2022 with a potential of 1.5 million tCO<sub>2</sub>/a delivered to Northern Lights. This will need a solution to the London protocol Art. 6 which bars cross-border CO<sub>2</sub> transport for sequestration offshore.





### 3.6. The players

#### *The Norwegian Government*

The Norwegian Government continues to play a crucial role in promoting CCS on the Norwegian shelf by providing (institutionalized) conceptual support including encouragement on technology development and economic assessment to support pilot projects. In the framework of Northern Lights and Longship, Norway provides substantial grant support covering the bulk of CCS investment of several billion Euros while retaining a share for private companies as an incentive for cost-efficient development. The support addresses the capture projects of Norcem and Fortum Oslo Varme but also the sequestration part (drilling) of the Northern Lights project.

All results of the work supported financially by the Norwegian Government are publicly available and shared globally via various avenues. A comprehensive overview on the activities initiated by the Norwegian Government is provided in the Report to the Norwegian parliament, Storting, (white paper) by the Ministry of Petroleum and Energy Meld. St 33 (2019-2020)<sup>41</sup>.

The following arrangements and institutions are also particularly noteworthy:

#### *Gassnova SF*

Gassnova was established as a state-owned enterprise by Norwegian authorities to promote technology development and competence building around CCS, in addition to being the Norwegian Government's closest advisor in this field.<sup>42</sup> Gassnova SF contributes to technology development and competence building by supporting specific CCS projects. The entity is responsible for key policy instruments for the development of CCS technology and is the advisor to the Ministry of Petroleum and Energy on issues related to CCS. Gassnova administers the state's interests in Technology Centre Mongstad (TCM) and shares administrative responsibilities with the Research Council of Norway for the national research programme for CCS technologies, CLIMIT. In recent years, a number of activities undertaken by both TCM and CLIMIT have been specifically aimed at solving challenges related to the project now known as Longship. Gassnova has coordinated the different sub-projects and worked on benefit realisation in the main project. Gassnova has also been responsible for following up on and evaluating the actors' projects, including the potential for benefit realisation.<sup>43</sup>

#### *Technology Centre Mongstad (TCM)*

TCM is the world's largest facility for testing and development of carbon capture technologies. TCM has been in operation since May 2012 and is an arena for targeted testing and qualification of technology for industrial CCS. The joint venture company TCM DA is responsible for operating Technology Centre Mongstad. The Norwegian State, represented by Gassnova, owns 73.9 percent of TCM DA. The other owners are equally Equinor, TotalEnergies, and Shell (with 8.7% shares each).

The technology centre has been built for long-term operation and has three different test areas for testing of both relatively mature and newer technologies. Flexible access to two different industrial flue gas sources enables the simulation of a large range of flue gases from various industries such as cement production, waste incineration, oil refining and power production. TCM cooperates with national and international universities and research institutions and performs test campaigns for commercial industrial actors from around the world. Since the start of its operations in 2012, Aker Solutions (Norway), Alstom SA (France), Cansolv Technologies Inc. (Canada), Carbon Clean Solutions (UK/India), ION Engineering (USA), Fluor Corporation (USA) and Mitsubishi Heavy Industries Engineering (Japan) have tested their technologies at TCM. In 2020, a new Participants Agreement

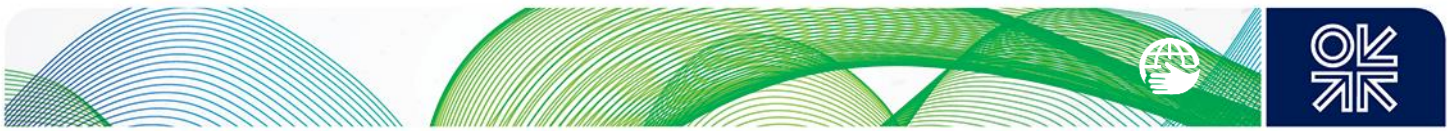
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<sup>41</sup> <https://www.regjeringen.no/contentassets/943cb244091d4b2fb3782f395d69b05b/en-gb/pdfs/stm201920200033000engpdfs.pdf>

<sup>42</sup> <https://gassnova.no/en/gassnova-en>

<sup>43</sup> Section 4.1.1: <https://www.regjeringen.no/en/dokumenter/meld.-st.-33-20192020/id2765361/?ch=5>





between the Norwegian State, Equinor, Shell and TotalEnergies was signed to secure continued operation of TCM until the end of 2023.<sup>44</sup>

### **Longship research**

The Longship project reflects the Norwegian Government's ambition to develop a full-scale CCS value chain in Norway by 2024, demonstrating the potential of this decarbonisation approach to Europe and the world. The Norwegian Government has demonstrated strong, long-standing leadership in realising full-scale CCS. With support from the Norwegian Government, the Northern Lights project can provide realistic decarbonisation opportunities for Norwegian and European industries.

The government issued feasibility studies on capture, transport and storage solutions in 2016. Combined, these studies showed the feasibility of bringing together the links of the value chain and realising a full-scale CCS project. Based on this outcome, the government decided to continue development through an agreement covering concept and FEED studies. The studies covered:

- Capture of CO<sub>2</sub> at the Norcem (Heidelberg Group) cement factory in Brevik;
- Capture of CO<sub>2</sub> at the waste-to-energy plant Fortum Oslo Varme in Oslo; and
- A combined transport and storage solution, managed by Northern Lights JV DA.<sup>45</sup>

### **JVA Equinor, Shell, Total**

The pre-project (concept and FEED studies) was governed by a study agreement between Gassnova and Equinor. A collaboration agreement between Equinor, Shell and Total governed the study and execution preparation work and the preparations for establishing a Joint Venture Agreement. In May 2020, the three companies took an investment decision, based on information on the quality and capacity of the reservoir acquired in the drilling of the "Eos" confirmation well in early 2020, and a commercial agreement with the state. Following a historic vote in parliament, in December 2020, the Norwegian Government took its funding decision and named the project Longship.<sup>46</sup>

## **3.7. Volume build-up**

At present, CO<sub>2</sub> sequestration is estimated to reach about 50 million tCO<sub>2</sub>/a in 2040 (continuing until 2050) (Figure 2). This would be short of the potential of the Norwegian shelf and also of the volumes corresponding to the CO<sub>2</sub> resulting from Norway's export of oil and gas.

So far it seems that volume development is driven by an increasing number of single projects collecting CO<sub>2</sub> by ship transport. A pipeline structure is anticipated to be triggered by large enough CO<sub>2</sub> volumes to be sequestered.

This raises the question of the driver for CO<sub>2</sub> sequestration in Norway:

- A contribution to reach the targets of the Paris Agreement, e.g. by reaching net-zero by 2050;
- A justification to continue producing oil and gas, compensated for by CO<sub>2</sub> sequestration;
- As a compensation for jobs and employment for shrinking oil and gas industry, using the existing skill basis; possibly at a later stage A source of state revenue (once CCS becomes profitable in view of an adequate CO<sub>2</sub> price; elements of rent taking beyond cost recovery and a corresponding change in taxation)

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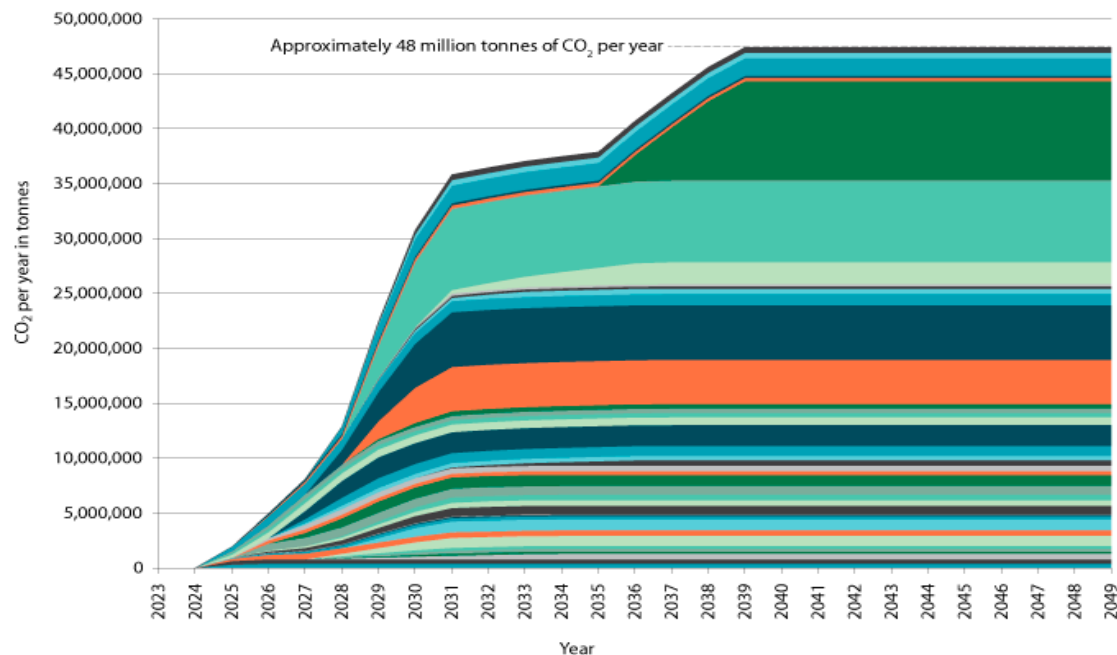
<sup>44</sup> <https://www.regjeringen.no/en/topics/energy/carbon-capture-and-storage/technology-centre-mongstad-tcm/id2345604/>

<sup>45</sup> <https://norlights.com/about-the-longship-project/>

<sup>46</sup> *ibid*



**Figure 2: CO<sub>2</sub> from potential transport and storage customers in tonnes per year.<sup>47</sup>**



Source: Norwegian Government (2020)

If Norway wants to compensate for the CO<sub>2</sub> production resulting from its continuing sale of oil and gas by sequestration of CO<sub>2</sub>, this would amount to a CO<sub>2</sub> sequestration volume of about 300 million tCO<sub>2</sub>/a. The question then becomes: should such large volumes be delivered by ship? Pipeline delivery would have to be focussed on deliveries from France, Belgium, Germany and Poland, and possibly Sweden and Finland. The volumes from Northern Europe would best be delivered by pipeline, with volumes beyond pipeline delivery being long-haul shipment.

