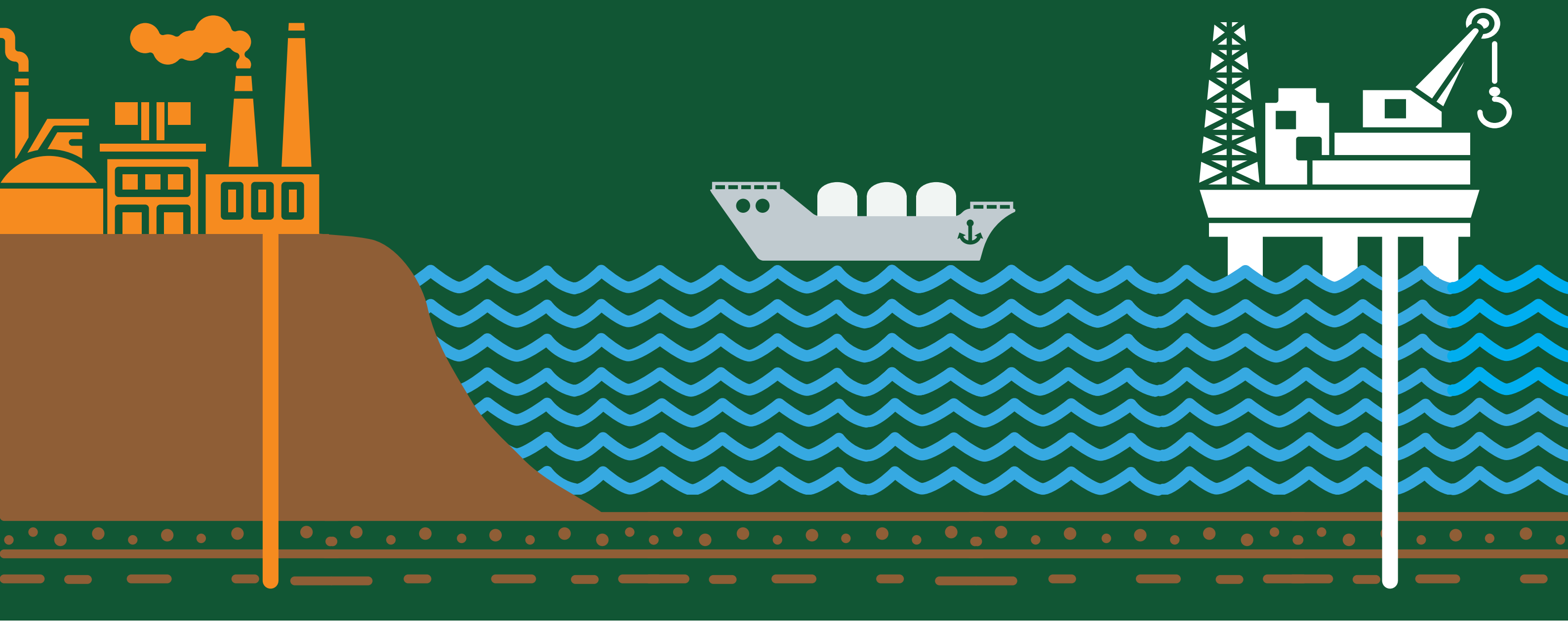
THE POTENTIAL FOR CARBON CAPTURE AND STORAGE IN DENMARK



DENMARK'S GREEN THINK TANK

The potential for Carbon Capture and Storage in Denmark

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Table of content

Highlights

CCS as a climate instrument

- Carbon capture and Storage (CCS) in Denmark can provide important emission reductions towards 2030 by capturing and storing CO_2 from emission sources that are difficult to avoid.

- The first large scale CCS project in Denmark is expected to be operational by 2026, capturing and storing minimum 0.4 Mt. Two grant funding programs for CCS has been established by the Danish government with a total budget of EUR 4.6 billion as well as a subsidy for negative emissions with a budget of EUR 0.34 billion. The total expected reduction from these measures is 3.2 Mt CO_2 in 2030.

- CONCITO's analyses shows that waste incineration plants, biogas plants and some industrial processes provide reasonable and sustainable sources for carbon capture in Denmark. These sources can contribute with up to 1 Mt CO_2 reductions in 2026 and at least 5 Mt in 2030. To reach this potential, a combination of carbon taxes and subsidies for negative emissions is necessary combined with an effective implementation plan.

- 5 Mt corresponds to CCS delivering around 25% of the necessary reduction between 2020 to 2030 to achieve the Danish climate target of reducing GHG emissions 70% by 2030, compared to 1990. CONCITO recommends the Danish government to aim well above 70% to allow for delays in implementation of both CCS and other mitigation efforts.

Capture potential

- Not all point sources are suitable for CCS. Coal and gas are being phased out. CCS on biomass heat- and power plants (CHP) will be relatively expensive due to decreasing operating hours in the future. Moreover, CCS on biomass CHP has a limited climate benefit since a high consumption of biomass, in practice, is not carbon neutral. Thus, CCS on biomass may not be economical in the long run or running risk of creating/sustaining the Danish dependency on an unsustainably high consumption of biomass for energy.

CCS is a tool for both reducing CO_2 emissions and carbon removal

- CCS in Denmark can contribute to reducing emissions from hard-to-abate sectors with no other feasible alternative (e.g., cement). Moreover, part of the CCS potential can contribute to carbon dioxide removal (CDR) if applied to biogenic CO_2 sources from using sustainable waste resource (biogas plants, waste incineration and industrial sources with biogenic fuels).

- Some of the Danish CCS potential may be realized with a high carbon tax on fossil CO_2. The national carbon tax and the EU ETS may be enough to realize part of the potential. However, most of the CCS potential is on biogenic sources, which are not covered by the Danish carbon tax or the EU ETS. Therefore, a subsidy for these negative emissions is needed and CONCITO recommends Denmark to introduce a fixed negative carbon tax.

- Since biogenic waste is a limited resource, carbon removal from using biomass must also be treated as a finite resource. CONCITO thus recommends Denmark to introduce a support ceiling for CDR at the level of the sustainable amount of carbon available for negative emissions. The sustainable amount of biomass carbon available must be explores further and in relation to other uses for biomass, before scaling up CCS on biogenic carbon.

Storage potential

- Denmark aims to become an importer of CO_2, The Danish CO_2-storage potential is at gigaton scale and thus well suited for import of CO_2 if the storage sites in development can provide cost-effective storage solutions.
- CONCITO recommends the Danish government, and neighboring countries, to establish close cooperation on developing CO_2-infrastructure and common planning to accelerate CCS and cross-border trade of CO_2.
- There are currently two Danish offshore storage projects in development in the Danish part of the North Sea: Project Greensand and Project Bifrost. Both have received government funding for further development.
- Project Greensand, led by INEOS and Wintershall Dea, will inject the first CO_2 in March 2023 and aims to establish a capacity of 1.5 Mt in 2026 and 8 Mt in 2030.
- Project Bifrost, led by Total Energies, aims to store 3 Mt per year before 2030 and explore the potential further.
- The Danish Energy Agency and the Geological Survey of Denmark and Greenland (GEUS) are currently exploring several Danish onshore storage sites.
- A small pilot onshore storage site is expected to be ready for operation in 2025 with approved storage capacity of 10 Mt.
- One private developer, Fidelis Energy, has announced plans for developing onshore storage sites of 20 Mt per year in 2030, with the aim of importing CO_2 from e.g. Germany and Sweden.
- Cooperation between Denmark and neighboring countries can contribute to advancement and development of large-scale storage capacity in Denmark, which may provide price competitive solutions for storage in the future

CO2 utilization as e-fuels

- From an economic point of view, storage is cheaper than producing fuels with CO_2 (carbon, capture and utilization, CCU). Thus, using CO_2 for producing e-fuels seems less effective than storing CO_2.
- From a climate perspective, CCS has the same climate benefit as CCU, but with a much lower energy demand. Thus, storage of CO_2 can provide a further indirect climate benefit compared to CCU, as it saves green electricity which will be a scarce resource for decades and thus necessary to prioritize. Energy savings from storing CO_2 instead of producing e-fuels, can be used to replace fossil fuels with direct electrification of e.g. heating and transport, or to replace grey hydrogen with green hydrogen in industry.

The momentum for CCS in Denmark

Within the last few years carbon capture and storage (CCS) has moved from a rather contested climate-instrument to a necessary part of the climate-solution.