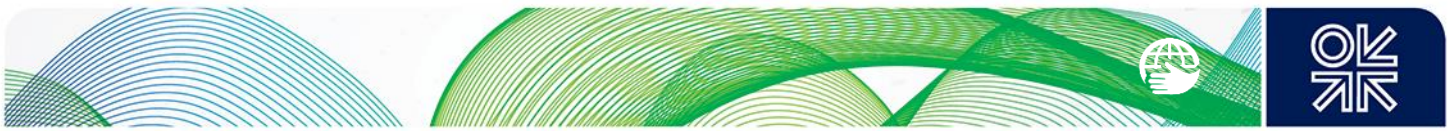
The present scheme based on transport via shipping would help to build up volumes. The introduction of a pipeline system would raise a number of questions going beyond the present Longship/Northern Lights scheme, involving larger volume injection capacity, onshore vs offshore handling, and CO<sub>2</sub> storage (injection and withdrawal) to steady the injection flow.

### 3.8. Economics, taxation, and handling of liability for eternity costs

So far Norway only levies the normal business tax on CO<sub>2</sub> sequestration activities, through which it should be possible to compensate for losses from CO<sub>2</sub> sequestration with gains from other business under the normal corporate tax (but not with the extra petroleum tax). Risks and costs of sequestration are cushioned by taxable income from oil and gas production of the companies.

A core issue is the transfer of costs and risks of CO<sub>2</sub> sequestration to the state at the end of a license and how to raise the necessary income for the state to cover the costs incurred. On a higher level, the question is if the state should claim a resource rent also for committing a part of its limited potential for CO<sub>2</sub> sequestration. Such a rent income could serve as an early compensation for later 'eternity costs' of the state for CO<sub>2</sub> sequestration. However, rent collection is usually derived from a certain market mechanism or at least a competitive price, which does not yet exist for CO<sub>2</sub> (except for the CO<sub>2</sub> ETS price).

<sup>47</sup> <https://www.regjeringen.no/en/dokumenter/meld.-st.-33-20192020/id2765361/?ch=5>



Also, the policy focus might be to maintain hydrocarbon activities on the Norwegian Shelf while abiding by the Paris Agreement, with additional or compensatory employment with highly qualified jobs, resulting from CO<sub>2</sub> sequestration on the Norwegian Shelf.

#### 4. The German need for CO<sub>2</sub> export

Germany's decarbonisation policy has a strong, almost exclusive, focus on renewables. Yet, adding CO<sub>2</sub> sequestration to Germany's decarbonisation strategy is essential to achieve its net-zero target by 2045 and to maintain reliable energy supply. In doing so, it is necessary to introduce CCS in parallel to other measures to bridge the substantial remaining decarbonisation gap. This can be done independently of the progress of renewables. CO<sub>2</sub> sequestration offers the diversification of technology development and rollout, where its deployment is mainly an investment (not a technological) issue and it can provide decarbonised energy on demand (hydrogen and dispatchable electricity), which in turn can be used to complement intermittent electricity and green hydrogen from renewables.

One of the main hurdles for CO<sub>2</sub> sequestration in Germany, however, is the fact that most of its geological storage capacity lies onshore: Onshore sequestration comes with more technical and social acceptance challenges than offshore sequestration. Germany has an onshore sequestration potential<sup>48</sup> which is blocked by legislation.<sup>49</sup> Moreover, the potential sites for CO<sub>2</sub> disposal in Germany are relatively small, limiting the pressurising of these geological structures. Still, they may be used for the disposal of smaller CO<sub>2</sub> volumes from local industry, once and if the legal environment improves.

For Germany, a country which strives to retain its steel and chemical industry as core competence clusters in a decarbonised world, CO<sub>2</sub> sequestration might be politically feasible if it takes place initially in the non-German part of the North Sea. This is more so the case if there were a public understanding that a mature green hydrogen economy may not materialise in time for the country to meet its decarbonisation targets. Given the size of its CO<sub>2</sub> emissions and resulting sequestration needs, and the legal and political blockade of domestic CO<sub>2</sub> sequestration Germany cannot achieve its climate targets without CO<sub>2</sub> exports.

If anything, this indicates that the time has come for a new discussion on the necessity of CCS.<sup>50</sup> In fact, the German Academy of Science and Engineering has called for assessing the need and the options for a broad application of CCS technologies and discussing them with all actors in society. This initiative was also supported by the NGOs WWF Germany and Germanwatch.<sup>51</sup>

##### 4.1. The need for a CO<sub>2</sub> collection system/aggregator

In view of the multitude of sites in Germany needing CO<sub>2</sub> capture, the design of a CO<sub>2</sub> collection and handling system for export in a form that works for the CO<sub>2</sub>-importing counterpart is a must for the country. For instance, collection by inland ships with transport to Rotterdam and transfer to sea-going ships seems possible and can serve as a starting point. Here, aggregation would take place at the transfer point in Rotterdam and at the collection point before sequestration, including quality management and storage to handle ship loading and unloading schedules.

A collection scheme by river-going ships could kickstart such development. Considering the large-scale CO<sub>2</sub> emissions to be captured, transport by pipelines seems more appropriate in the longer run. For such distances, pipeline transport could be a more economical alternative due to substantial economies of scale. What's more, not all CO<sub>2</sub>-emitting sites in Germany can be reached by inland waterways. As

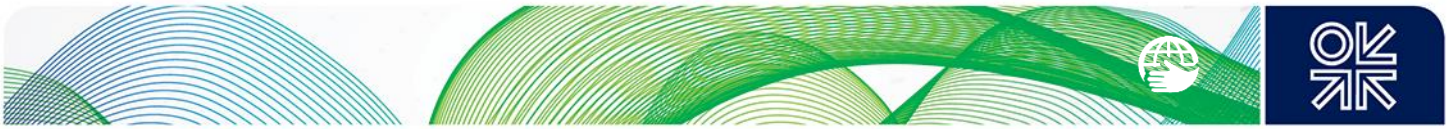
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<sup>48</sup> According to Germany's Federal Institute for Geosciences and Natural Resources, the country has a CO<sub>2</sub> sequestration potential of 20 Gt +/- 8 Gt CO<sub>2</sub> German Federal Institute for Geosciences and Natural Resources (2010) p. 76 (*in German*)

<sup>49</sup> The unfortunate public association of CO<sub>2</sub> disposal with the disposal of highly radioactive waste – an extremely contentious topic in Germany – has led to strong political resistance to carbon sequestration (see section 3.7 of Dickel (2022)). All activities for the storage of CO<sub>2</sub> were de facto blocked by law as of 1 December 2016 (meaning today: no projects).

<sup>50</sup> See: <https://journals.sagepub.com/doi/full/10.1177/0306312720941933>, pp. 7-8

<sup>51</sup> Ibid.



an example, a reach of 800 km for a CO<sub>2</sub> onshore pipeline has been proven in the US corresponding to the distance between South Germany and the North Sea coastline. Large offshore CO<sub>2</sub> trunklines from the German coast to places for sequestration on the Norwegian shelf should also be possible in view of existing offshore gas pipelines of 800-1200 km in length (without intermediate compression).

In the medium run, an onshore CO<sub>2</sub> collection system by pipeline(s) may be orchestrated, taking into account differences in volumes, spread of locations of CO<sub>2</sub> sources and different load factors. This suggests creating an aggregator function (including quality management, volume collection management, load management). At least in the beginning, this would not be possible by a TPA system, in particular given the limited technical experience in Germany with CO<sub>2</sub> handling.<sup>52</sup>

## 4.2. CO<sub>2</sub> registration, metering and certification

So far, it can be assumed that all the CO<sub>2</sub> created by combustion processes enter the atmosphere, so it would be sufficient to register the carbon entering the processes themselves. If the CO<sub>2</sub> were to be captured, these CO<sub>2</sub> streams must be measured as only a small part of the CO<sub>2</sub> created is entering the atmosphere while the majority of it is captured and then disposed of by sequestration. The CO<sub>2</sub> pathway should then be monitored (and certified), first in the transformation and capture process and subsequently for all elements and their interfaces along the chain. If the CO<sub>2</sub> is transported across borders, mutually-agreed standards and procedures shall be in place.

While this is not a problem per se, CO<sub>2</sub> metering must be implemented on a large scale. This must be accompanied by a certification system, which ensures that the CO<sub>2</sub> volumes handled will be sequestered with suitable standards and the losses along the chain including sequestration are minimized and registered.

While CO<sub>2</sub> sequestration in Germany is de facto legally excluded by the 2012 CCS Act<sup>53</sup>, CO<sub>2</sub> transport is possible. There is even an eminent domain provision in the CCS Act, including for export, if it reduces Germany's CO<sub>2</sub> emissions. Under Section 4 of the CCS Act the Minister of Economics is empowered to issue standards for CO<sub>2</sub> transport and handling as well as permitting procedures for construction of CO<sub>2</sub> pipelines. One element which is not mentioned involves the handling of CO<sub>2</sub> for storage sites for injection and withdrawal.