This is largely driven by the Danish climate target of 70% reduction of greenhouse gases (GHG) by 2030 compared to 1990. The target, adopted in 2019, put pressure on parliament to pursue all reasonable mitigation technologies.
Moreover, the independent climate advisor to the government and parliament, The Danish Council on Climate Change published a report in 2020 on how to achieve the 70% target in 2030, where it defined CCS as a 'crucial' part of this transition.

Within the last two years, a combination of subsidies and carbon-taxes has been approved by the Danish Parliament to scale-up CCS among other technologies. The government estimates that the planned funding and taxes together will realize CO_2 reductions of 0.9 Mt in 2026 and 3.2 Mt in 2030.

By the end of 2022, the newly elected government proposed a climate neutrality target in 2045, instead of 2050, and introduced a "110%" target in 2050, meaning an ambition to become net-climate negative by then.
CONCITO estimates that the feasible level of CCS from Danish sources, in terms of costs and climate impact, is around 5 Mt in 2030. This corresponds to around about 25% of the remaining reductions between 2020-2030 necessary to achieve the Danish climate target of 70%. Although this is a major part of the transition in the coming years, it is still a limited part of the total necessary mitigation effort to achieve climate neutrality.

CCS can be perceived as a mitigation technology when applied to point sources with fossil CO_2, and a carbon removal technology when applied to points sources with biogenic CO_2, or directly from the air. A large part of the CCS potential in Denmark is actually from biogenic sources and most CCS in Denmark may therefore be counted as carbon removals. Using only sustainable waste-biomasses and treating this like a limited resource is thus crucial to secure an actual climate benefit.

By achieving this target Denmark can contribute to the development of CCS technology and further showcase how the technology fit into an ambitious climate policy.
Moreover, by developing storage capacity, Denmark can become a cost-effective CO_2-storage location for neighboring countries, such as Germany. This may contribute to accelerating decarbonization of German industry with transport of CO_2 by ship or a possible pipeline connection to Denmark.

Incentives for CCS

The main incentives driving the development of CCS are a combination of 1) national funding schemes, 2) the EU ETS and 3) a national carbon price.

Carbon taxes

In Denmark, the EU emissions trading scheme (ETS) covers waste incineration and most major industrial processes, including cement production, which is responsible for a large part of industrial emissions in Denmark. The increase in the ETS price provides some incentive to reduce emissions but it will not be enough to drive all the necessary reductions from the sectors in order to achieve the Danish climate target in 2030.

In June 2022 a great majority of the Danish parliament agreed to introduce a carbon tax on all sectors, excluding road transportation, agriculture and the land-use sector[1]. The level of the national carbon tax differs between sectors and industries but will be implemented gradually from 2025 to 2030. The tax floor is 100 EUR/ton for non-ETS industries, 50 EUR/ton for ETS industries and 13.5 EUR/ton for mineralogical processes (on top of an expected EUR 100 EU ETS price).

Although waste incineration in Denmark is included in the EU ETS, they will also be covered by the tax of 100 EUR/ton in 2030 for their emissions related to heating, which is the majority of emissions. Hence, waste incineration will thus have to pay close to 200 EUR/ton of CO_2 emitted in 2030 and thus receive a high incentive to avoid emitting CO_2.

However, the taxes only cover fossil CO_2 emissions and not biogenic emissions occurring from waste incineration, biomass CHP and biogas upgrading. However, the agreement on the CO_2 tax is accompanied by a subsidy scheme described below, which may be relevant to biogenic sources of CO_2.

Funding programs

Two grant funding programs for CCS has been established by the Danish government, the CCUS fund and the NECCS fund. The Danish Green Tax Reform also includes funding for negative emissions as described in table 1.

The CCUS Fund aims to establish large-scale carbon capture in Denmark from 2025 and realize CO_2 reductions of 0.4 Mt per year from 2026 and 0.9 Mt from 2030. The CCUS fund will grant a total of EUR 2.15 billion from 2025 and the following 20 years.

The Danish Energy Agency has pre-qualified three applicants for the CCUS Fund first round. They are expected to deliver the final offer at the end of March 2023. The winner of the first tender is expected in May 2023, after a number of delays, and will be awarded a maximum om EUR 1,1 M, incl. VAT, for up to 20 years (approx. EUR 0.5 M/year).