## 4.3. Status of CCS technologies in Germany

### Capture

Autothermal Reforming (ATR) is state of the art but has to be adapted and optimized for CO<sub>2</sub> capture. In the ammonia industry, ATR is a necessary part of the production process, where the extra costs of decarbonisation involve CO<sub>2</sub> capture plus transport and sequestration costs (the transport and sequestration part accounts for about 40% of the total costs, in addition to a few percentage points to adapt the ATR process to optimize the capture of CO<sub>2</sub> which is produced in high concentration anyway). This is in contrast to energetic use of blue hydrogen e.g. from natural gas where also the costs of the ATR process are extra costs for decarbonization.

For the steel industry, the extra costs of the ATRs to produce blue hydrogen are driven by the fact that the steel industry is moving towards decarbonisation by using hydrogen instead of coke for reduction of iron ore. In addition, the costs of CO<sub>2</sub> transport and sequestration have to be added. It is estimated that a price of around 100 €/tCO<sub>2</sub> could cover the costs of the chain for the steel industry, so that paying for CO<sub>2</sub> trading rights (ETRs) or for CO<sub>2</sub> disposal might be on par. In both cases the extra costs will have to be earned in the steel market. The difference is that with CO<sub>2</sub> sequestration, the CO<sub>2</sub>

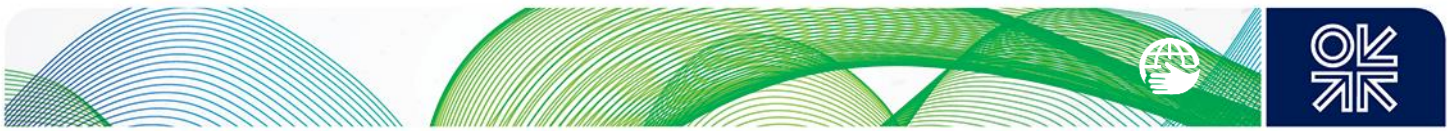
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<sup>52</sup> But a FEED was produced for the Jämschwalde project. See:

<https://www.globalccsinstitute.com/archive/hub/publications/77446/feed-study-co2-transport-pipeline.pdf>

<sup>53</sup> CCS act §3 definitions, sec 7: „Kohlendioxid-speicher zum Zwecke der *dauerhaften* [emphasis RD] Speicherung...“ *dauerhaft* = permanent hint at sequestration, not storage.





sequestered does not enter the atmosphere, while it remains to be seen if and when the extra state income from the CO<sub>2</sub> ETRs will result in reducing the release of CO<sub>2</sub> into the atmosphere.

In the cement industry, most of CO<sub>2</sub> emissions are process emissions and only a smaller share comes from energy use. The process is steady, but the cement industry is rather scattered with a variety of production sizes. Because of the high weight of cement, economies of scale of production are easily hampered by transport costs. Moreover, cement tends to be based on local/national markets, except where countries are close to each other, as is the case in Northwest Europe (see OIES Energy Insight 115). A first project to decarbonize cement production is underway at Brevik in Norway at Norcem, the Norwegian affiliate of Heidelberg cement (to become fully operational in 2024). Yet, project costs are still high as of now.

In the power sector, post-combustion CO<sub>2</sub> capture was tested in two smaller pilot projects (partial retrofitting of lignite power plants) in Germany for

- Oxyfuel (Schwarze Pumpe)
- Amine scrubbing (Niederaussem)

Given the need to make up for the delays in scaling up CO<sub>2</sub> sequestration in power plants, decarbonisation of existing fossil-fuelled power plants requires several scaled up pilot projects in the range of 300 MW (such as in the Petra Nova project in Texas and Boundary Dam in Saskatchewan), followed by a rollout on the scale needed for decarbonisation of power generation on demand. While post-combustion decarbonization in the power process is TRL 9 (Technical Readiness Level 9, the highest readiness level), it will take several years to scale it up and roll it out. However, the alternative of using hydrogen in the power process has more obstacles to overcome, such as the (lack of) availability of large enough volumes of low-carbon hydrogen, of a hydrogen infrastructure (transport and storage) and hydrogen-fit turbines.

### **Transportation of CO<sub>2</sub>**

A detailed planning (FEED) was undertaken for a 52 km CO<sub>2</sub> pipeline by Vattenfall to transport CO<sub>2</sub> from Jämschalde to a planned sequestration site, but was abandoned with the cancellation of the Project in Jämschalde<sup>54</sup>. Another recent project by Total<sup>55</sup> seeks to evaluate possibilities to use part of existing gas transport infrastructure. Moreover, a project announced by OGE /TES<sup>56</sup> looks for a nationwide collection system of CO<sub>2</sub> from industry and power plants which could eventually be upscaled. A start grid could be ready by 2027 with 1000 km and 18 million tonnes of CO<sub>2</sub> per year transport capacity. The core objective of this project is to import green methane based on cheap renewable electricity and a Sabatier process from CO<sub>2</sub> and green hydrogen to be transported as LNG to Wilhelmshaven, and to use the emptied tanker to return CO<sub>2</sub> to the location of the Sabatier process. The German part of the collection system of CO<sub>2</sub> would very much be the same if the CO<sub>2</sub> is sent for sequestration to Norway by tanker from Wilhelmshaven or by pipeline via nearby Dornum.

## **4.4 Future outlook**

In light of the above, a number of issues stand out and which Germany ought to address as soon as possible:

- The need for CO<sub>2</sub> sequestration by 2045 is in the order of 200-300 million tCO<sub>2</sub>/a (see recent OIES paper ET 13<sup>57</sup>), which is certainly an immense challenge but within the frame of similar industrial developments in the past;

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<sup>54</sup> <https://www.globalccsinstitute.com/archive/hub/publications/77446/feed-study-co2-transport-pipeline.pdf>

<sup>55</sup> OGE. (n.d.). On the way to climate neutrality with OGE. Retrieved from <https://www.co2-netz.de/de>

<sup>56</sup> <https://www.co2-netz.de/de#co2-netz>

<sup>57</sup> See Ralf Dickel (2022), 'Achieving Net Zero Plus Reliable Energy Supply in Germany by 2045: The Essential Role of CO<sub>2</sub> Sequestration', OIES paper ET 13.



- With a CO<sub>2</sub> price of about 100 €/t CO<sub>2</sub>, ATRs with CO<sub>2</sub> capture, transportation and sequestration appear to be economically feasible (see OIES NG 159<sup>58</sup>, p. 29 ff).
- For fossil-fired power plants with CCS, several pilot plants (retrofits) of industrial size (lignite- and gas-based, amine scrubbing and oxyfuel) should be tested to prepare for a Germany-wide rollout (and technology export);
- The load factor of load following power to compensate for intermittent renewables is in the order of 1000 and 1500 h/a, which can be matched as a combination of some relatively high loads and some lower loads. New or retrofitted lignite- or coal-fired power plants with relatively high load factors (ca 3000 h/a) with post-combustion CO<sub>2</sub> capture and sequestration should be considered together with biofuel fired peak plants; and
- A concept for a completely new large-scale CO<sub>2</sub> transmission infrastructure is needed to collect CO<sub>2</sub> volumes at the level of around 200-300 million tCO<sub>2</sub>/a in Germany and transfer them for disposal in the Norwegian part of the North Sea.

#### 4.5. Germany's interface with Norway

As far as exporting CO<sub>2</sub> from Germany to Norway is concerned, the main hindrance remains Article 6 of the London Protocol, which bars the export of CO<sub>2</sub> for sequestration offshore.<sup>59</sup> This has been addressed by the 2009 Amendment to Art. 6, which Germany has not ratified yet. Overall ratification would take a long time, considering the slow ratification progress by the signatories to the amendment. However, Resolution LP.5(14) adopted on 11 October 2019 on provisional application allows members who have ratified the Amendment to Art. 6 to agree on provisional application amongst each other following specific standards; the first such case was between Norway and the Netherlands.<sup>60</sup>

In parallel, the technicalities of CO<sub>2</sub> transfer should be addressed by including the interested industry in the concept development process (i.e. potential locations, details on CO<sub>2</sub> streams such as metering, quality, certification procedures and the concept of crossing the Wadden Sea, etc.). For CO<sub>2</sub> export from Germany to Norway, a landing point for CO<sub>2</sub> pipelines near Dornum (between Emden and Wilhelmshaven) looks reasonable, using the same approach as for Europipe 1 and 2, which were laid into a tunnel under the relevant part of the Wadden Sea<sup>61</sup> and taken up outside the Wadden Sea area. The proximity to the large salt domes/salt caverns in this area might be useful for the temporary storage of CO<sub>2</sub> to even out the gas flow before transfer.<sup>62</sup>

Paragraph 4 Section 5 of the 2012 CCS Act provides for eminent domain (allowing expropriation) for CO<sub>2</sub> pipelines serving final sequestration of CO<sub>2</sub> outside of Germany if the CO<sub>2</sub> emissions in Germany are permanently reduced. The Ministry of Economy is authorised under Para 4 Section 6 to issue an ordinance stipulating the details of the permitting procedure and the standards for CO<sub>2</sub> pipelines (where the Ministry of Economy should fill in these details). For technical standards of CO<sub>2</sub> handling, the impeccable safety performance of the US may serve as guidance. The industry jointly with BNetzA (the regulatory authority) should develop a technical, economic and regulatory concept for a CO<sub>2</sub> collection infrastructure.

CO<sub>2</sub> storage (when including injection and withdrawal) is not covered by the 2012 CCS Act but should be addressed to allow for intermediate storage first in salt caverns in the north (for stabilizing the CO<sub>2</sub> flow).

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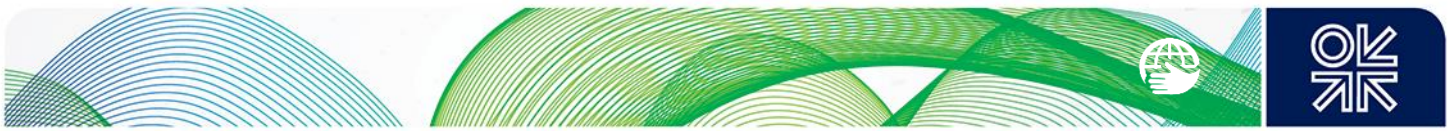
<sup>58</sup> See Ralf Dickel (2020), 'Blue Hydrogen as an Enabler of Green Hydrogen: the Case of Germany', OIES NG 159

<sup>59</sup> See <https://www.ucl.ac.uk/ccip/ccsprotocol.php>.

<sup>60</sup> Overview: <https://www.club-co2.fr/files/2021/04/IEAGHG-2021-TR02-Exporting-CO2-for-Offshore-Storage-The-London-Protocol-s-Export-Amendment-and-Associated-Guidelines-and-Guidance.pdf>.

<sup>61</sup> See <https://www.daub-ita.de/projektdatenbank/deutschland/europipe-landfall-tunnel-dornumersiel/>.

<sup>62</sup> See [http://www.ifg-leipzig.com/fileadmin/user\\_upload/News/EEK\\_2021\\_001\\_IFG-Leipzig\\_Liz\\_.pdf](http://www.ifg-leipzig.com/fileadmin/user_upload/News/EEK_2021_001_IFG-Leipzig_Liz_.pdf).



These measures would not be highly costly and no large-scale investment decision would be needed.

#### 4.6. Need for a concept for CO<sub>2</sub> handling in Germany

A concept for CO<sub>2</sub> collection pipeline systems in Germany must be developed based on the transfer point(s) at the German coast of the North Sea. The concept should address the pipeline dimension and pressure regime, fluctuation handling, routing, timing/sequencing of CO<sub>2</sub> input, and economic rules. This is also a request by the German cement industry,<sup>63</sup> which has no alternative to CO<sub>2</sub> sequestration for decarbonisation due to the nature of the cement production process. This concept should be complemented by inland ship transport for building up volumes.

As Germany does not yet have much experience with CO<sub>2</sub> handling by pipeline, it should start with collecting CO<sub>2</sub> from large industrial CO<sub>2</sub> emitters with a high load factor, which does not depend on further technological development. These include the cement industry, ammonia industry and ATRs for hydrogen production e.g. for the steel industry and other large high-load CO<sub>2</sub> volumes. Such a system would largely resonate with the existing US systems with high load factors.

These considerations suggest that CO<sub>2</sub> pipeline construction should start in regions with large CO<sub>2</sub> producing industries (i.e. cement, steel, ammonia) close to the North Sea coast, i.e. Ruhr (around 300 km) and Leipzig (450 km). A trunk line from the Rhine-Ruhr area to a transfer point, e.g., near Dornum, would be a good start because of the demand for CO<sub>2</sub> sequestration in that area and the relatively short distance of around 300 km. Such a pipeline should be built with the largest technically reasonable diameter to benefit from the economies of scale for later use and for expansion to the south of Germany.

The second phase should address CO<sub>2</sub> transportation for high volumes from load-following power and from blue hydrogen production for smaller low-load factor applications, such as the residential and commercial sectors. As far as load factors are concerned, the starting question relates to the operational requirements of CO<sub>2</sub> pipelines for a steady flow, followed by addressing the load factor as a major influence on costs along the chain.

The pipelines' load factors can be improved by storage for the part further downstream. Salt caverns close to the transfer point appear to be a clear choice for equalising streams for the offshore part of the system; newly leached or repurposed caverns near Dornum could be used for this purpose. Upstream salt caverns exist also in Sachsen Anhalt. Technically, CO<sub>2</sub> storage in salt caverns does not pose a problem. The Ketzin project<sup>64</sup> suggests that CO<sub>2</sub> storage (injection and withdrawal) also might be possible in porous storages: this could open possibilities for their use in upstream CO<sub>2</sub> streams equalisation, subject to further large-scale testing.

ATRs for the industrial use of H<sub>2</sub> will have high load factors, where their CO<sub>2</sub> streams would be steady and would not particularly entail levelling out variations. By contrast, any production of blue hydrogen for heating purposes would come with low load factors, which would be further reduced due to better building insulation.

Apart from these technological issues, appropriate and sufficient economic incentives (e.g. high CO<sub>2</sub> price) must be in place to pay for the whole chain i.e. CO<sub>2</sub> capture, treatment (quality, pressure, evening the flow) and onshore transport to the transfer point, in addition to costs beyond the transfer point (offshore transport and sequestration). Germany and the EU should ensure an adequate reliable price level for CO<sub>2</sub> abatement covering all costs along the CCS chain, including a risk-commensurable profit.

#### 5. Cooperation between Germany and Norway

Transport by ships for onshore handling and following transport by a feeder line to the place of sequestration is already a reality at the Snøhvit project and is further envisaged for the Longship project.

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<sup>63</sup> CO<sub>2</sub>-Strategie für einen klimaneutralen Industriestandort Deutschland, see <https://www.vci.de/ergaenzende-downloads/gemeinsames-papier-zu-ccs-ccu-2021-10-04.pdf>.

<sup>64</sup> See chart 11: <https://www.vdz-online.de/fileadmin/Forschung/4.pdf>.





So far, except for drilling a horizontal CO<sub>2</sub> sequestration well from the Sleipner platform into the Utsira formation, a feeder line of around 1 million tCO<sub>2</sub>/a over 100-200 km to the place of sequestration is realised for Snøhvit and is foreseen for new envisaged projects.

For a scheme with substantial volumes (>100 million tCO<sub>2</sub>/a), it is expected that transport by ships may not suffice and several large diameter pipelines would have to be built between Germany and the Norwegian Shelf to handle the volumes and for cost saving reasons. The construction and operation of such systems will be ruled by the necessities of sequestration in saline aquifers (steady flow and purity of CO<sub>2</sub>) and transport requiring pressures which are above the critical point and purity (in the US these include a minimum 95% of CO<sub>2</sub> and very low water content). This, however, raises the issue of intermediate storage needed at some place to stabilize the flow before injection.

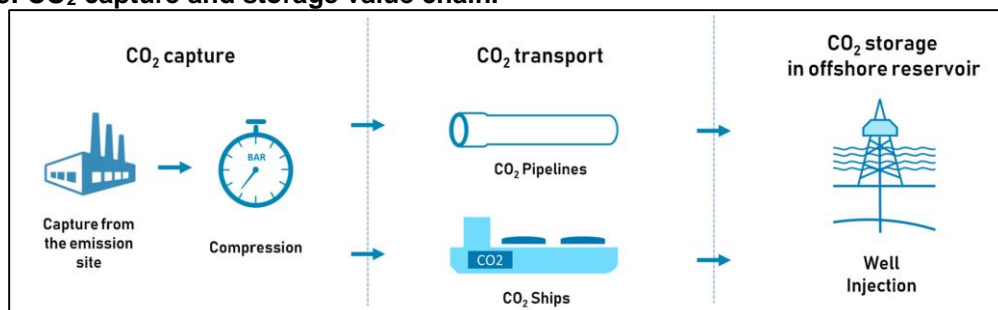
## 5.1. The CO<sub>2</sub> chain

It is worth noting here that EOR might be served with a different operational strategy however does not seem to be on Norwegian agenda and remains beyond the scope of this discussion. Functions along the chain include:

- I. Capture at the respective plant, purification, compression from gas to supercritical CO<sub>2</sub> for handover to a collection system. Subsequently, after entry to the collection system, functions include metering, quality control, and additional compression of the supercritical CO<sub>2</sub>, modulation by storage close to the entry point and/or exit point of a trunkline system to hand over a steady stream at the transfer between onshore and offshore which complies with the quality needed for transport to and injection into the chosen saline aquifers. At the point of offshore transfer, quality and pressure control and metering are again necessary. Eventually, and if possible, offshore storage for smoothing the CO<sub>2</sub> flow and finally injecting it into an aquifer is needed. After injection, control of CO<sub>2</sub> migration in the structure and the eventual certification of successful sequestration is needed.
- II. Aggregation/collection is needed into a trunkline system, bearing in mind that CO<sub>2</sub> transport is sensitive to flow and quality variations which can be difficult to trace to a specific CO<sub>2</sub> supplier. Here, CO<sub>2</sub> ownership should be transferred to/from the aggregator including transfer of liability and risk on both ends of the aggregator (i.e. at collection and at transfer points for transport to sequestration).

The aggregator collects CO<sub>2</sub> from various process run by different actors, where the aggregated flow would be delivered with specific parameters (e.g. stable flows and quality requirements) to the sequestration company(ies) which transfer it to the point(s) of sequestration and monitor its performance within geological structures. The aggregator would negotiate compensation for poor load structuring and deficiencies in quality, albeit it has to commit to deliver a steady flow on spec at the transfer point to the pipeline to sequestration at negotiated conditions.

**Figure 3: CO<sub>2</sub> capture and storage value chain.**



Source: Ansaloni et al. (2020)<sup>65</sup>

<sup>65</sup> Ansaloni, L., Alcock, B., & Peters, T. A. (2020). Effects of CO<sub>2</sub> on polymeric materials in the CO<sub>2</sub> transport chain: A review. *International Journal of Greenhouse Gas Control*, 94, 102930.