The three potential beneficiaries are:

- **Vestforbraending**, which is the largest waste incineration and waste management company in Denmark,
- **Orsted**, which among other things, owns a number of biomass heat- and power plants
- **Aalborg Portland**, a cement producer with a capacity to produce 3 Mt cement and the largest point source in Denmark emitting 2.2 Mt CO2 in 2021.

1 For agriculture and land-use the parliament is awaiting recommendations from an expert working group due to deliver recommendations during 2023.

The NECCS fund seeks to realize 0.5 Mt of negative emissions in 2025 through CCS. The fund has a total budget of EUR 340M and supports negative emissions from carbon capture at biogas upgrading plants with subsequent underground storage, production of biochar through pyrolysis in agricultural land, and Direct-Air-Capture.

Except for the ongoing tender, details regarding allocation of remaining funds have yet to be decided, as described in table 1.

Funding CCS / CDR	2025/2026 Mt	2030 Mt	Description
CCUS-fund **Fund for carbon capture, usage, and storage**	0.4	0.9	Budget: EUR 2,2 billion Aimed at large point sources, both biogenic and fossil. First tender ongoing with expected winner February 2023. First winner shall deliver 0.4 Mt 2026 with approx. half the budget.
NECCS-fund **Fund for negative emission carbon capture and storage**	0.5	0.5	Budget: EUR 0.35 billion. Only for CDR. Designed for CCS on biogas or biochar from pyrolysis. No tender yet. Funding over 8-year period corresponding to just below 90 EUR/ ton CO_2.
CCS-fund from Danish national green tax reform	-	1.8	Budget: EUR 2.6 billion. Aimed at point sources both biogenic and fossil. Pending specifications. Awaiting experiences from the first tender of the CCUS fund
I alt	**0.9**	**3.2**	

Table 1: Overview of funds for CCS/CDR and their expected climate benefit.

Potential for carbon capture

Existing funding aims to establish 3.2 Mt CCS in 2030, and the Danish Energy Agency has estimated a technical potential between 6-14 Mt in 2030

CONCITO recommends 5 Mt CCS in 2030, which is more sustainable potential from an economic and climate perspective. Reaching this will require a huge effort in few years, but only targets point sources with no real alternatives, while still decreasing the Danish dependence on importing and burning woody biomass for combined CHP.

We look at three criteria that must be met for CCS to make sense from a climate and economic perspective:

1) **Are there better and cheaper alternatives?** Is the emission unavoidable or can it be replaced by renewables? This is largely the case for coal and a large part of biomass CHP facilities over time.

2) **How many operating hours and what is the plant lifetime?** A long lifetime is necessary since a carbon capture plant has a technical lifetime of 25 years and would be expensive to amortize over a few years. Further, many operating hours during a year is a pre-condition for the economics. Otherwise, the carbon capture plant, which is a large capital investment, would be unused most of the time. In line with this, transportation and storage costs may be high if infrastructure is dimensioned to transport and store carbon only part of the year.

3) **A large climate benefit.** If CCS is to make sense from a climate perspective the actual climate benefit of CCS must be high. If CCS creates lock-in, or increases use, of input with a questionable climate profile, such as wood pellet biomass, the capital and resource is better spent elsewhere.

Based on these criteria, CONCITO estimates that there is a potential of 5 Mt CCS in 2030 from waste incineration plants, industrial processes (cement) and biogas plants, as summarized in table 1. Appendix 1 provides further details on the potential for CCS from each type of points source.

CCS on coal makes no sense with the option of replacing it with cheaper wind and solar. The last coal fired plant in Denmark will be closing no later than 2028. Further, biomass CHP, which today generates a large amount of the Danish district heating, has a questionable climate benefit and is heading towards fewer operating hours over the coming decade.

CCS in 2030 (Mt)	Fossil CO_2	Biogenic CO_2 (negative emissions)	Total
Waste-to-Energy	0.5	1.5	2
Biogas upgrading		1.5	1.5
Industrial processes (cement/refineries)	1	0.5	1.5
Total	1.5	3.5	5

Table 2: CONCITO estimate of the feasible CCS potential in 2030 by sector, including the expected origin of CO_2, fossil and biogenic.