## 5.2 Economics

For an effective decarbonisation strategy, costs along the whole chain must be compensated for (inclusive of a risk-commensurate profit). Unless CO<sub>2</sub> has a commercial value – such as in the case for CO<sub>2</sub> used for EOR – additional costs are incurred which must be covered by a public financial mechanism, meaning they are eventually borne either by the taxpayer (an example is the current US model under IRS 45Q) or imposed on the industry and ultimately passed onto their customers (an example being the EU CO<sub>2</sub> pricing scheme). The immediate (*ceteris paribus*) impact on the state budget is a loss of revenues (in the US) and an increase of tax income (in the EU). Here, a carbon border adjustment (CBA) mechanism would serve to accommodate and compensate for difference in state subsidies, rather than for different decarbonisation standards.

As long as there is no market specific to CO<sub>2</sub> sequestration in the EU, the reference point is the CO<sub>2</sub> price under the EU-ETS, in addition to any extra national tax on CO<sub>2</sub> emissions. Currently, it is estimated that a price of 100€/tCO<sub>2</sub> should suffice to cover costs along the entire chain. This coincides with ongoing analysis by the National Petroleum Council in the US – targeting a price of 110-130 \$/tCO<sub>2</sub>.

## 5.3 Aspects for governments

Governments have a key role to play in mobilising CCS investments. In the context of a regime based on pricing CO<sub>2</sub> emission trading rights, this means establishing a pricing regime which is stable and predictable to justify investment decisions and one which removes all non-commercial obstacles to CO<sub>2</sub> capture and storage.

***Economic aspects for governments in Norway:*** Beyond the more administrative license fee, the country is in the longer run interested in raising a compensation for long-term liabilities after the end of the license. This could either be collected during the term of the license as a royalty (linked to the CO<sub>2</sub> price, e.g. 10% of the ETS price) or via corporate tax by deriving income from a norm price e.g. as a percentage of the ETS price, exceeding the estimated costs of CO<sub>2</sub> sequestration and transport (e.g. if 30% of the ETS price are the costs incurred in the Norwegian part of the scheme than stipulating a norm price of 30% of the ETS price would lead to taxing the normal profit, with an upside if costs are reduced or are lower than the ETS prices, or if ETS prices were to increase). Such extra tax/royalty income could be used to cover the state's costs to monitor sequestration, long-term risks and the "eternity cost".

***Economic aspects for governments in Germany:*** The German Government will lose income from CO<sub>2</sub> emission trading rights but can achieve emissions reduction while maintaining industry and jobs.

## 5.4 Financing

The incentive for the investment along the chain comes from avoiding the ETS payment, while other competitors in EU face the same costs (either ETS price or actions to avoid it). If it were only for EU competitors, the extra costs could be passed on to the final customer with some volume effects on demand, but it will be difficult to compete with equally-green products, from the US for instance, where greening is paid for by the government through other mechanisms (e.g. IRS 45Q).

Ensuring financing of the decarbonisation chain would need a credible commitment by the EU or Germany to guarantee that the ETS price will remain at a level high enough to pay for the whole chain. Reasonable coordination should also be ensured along the chain from the CO<sub>2</sub> capture to the sequestration, at least a dedication by the German State to overcome obstacles in permitting by streamlining the permitting process, including adequate staffing of the administration and courts (perhaps an approach such as used for accelerating building of new power lines might be useful).



Certainly, filling in the regulatory tasks defined by the 2012 CCS Act (on permitting, HSE standards) is urgently needed without incurring much costs.

A regulatory approach to CO<sub>2</sub> infrastructure in Germany should also be agreed upon, one which allows industry to develop and gain experience under a light-handed regime (i.e. only subject to competition law at the beginning) and more detailed regulation later on, as it becomes clearer how a sound and profitable business can be run. Taxation should favour upfront investment into economies of scale by upfront depreciation.

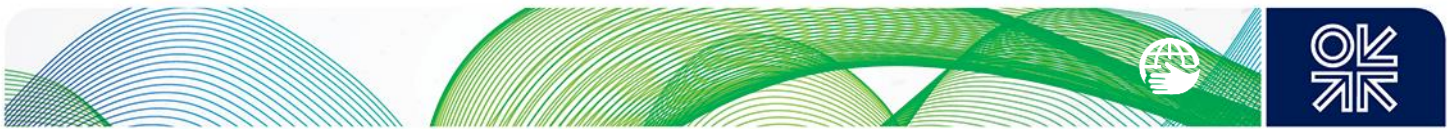
### 5.5 A business model

As noted earlier, the business case for CO<sub>2</sub> sequestration in the first instance would be the avoidance of costs of buying ETS emission rights for those participating in the EU-ETS. This assumes that the CO<sub>2</sub> price is high enough to cover the total costs of all elements of the chain, or at least for a substantial part of the decarbonization cases. In cases where it does not cover all costs of the chain, companies would have to wait until costs come down, the CO<sub>2</sub> price rises to a sustainable level or support mechanisms such as Carbon Contracts for Difference are in place.

On the Norwegian side, one way to ensure revenue could be to tax companies active in providing CO<sub>2</sub> sequestration by taxing the income from CO<sub>2</sub> sequestration by a norm price (which might be designed to cover later “eternity costs”). Such a norm price could be a certain percentage of the ETS price as described above. On that basis, companies could decide whether and how to enter the CO<sub>2</sub> sequestration part of the business. Downstream of the delivery point (offshore), functions include: transport to the point of injection, possibly with intermediate storage to help steady the flow, injection into the structure, surveillance and certification of CO<sub>2</sub> flows, and eventually maintaining or preparing a substitute structure if the original structure fails for whatever reason.

For Germany, creating a CO<sub>2</sub> pipeline collection system means breaking new ground. Points of reference might be (i) the US CO<sub>2</sub> pipelines and (ii) the existing German gas infrastructure:

- (i) While the US CO<sub>2</sub> pipelines can serve as reference for technical issues, especially safety issues, they are not well-suited as reference for economic and business models as they are predominantly point-to-point pipelines for withdrawal from geological sources for steady use for EOR compared to a variety of source points with different characteristics in Germany, and
- (ii) Looking at the present regulatory and business structure of the gas industry with unbundling and TPA does not serve as a reference for the initial phase for several reasons:
  - The CO<sub>2</sub> flow should be as steady as possible, not only in view of injection into aquifers, but also in terms of keeping the dense phase of CO<sub>2</sub>. This aspect suggests – at least for several years in the beginning – that management of these issues may be best handled by one party to gain practical experience.
  - This would also include the integration of flexibility/storage instruments which, because of the need for steadiness of flow and narrow quality margins, should be an integrated business.
  - In the beginning, the aggregator would deal with a small number of large anchor customers with individually-negotiated contracts to back the financing of the upfront investment. A change in the regulatory model might be possible but only after some time in order to support the upfront investment decision.
  - The ownership of the CO<sub>2</sub>, including all risks linked to it, should be passed to the aggregator who provides the corresponding number of certificates of disposal against a negotiated compensation. The aggregator needs to ensure the handover of a corresponding volume of CO<sub>2</sub> for sequestration at the transfer point to Norway with a corresponding number of certificates for a negotiated compensation. The transfer of CO<sub>2</sub> at the entry and exit does not need to occur simultaneously but the aggregator should always have enough certificates to hand over for the CO<sub>2</sub> taken into its system.



- In view of potential substantial economies of scale, it may be appropriate to invest upfront into larger diameter pipelines as a business decision, perhaps supported by government e.g. by early depreciation.
- In terms of its investment into a large-scale CO<sub>2</sub> transport and sequestration infrastructure, the Norwegian side may be interested in having one or only a few companies able to collect and transfer large volumes of CO<sub>2</sub> to Norway on a longer-term basis to support the necessary investment decisions.

## 5.6 Companies involved

Companies undertaking sequestration on one side and capture on the other are likely to be ones with needed skills and experience: for sequestration companies, these may include those operating in the oil and gas industry while for capture in the steel, chemical, cement industries as well as power-generating companies. In contrast, companies taking on the role of onshore collection and offshore transport are not so obvious, as are the rules for such businesses. Offshore CO<sub>2</sub> pipelines are likely to serve several CO<sub>2</sub> injection points operated by several companies, so that the offshore trunkline acts more as a common carrier (eventually with some flow moderation tasks). Yet, depending on the size of injection hubs, they may be integrated with the CO<sub>2</sub> transport pipelines.

Integrating CO<sub>2</sub> capture with its collection looks more remote except perhaps for the largest steel manufacture schemes. As such, having an independent company that takes on both collection and aggregation of CO<sub>2</sub> may be a better option. Such an entity may have shareholders from infrastructure companies (e.g. in gas), but also shareholders from upstream oil and gas companies or some large suppliers of CO<sub>2</sub>. A cross-over participation may also be sensible, for instance with a share of 25% upstream companies in the aggregator companies and 25% of aggregator companies in the upstream trunkline. This would help coordinate construction and operational activities offshore and onshore and mitigate the coordination risk.