CCS is important to achieve the national 70% reduction target

To reach the national 70% reduction target, Denmark needs to cut emission from 42.3 Mt in 2021 to 23 Mt in 2030. 5 Mt CCS in 2030 as CONCITO recommends, is thus only a small part of the total necessary reductions, especially after 2030 towards climate neutrality. CCS is only a minor part of the puzzle, and not a technology that will make other mitigation efforts redundant. So far state funding is expected to realize about 3.2 Mt of the CCS potential in 2030.

Negative emissions

Negative emissions, or CDR, will play an important role in achieving climate neutrality in Denmark, since not all emissions can be abated. CONCITO has assessed a plausible way to achieve climate neutrality in Denmark already in 2040, which shows that large scale CDR is necessary to balance out residual emissions, especially from agriculture. More CDR is necessary to reach the Danish governments ambition of reaching 110% reductions in 2050.

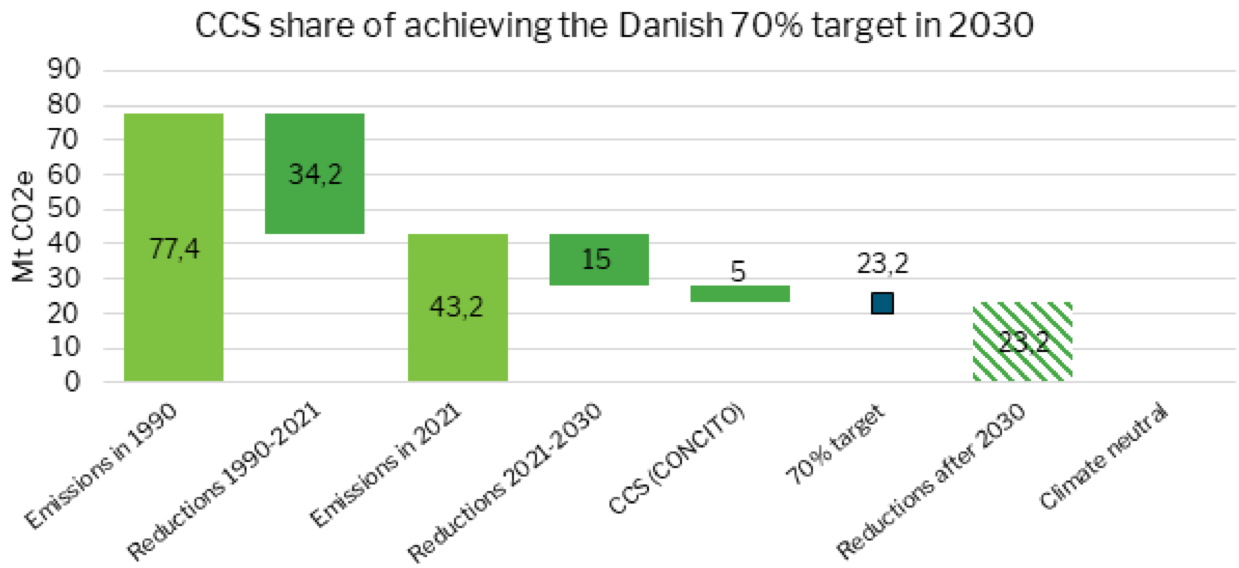


Figure 1: CCS share of reductions towards 2030.

CCS in 2040

The Danish Energy Agency asses the upper technical potential for carbon capture on Danish point sources to 10.6 Mt in 2040. CONCITO finds this estimate too high, and a more realistic assessment may be op to 7 Mt in 2040.

CONCITO's upper estimate excludes biomass CHP, since this use of biomass might not be economically feasible in the long run due to fewer operating hours when competition increase from direct use of green electricity with heat pumps and geothermal energy. Moreover, CCS on biomass CHP entails risk of sustaining the Danish dependency on an unsustainably high consumption of biomass for producing heat and electricity. Biomass for heating and electricity covers more than half of the Danish consumption of renewable energy in 2021 with the majority being from biomass CHP.

CDR - in the form of CCS on biogenic sources - will likely happen under current national funding schemes, but there is no national policy framework in place for CDR. Thus, in order to secure a balanced and effective implementation of CDR, CONCITO has provided four recommendations for CDR in Danish climate policy.