## 5.7 Bilateral tasks between Germany and Norway

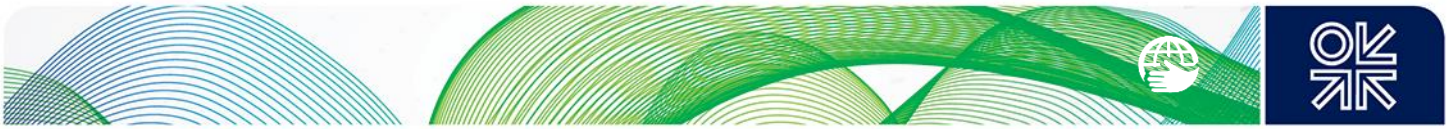
### *Transfer point(s)*

Transfer point(s) must be found between the Denmark-Germany and the Netherlands-Germany borders – areas which are subject to the Waddensee natural park rules (except for the area of shipping routes). Here, Dornum would be a suitable transfer point considering the two Europipes crossing the Waddensee in a tunnel under the natural park, and Dornum being close to the large salt caverns. Another option would be to have several transfer points, to allow for diversification and parallel aggregators, however the implications and logistics of this are to be evaluated.

### *Impacts of crossing borders*

A project between Norway and Germany includes these two countries and in addition has to cross the EEZ of Denmark. As such, major points concerning the involvement of both countries and which should be noted are:

- Need for removal of the formal obstacle of Article 6 of the London protocol. This can be done by Germany (finally) ratifying the amendment regarding non application of Article 6 for CCS and by mutual provisional application agreed between Norway and Germany as is the case between Norway and the Netherlands.
- Define criteria for certifying CO<sub>2</sub> sequestration - "Emissions accounting under the EU-ETS: The current monitoring system at Sleipner is not directed towards the requirements of emissions accounting which require some form of quantitative assessment of site leakage. In fact, even if



Sleipner were operating under European CCS regulations, there would not currently be a requirement for emission accounting as there is no evidence that the site might be leaking.”<sup>66</sup>

- Managing issues relating to an offshore pipeline system between Norway and Germany, which could be covered by an intergovernmental agreement and joint committee such as that for Norpipe, while ensuring that crossing the Danish side in line with UNCLOS is possible.
- Coordination at a governmental level including:
  - I. Legal, London protocol article 6, provisional application
  - II. Coordination of building up volumes, target volumes
  - III. Basic economics (offshore: royalty or tax with norm price)
  - IV. Onshore: Ensure high enough ETS prices for CO<sub>2</sub> avoidance
- Coordination at a company level including:
  - I. Structure of aggregator company, offshore transport company, possibly including cross-over participation
  - II. Coordination of construction
  - III. LTCs for horizontal interface at transfer point to offshore dealing with transfer of ownership, liability for CO<sub>2</sub>, certification of orderly disposal, payment, steady flow, quality, volumes commitment on both sides (based on LTCs with capture companies)
  - IV. Load and flow management in line with injection needs
  - V. Quality control, measurement, communication interface, certification

From the above, it becomes clear that new rules or amendments to existing rules need to be established or actions taken in order to promote the possibility of CO<sub>2</sub> export from Germany to Norway, most specifically:

- Provisional application of Amendment on Article 6 of the London protocol, using the case of Norway and Netherlands as a blueprint
- Establishment of rules for construction and operation of CO<sub>2</sub> pipelines in Germany
- Development of technical skills for CO<sub>2</sub> capture in Germany
- Establishment of a joint committee to discuss:
  - I. Coordination of large pipeline systems, specs and standards, certification procedures
  - II. Provisional application of amendment to London protocol
  - III. Volume coordination, building up of injection capacity and infrastructure, build-up and target volumes, coordination pipeline systems, definition transfer point, definition of CO<sub>2</sub> specifications

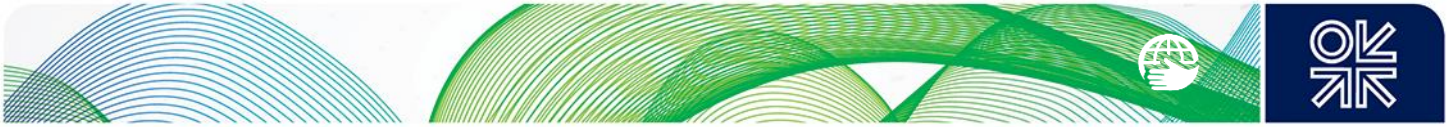
## 6. Conclusions

The opportunity offered by Norway to sequester large volumes of CO<sub>2</sub> under its shelf in the North Sea is one that Germany should use to meet its ambitious net-zero goal for 2045. While the infrastructure needed on both sides requires vast investments, coordination and regulatory and legal efforts, endeavours of comparable scale have been achieved by cooperation between both countries in the past such as the successful development of the Troll gas export project and the infrastructure linked to it both offshore and onshore and the development of its market in less than 20 years. The opening of

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<sup>66</sup> Ibid.





the NordLink cable in 2021 is another example of a successful cooperation. One important conclusion is the need to develop a joint vision on the necessary development in the short time (and the limited size of the CO<sub>2</sub> budget) left, and to create procedures and institutions needed for cooperation and coordination.



## Appendix: Transport Infrastructure

By ships or by pipeline (CO<sub>2</sub> in super-critical state becomes similar to a fluid which can be pumped and needs high enough pressure – in practice more than 100 bar is used). Transport by ships is advantageous in the beginning or flexibility reasons; but pipeline transport offers better economics. Offshore pipelines have a limited reach (without intermediate compression) up to about 1000 km while ship transport has no limits.

### CO<sub>2</sub> transportation by ships

- Ship transportation of CO<sub>2</sub> has been taking place for nearly 20 years, although only in small parcels for industrial and alimentary purposes. For large volumes required for CCS purposes it is likely that the CO<sub>2</sub> will be carried at 7-9 bars and down to around -55°C, which is practically the same cargo condition as that of the significant fleet of Semi-Ref LPG carriers currently in operation.
- Ships are more flexible for building up the market, compared to fixed CO<sub>2</sub> pipelines with high economies of scale.

### CO<sub>2</sub> transport by pipeline

- The US has 50 years of experience of CO<sub>2</sub> transportation by onshore pipelines.<sup>67</sup> The largest is the Cortez Pipeline of Kinder Morgan, which has 19.3 million tCO<sub>2</sub>/a capacity, 803 km length, 30-inch diameter and operates at a pressure of 186 bar.<sup>68</sup> Overall, 66 Mtpa are handled by CO<sub>2</sub> pipelines in the US. CO<sub>2</sub> has been safely and reliably transported in the United States via large-scale commercial pipelines since 1972. During the last 50 years, there have been no fatalities associated with the transportation of CO<sub>2</sub> via pipeline.<sup>69</sup>
- So far, there are several disjoint CO<sub>2</sub> transportation systems in the US. A strategy for CO<sub>2</sub> reinjection was presented in December 2019 by the National Petroleum Council,<sup>70</sup> which recommended considering 2-3 large trunk lines to collect CO<sub>2</sub> from industrial sources for EOR and sequestration.
- Offshore pipelines are in operation for offshore CO<sub>2</sub> injection at Sleipner (160 km) and the Snoehvit project (153 km).<sup>71</sup>
- CO<sub>2</sub> pipelines are usually run at a pressure where CO<sub>2</sub> is in its superfluid state where CO<sub>2</sub> behaves as a fluid that can be pumped (cheaper than compressors).
- Repurposing onshore gas pipelines (with pressure of max 100 bar) does not seem sensible due to the differences in the pressure regime (the pressure of CO<sub>2</sub> pipelines in the US is designed for 151.7 bar (2200 psig)).<sup>72</sup>
- CO<sub>2</sub> impurities can play an important role in the design and operation of CO<sub>2</sub> pipelines.<sup>73</sup> In the US, the concentration of CO<sub>2</sub> in pipelines is generally above 95%.

<sup>67</sup> A concise overview of the US CO<sub>2</sub> pipeline system and the experience from it is given in NPC, Meeting the Dual Challenge, Chapter 6, <https://dualchallenge.npc.org/>.

<sup>68</sup> See [http://publications.europa.eu/resource/cellar/4ab1c4e2-398e-426c-b06f-1175d3c5a403.0001.02/DOC\\_1](http://publications.europa.eu/resource/cellar/4ab1c4e2-398e-426c-b06f-1175d3c5a403.0001.02/DOC_1), p. 3.

<sup>69</sup> *Ibid.*, pp. 6-8.

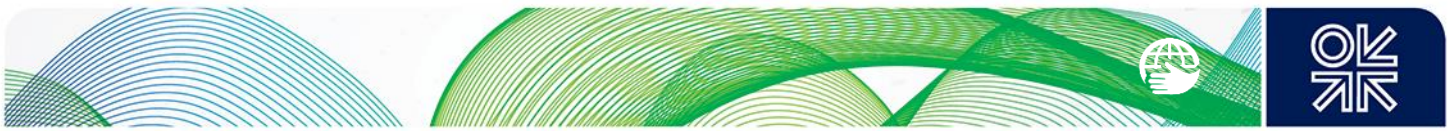
<sup>70</sup> US National Petroleum Council (2019): "Meeting the dual challenge", December 2019

[https://dualchallenge.npc.org/files/CCUS\\_V1-FINAL.pdf](https://dualchallenge.npc.org/files/CCUS_V1-FINAL.pdf)

<sup>71</sup> See: <http://www.zeroco2.no/projects/snoehvit> and [https://dualchallenge.npc.org/files/CCUS-Chap\\_6-030521.pdf](https://dualchallenge.npc.org/files/CCUS-Chap_6-030521.pdf) page 6-3/4; also JRC paper, p. 3.

<sup>72</sup> See NPC, Chapter 6, updated 12 March 2021: [https://dualchallenge.npc.org/files/CCUS-Chap\\_6-030521.pdf](https://dualchallenge.npc.org/files/CCUS-Chap_6-030521.pdf).

<sup>73</sup> *Ibid.*, pp. 6-10 ff.