We argue that a fixed subsidy for CDR, at the same level as the national carbon tax, can secure a cost-effective implementation of CDR. This subsidy must be combined with a cap on CDR from biogenic sources on par with the level of sustainable waste biomass available to CDR. The level of sustainable biomass available for CDR in Denmark should be defined. A good guidance can be found in the IPCC's estimate of a 100 EJ limit in 2050. This corresponds to 10 GJ per person in 2050. Denmark currently uses 40 GJ biomass for energy per person.

Large potential for import of CO_2 in Denmark

The Geological Survey of Denmark and Greenland (GEUS), estimates that the Danish underground is suitable for storing 22 Gt CO_2. Together with export of green electricity and green hydrogen, CO_2-storage is thus a major opportunity for Denmark to help accelerate climate action in neighboring countries. There are several companies eyeing a business case and the Danish state may also demand a stake in future storage sites.

Two consortiums are exploring storage offshore in the North Sea and one company has announced intention to build large scale onshore storage. Further, a promising minor onshore storage site is being explored and may provide the first important experiences with onshore storage, including pricing, public acceptance, and infrastructure.

Onshore storage

Currently, GEUS is doing geological and seismic investigations of possible storage sites in the Danish underground. Following this, the Danish Energy Agency will conduct strategic environmental consequence reviews of the sites. The state has announced that between 1-8 onshore/nearshore sites will be opened for a tender of rights by the end of 2024 (see appendix 2). This will allow bidders to do more detailed investigations of the possible storage sites.

Project Norne is developed by Fidelis New Energy in partnership with Ross Offshore. They have announced a target of developing 20 Mt CO_2 storage per year capacity by 2030 and aim at beginning injecting CO_2 in 2026. This is ambitious in such a short time but could accelerate development of much needed storage capacity in Northern Europe. The project aims to develop the Havnsø and Gassum Structures which hold a combined storage potential of more than 1,500 Mt (see appendix 2).

Stenlille demo project is run by Gas Storage Denmark (GSD), which is a publicly owned company and historically responsible for underground storage of natural gas. In the village of Stenlille in Zealand GSD operates a gas storage facility and is investigating the potential for onshore CO2-storage as the subsoil is ideal. GSD has received a permit to store 10 Mt, which corresponds to 20 years of CO_2 from the nearby waste-incineration plant, Vestforbrænding, one of the three pre-qualified bidders for the first Danish CCS tender. The Stenlille project is expected to be able to store 0.5 Mt per year from 2025.

Offshore storage

In the beginning of February 2023 two offshore projects have received permits to explore large-scale storage capacity in depleted oil and gas fields. The state will participate in each of the projects with a stake of 20%.

Project Greensand is developed by Ineos and Wintershall Dea International and aims to store between 0.5 and 1.5 Mt CO_2 in 2025 and up to 8 Mt CO_2 per year from 2030.
Currently, project Greensand is establishing a demonstration project where CO_2 will be transported from INEOS Oxide site in Antwerp, Belgium, by ship to the Danish part of the North Sea where it will be injected into existing wells in the Nini offshore platform. The first injection of CO_2 is scheduled to begin in March 2023. The demonstration project is funded by the Danish EUDP funding program with EUR 26 million.

Project Bifrost explores CO_2-storage by using existing infrastructure in the Danish North Sea owned by TotalEnergies, Noreco, Nordsøfonden (offshore fields and associated facilities) and Ørsted (pipeline). The aim is to store 3 Mt CO_2 per year initially around the Harald gas field more than 200 km from the coast of Jutland.

The aim is also to explore the opportunity to store up to 16 Mt after 2030. This field is expected to be able to store CO_2 from 2027 or 2028. Bifrost plans to develop an offshore floating unit as an intermediate storage- and injection facility to which CO_2 is transported by ship. The project aims to repurpose existing gas-pipelines for CO_2 transport from shore. The project has received funding by the Danish EUDP of EUR 10.2 million

Cooperation with neighboring countries is necessary

As figure 2 shows, the Danish carbon capture potential only fills up a minor part of the announced storage capacity of 33.5 Mt in 2030, and an even smaller part of the theoretical capacity.