- From Snoevhit raw gas to onshore liquefaction plant, the separated CO<sub>2</sub> is transported by a 150 km pipeline to an offshore subsea completion well.
- In the Longship project, CO<sub>2</sub> is transported by ship to the transfer point, from there to injection offshore by subsea pipeline.

### Generic rules and requirements

Economies of scale of diameter applies; cost are roughly proportionate to the diameter, while capacity is proportionate to the power of 2.5 of the diameter: a doubling of diameter results in an increase of capacity by a factor 5.5 or an increase of one third of the diameter doubles the capacity.<sup>74</sup>

The need for a pig catcher for a larger offshore pipeline suggests some fixed platform in case of a direct pipeline from Germany to the place of sequestration. A practical issue (on volumes) is the use of some central infrastructure vs many (smaller) spur lines from the shore instead of the use of several subsea completion templates.

Onshore, the existing pressure limitations of gas pipelines (pressure not exceeding 100 bar, usually less than 80 bars) suggests that repurposing of onshore gas pipelines will in general not work. Offshore pressures are higher, but gas export pipelines are still in use for some decades. This suggests a completely new design upstream (onshore) and downstream (offshore).

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<sup>74</sup> For an overview on CO<sub>2</sub> pipeline design see: [https://mdpi-res.com/d\\_attachment/energies/energies-11-02184/article\\_deploy/energies-11-02184.pdf?version=1534854457](https://mdpi-res.com/d_attachment/energies/energies-11-02184/article_deploy/energies-11-02184.pdf?version=1534854457)



## Appendix: International Law on Cross Border Transfer of CO<sub>2</sub>

Cross-border transfer of CO<sub>2</sub> and especially for sequestration under the North Sea is subject to international legislation. Despite its environmental merits, CO<sub>2</sub> sequestration is not yet fully supported by international law, mainly due to the long time it takes to achieve the number of ratification instruments needed.

The following addresses the most important international legislations relevant to the transport and sequestration of CO<sub>2</sub> from Germany under the Norwegian Shelf. An analysis of international laws involved in cross-border transport of CO<sub>2</sub> was provided by the UNFCCC in its 2012 technical paper “Transboundary carbon capture and storage project activities”<sup>75</sup>. A more recent analysis on issues related to exporting CO<sub>2</sub> from Sweden (an EU member country) to Norway is also provided in a SINTEF report published in January 2022 on the legal and regulatory framework for Swedish/Norwegian CCS cooperation<sup>76</sup>. Both reports highlight the importance of overcoming the restrictions stemming from Article 6 of the London Protocol for CO<sub>2</sub> crossing a border for sequestration under the sea.

### The London Protocol (LP), Amendment, Guidelines and Guidance

A comprehensive overview of the London Protocol and its Amendments and guidelines is provided by the IEA GHG technical Review 2021-TR02 (April 2021)<sup>77</sup>:

“The London Convention [...] of 1972, entered into force in 1975, and the London Protocol of 1996, in force since 2006 [...] are the global treaties that protect the marine environment from pollution caused by the dumping of wastes. Since 2006 the London Protocol has provided a basis in international environmental law to allow carbon dioxide storage beneath the seabed when it is safe to do so, and to regulate the injection of CO<sub>2</sub> into sub-seabed geological formations for permanent isolation. However, Article 6 of the London Protocol prohibits the export of waste or other matter for dumping in the marine environment. Therefore, in 2019, Contracting Parties to the London Protocol adopted a resolution to allow provisional application of the 2009 amendment to Article 6 of the Protocol to allow export of CO<sub>2</sub> for storage in sub-seabed geological formations in advance of its ratification, which was progressing slowly. This removed the last significant international legal barrier to carbon capture and storage (CCS), and means that CO<sub>2</sub> can be transported across international borders to offshore storage”.<sup>78</sup>

“[...] Article 6 of the London Protocol prohibits export of waste or other matter for dumping in the marine environment, the intention being to stop Parties exporting their waste to non-Parties as a backdoor route of dumping. Cross-border transport of carbon dioxide for the purpose of permanent geological storage below the seabed was therefore prohibited, but there may well be a need for such export in the situation where a Party does not have sufficient suitable geological storage capacity but may still wish to use CCS to reduce emissions.”<sup>79</sup>

“The 2009 amendment effectively allows CO<sub>2</sub> streams to be exported for CCS purposes (provided that the protection standards of all other LP (London Protocol) have been met) between cooperating countries. The responsibilities have to be clearly agreed between cooperating countries”.<sup>80</sup>

“However, the 2009 export amendment is not yet in force as it needs to be ratified by being formally accepted by two-thirds of the Parties to the London Protocol and will then come into force globally 60 days later. Acceptance had been extremely slow with just six of 53 Contracting Parties (Norway, UK, Netherlands, Iran, Finland and Estonia) having accepted the amendment by 2019, meaning that there

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<sup>75</sup> United Nations FCCC/ TP/2012/9 : <https://unfccc.int/resource/docs/2012/tp/09.pdf>

<sup>76</sup> [https://www.preem.se/globalassets/om-preem/hallbarhet/preemccs---d4.2\\_legal-and-regulatory\\_final.pdf](https://www.preem.se/globalassets/om-preem/hallbarhet/preemccs---d4.2_legal-and-regulatory_final.pdf)

<sup>77</sup> <https://www.club-co2.fr/files/2021/04/IEAGHG-2021-TR02-Exporting-CO2-for-Offshore-Storage-The-London-Protocol-s-Export-Amendment-and-Associated-Guidelines-and-Guidance.pdf>

<sup>78</sup> *ibid*

<sup>79</sup> *ibid*

<sup>80</sup> *ibid* page 3





was still a legal barrier to exporting CO<sub>2</sub> from one country to another for offshore geological storage projects”.<sup>81</sup>

“In 2019, Norway and the Netherlands looked into options to address this barrier to cross-national collaboration on CO<sub>2</sub> capture and permanent geological storage in sub-seabed formations, in line with the Vienna Convention on the Law of treaties (VCLT) Article 25. This article states that a treaty or part of a treaty is applied provisionally pending its entry into force if (a) the treaty itself so provides or (b) the negotiating states have in some other manner so agreed.

Consequently, there was a proposed Resolution on the provisional application of the 2009 amendment to Article 6 of the London Protocol, co-sponsored by the Netherlands and Norway and submitted to the Forty-first Consultative Meeting of Contracting Parties to the London Convention and Fourteenth of Contracting Parties to the London Protocol (LC41/LP14) held in October 2019.

“A provisional application in this case was identified to be an interim solution to enable two countries to apply the 2009 CO<sub>2</sub> export amendment, pending its entry into force: the rationale being to allow states to provide their consent to cross-border transport of CO<sub>2</sub> for the purpose of geological storage without being non-compliant with international commitments. The co-sponsors further argued that the London Protocol did not provide for provisional application in itself. Therefore, provisional application of an amendment to the London Protocol could be based on an agreement between the negotiating state, according to the VCLT, which provided the legal basis for provisional application of a treaty in international law”.<sup>82</sup>

“The provisional application of the 2009 amendment to Article 6 of the London Protocol now means that two or more countries can agree to export CO<sub>2</sub> for geological storage. In order to do so they must deposit a formal declaration of provisional application with the Secretary-General of the International Maritime Organisation (IMO), which provides the Secretariat for the London Convention and the London Protocol and is the depositary organisation for the London Protocol. Countries must also notify the IMO of any agreement for permitting and responsibilities between the Parties following the existing guidance”.<sup>83</sup>

“At the 2020 meeting of the Contracting Parties to the London Protocol it was reported that the IMO had received declarations of provisional application of the 2009 amendment from the Governments of Norway and the Netherlands”.<sup>84</sup>

A recent project report for Swedish/Norwegian CCS cooperation by SINTEF<sup>85</sup> concludes that “it should be noted that countries can deposit unilateral declarations on the provisional application of the 2009 Amendment to the LP Article 6, even if they have not ratified the amendment to Article 6”.<sup>86</sup>

### **Crossing third-party territory (here: crossing Denmark between the German and the Norwegian sectors)**

The UNFCCC report on transboundary carbon capture and storage project activities analyses a scenario with capture in Party A (here Germany) and storage in Party B<sup>87</sup> (Norway) while crossing a third-party's EEZ (Denmark):

“In the case of offshore transportation by pipeline, under UNCLOS the right to lay a pipeline across the continental shelf rests with all States, provided that the coastal State consents to the delineation[...]. A coastal State cannot impede the laying of a pipeline, but may take reasonable measures to ensure that

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<sup>81</sup> *ibid*

<sup>82</sup> *ibid* page 6

<sup>83</sup> *ibid* page 8

<sup>84</sup> *ibid*

<sup>85</sup> [https://www.preem.se/globalassets/om-preem/hallbarhet/preemccs---d4.2\\_legal-and-regulatory\\_final.pdf](https://www.preem.se/globalassets/om-preem/hallbarhet/preemccs---d4.2_legal-and-regulatory_final.pdf)

<sup>86</sup> *Ibid* page 13/14

<sup>87</sup> United Nations FCCC/ TP/2012/9: <https://unfccc.int/resource/docs/2012/tp/09.pdf>



the delineation does not impinge on its rights to explore and exploit the natural resources within its territory and take steps to prevent pollution from the pipeline”.<sup>88</sup> The state through whose EEZ a pipeline is built can impose reasonable Health, Safety and Environmental (HSE) standards, as was the case for the Norpipe gas pipeline from Ekofisk in the Norwegian EEZ to Emden in Germany crossing the Danish sector.

The “Legal and regulatory framework for Swedish/Norwegian CCS cooperation” report assesses the need of provisional application of the amendment to Article 6 of the London Protocol for countries with offshore transit such as Denmark in the case of exporting CO<sub>2</sub> from Germany to Norway: “It is the authors’ understanding that the unilateral declaration of the provisional application of the amended Article 6 is only necessary for the two countries exporting and receiving CO<sub>2</sub>, and for the purpose of offshore storage. This means that a ship carrying CO<sub>2</sub> can pass through the territorial waters of a third country, without the third country having to deposit a unilateral declaration to the IMO or enter into an agreement with the exporting and receiving countries”.<sup>89</sup>

This conclusion is likely to also apply for CO<sub>2</sub> transport by pipeline, provided the pipeline meets the HSE norms applied by the transit country under UNCLOS.

## OSPAR

The Convention for the Protection of the Marine Environment of the North-East Atlantic (the ‘OSPAR Convention’) was open for signature at the Ministerial Meeting of the Oslo and Paris Commissions in Paris on 22 September 1992. It was adopted together with a Final Declaration and an Action Plan. In this decade, the Convention will be implemented through OSPAR’s North-East Atlantic Environment Strategy 2030.<sup>90</sup>

The OSPAR Convention is concerned with protecting the marine environment in the NE Atlantic. A CCS amendment to OSPAR was published in June 2007 and is still in the process of ratification by partner nations. CCS requirements under OSPAR are focused around robust site selection and characterization; risk characterization and management, environmental exposure and impacts. Monitoring is a key OSPAR requirement. It should be carried out throughout a project, must be linked to the risk assessment and focus on specific issues including performance verification, leakage monitoring, monitoring local environmental impacts and demonstration of emissions reduction efficacy.

## EU directive and rules

CO<sub>2</sub> collected and transferred for transport to CO<sub>2</sub> sequestration sites can be subtracted from CO<sub>2</sub> emissions of the capturing site. Also transport and sequestration of CO<sub>2</sub> are considered – under certain conditions – a substantial contribution to climate change mitigation under the delegated taxonomy regulations.

## Subtraction under the EU-ETS

The EU Emission Trading System (EU-ETS) allows subtracting the CO<sub>2</sub> emissions that are captured and transported for storage. Up till now in the EU-ETS CO<sub>2</sub> transport network has been defined as transport by pipelines. A clarification regarding CO<sub>2</sub> transport by ship was requested by Norway in 2019. In a letter in July 2020, the EU Commission agreed with the Norwegian view that when the transfer of CO<sub>2</sub> from ship or truck to the pipeline transport network or storage is completed the capture installation can subtract the CO<sub>2</sub> from its emissions.<sup>91</sup>

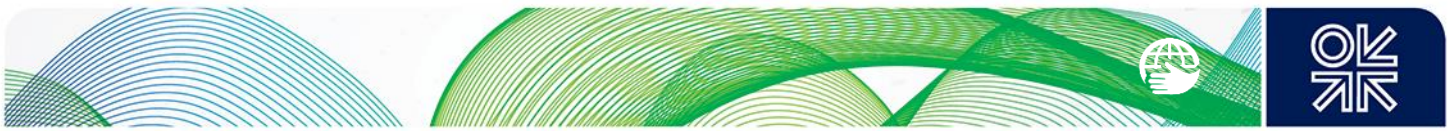
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<sup>88</sup> Ibid 26/27

<sup>89</sup> [https://www.preem.se/globalassets/om-preem/hallbarhet/preemccs---d4.2\\_legal-and-regulatory\\_final.pdf](https://www.preem.se/globalassets/om-preem/hallbarhet/preemccs---d4.2_legal-and-regulatory_final.pdf), page 14

<sup>90</sup> <https://www.ospar.org/convention>

<sup>91</sup> [https://www.preem.se/globalassets/om-preem/hallbarhet/preemccs---d4.2\\_legal-and-regulatory\\_final.pdf](https://www.preem.se/globalassets/om-preem/hallbarhet/preemccs---d4.2_legal-and-regulatory_final.pdf)



## EU delegated taxonomy regulations

“The delegated taxonomy regulation sets technical screening criteria for “Transport of CO<sub>2</sub>” (Activity 5.11) and “Underground permanent geological storage of CO<sub>2</sub> (Activity 5.11). With regard to transport of CO<sub>2</sub> the following criteria must be met:

- The CO<sub>2</sub> transported from the installation where it is captured to the injection point does not lead to CO<sub>2</sub> leakages above 0.5% of the mass of CO<sub>2</sub> transported.
- The CO<sub>2</sub> is delivered to a permanent CO<sub>2</sub> storage site that meets the criteria for underground geological storage of CO<sub>2</sub> or to other transport modalities, which leads to permanent CO<sub>2</sub> storage that meet those criteria.
- Appropriate leakage detection systems are applied, and a monitoring plan is in place, with the report verified by an independent third party.

With regard to Activity 5.12, the screening criteria refers to the CCS Directive for characterisation and assessment of the potential storage complex and surrounding area, and that the site has an appropriate leakage detection system and a monitoring plan of the injection facilities, the storage complex, and the surrounding environment”.<sup>92</sup>

## EU CCS Directive

“The European Union (EU) CCS directive is considered to be the first comprehensive legal framework for the management of environmental risks related to CCS. It aims to ensure that CCS technology is deployed in an environmentally safe way within the territory of the EU member States. As such, it provides a number of CCS-specific requirements and amends other pieces of EU legislation to extend their application to CCS.”<sup>93</sup>

“The European Directive on Storage was published in April 2009 and builds upon many of the OSPAR principles. Monitoring is a key requirement and is framed around enabling the operator to understand and to demonstrate understanding of current site processes, to identify any leakages and to predict future site behaviour. Further requirements of the monitoring include early identification of deviations from predicted site behaviour, provision of information needed to carry out remediation actions and the ability to progressively reduce uncertainty. In other words, monitoring should effectively underpin the project risk management plan”.<sup>94</sup>

“Perhaps the most challenging elements of the current regulations are the arrangements for site closure i.e. transfer of liability from the operator to the State. The overall philosophy of the EU Directive is enshrined in the three minimum geological criteria for transfer of liability:

- Observed behaviour of the injected CO<sub>2</sub> is conformable with the modelled behaviour.
- No detectable leakage.
- Site is evolving towards a situation of long-term stability.

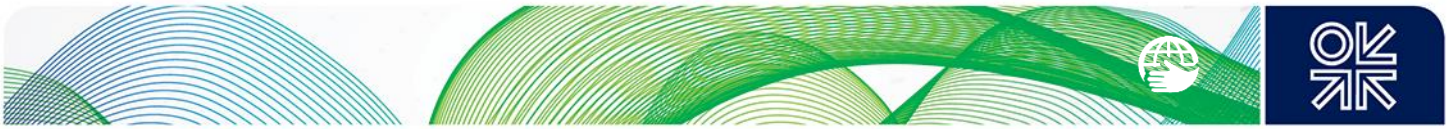
The first two bullets have been covered above. The requirement concerning demonstration of long-term stabilization is more challenging and depends almost exclusively on long-term predictive simulation of site behaviour. Post-injection monitoring will be a requirement, and this can help establish the path to long-term stabilization, but the ability of short-term monitoring to convincingly support such long-term forecasts will always be limited. For Sleipner, the key stabilization process is dissolution of free CO<sub>2</sub> into the reservoir pore-waters. The current non-invasive monitoring programme is unable to do this

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<sup>92</sup> ibid page 16

<sup>93</sup> United Nations FCCC/ TP/2012/9: <https://unfccc.int/resource/docs/2012/tp/09.pdf>

<sup>94</sup> [https://nora.nerc.ac.uk/id/eprint/508611/1/Sleipner\\_Chapter\\_V5\\_withFigs\\_singlespace.pdf](https://nora.nerc.ac.uk/id/eprint/508611/1/Sleipner_Chapter_V5_withFigs_singlespace.pdf)



process directly. However, the time-lapse gravimetry, as discussed above might be able to provide some constraints.<sup>95</sup>

### **Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal<sup>96</sup>**

The Basel Convention may or may not be an obstacle to cross-border CO<sub>2</sub> transport. The UNFCCC comes to the following assessment:

“There is a debate as to whether CO<sub>2</sub> falls within the definition of a hazardous waste for the purposes of transboundary movement, with some noting that CO<sub>2</sub> in some forms may have characteristics that could bring it within the definition of a hazardous waste”.<sup>97</sup>

“If CO<sub>2</sub> is characterized as a hazardous waste under either the Basel Convention or the Bamako Convention (see paras. 36-40 above), then its export from Party A to Party B may be prohibited. Where the export of CO<sub>2</sub> is not prohibited and Party A and Party B are both parties to the same waste-related Convention (e.g. the Basel Convention), it remains open for Party B to refuse to consent to the import of the CO<sub>2</sub>. If consent is given, the export may still need to be carried out in accordance with appropriate technical guidelines or codes of practice and may be subject to a number of conditions, related to, for example, labelling, notice and tracking. Furthermore, insurance, bonds or other guarantees may need to be in place. Consequently, a layer of international rules in addition to the CDM (Clean Development Mechanism) rules may apply if CO<sub>2</sub> is characterized as a hazardous waste”.<sup>98</sup>

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<sup>95</sup> *ibid*

<sup>96</sup> <http://www.basel.int/TheConvention/Overview/Milestones/tabid/2270/Default.aspx>

<sup>97</sup> <https://unfccc.int/resource/docs/2012/tp/09.pdf> , page 9

<sup>98</sup> <https://unfccc.int/resource/docs/2012/tp/09.pdf> , page 19