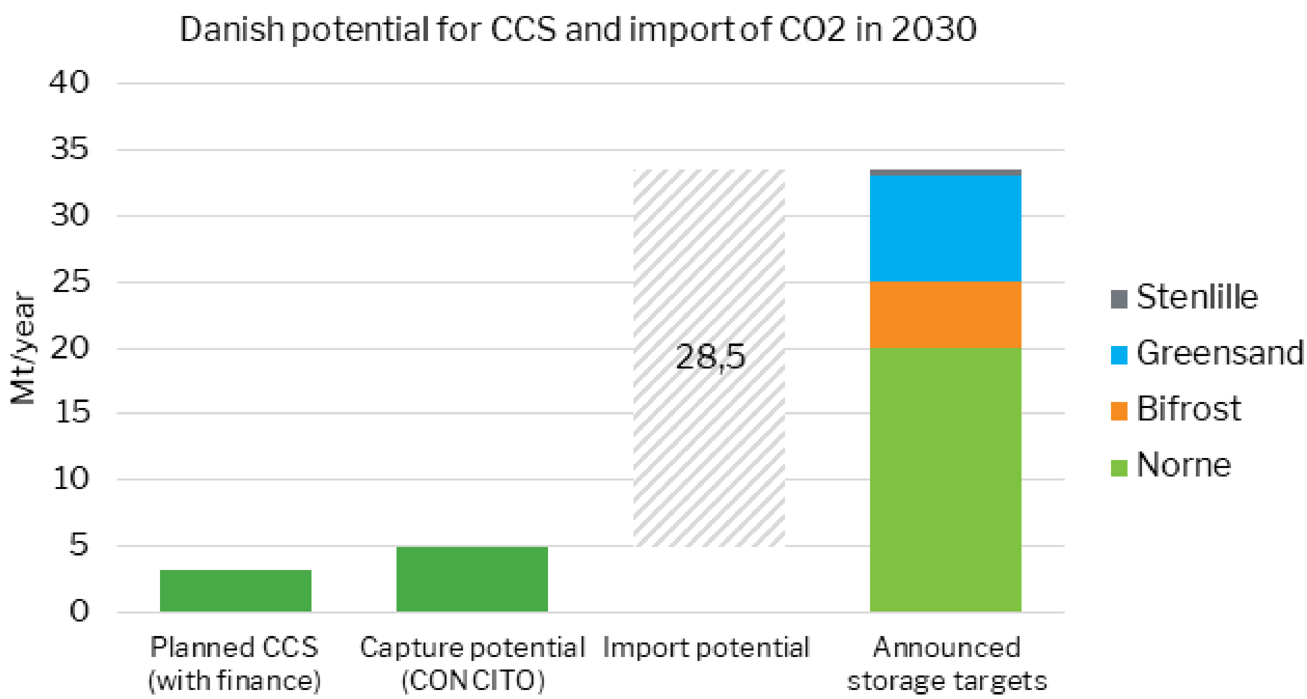
With current announced capacity the potential for import of CO_2 is 28.5 Mt/year from 2030. The market potential for CO2-storage in Denmark is bigger but it also would entail Denmark and neighboring countries to cooperate on CCS, including establishing cross-border trade and ensure that the infrastructure is dimensioned to large scale transport and storage.

From a Danish perspective, the potential for import seems likely from Germany and Sweden but may also be from other countries depending on alternative developments in storage capacity and prices. Nevertheless, Denmark should pursue cooperation agreement with Germany and Sweden to enhance cooperation to ensure timely development and implementation of carbon capture, transport infrastructure and storage capacity.

According to the consultancy Ramböll, onshore storage may cost 20 EUR/ton before 2030 and closer to 10 EUR/ton after 2030. There is also a cost of transportation which is cheaper onshore in pipelines than by ship. Import of CO_2 to Denmark may be necessary by ship but in the longer run a pipeline infrastructure is a cheaper option. For reference, Ramböll estimates that point sources in Denmark saves 30-50 EUR/ton by pipeline transport to onshore storage compared to shipping to an offshore storage.

The German thinktank Agora Energiewende has estimated that Germany will need to store 73 Mt CO_2 yearly to become climate neutral in 2045. Denmark could potentially store part of this and eventually import CO_2 by pipeline.

Figure 2: Overview of CCS potential in 2030 in Denmark.



CCS is more efficient than CCU

There is a limited amount of CO_2 available from biogenic sources, which can be either stored as negative emissions or used to produces synthetic fuels, also known as e-fuels or CCU (carbon, capture and utilization).

CONCITO estimates that both economic and climate considerations argue in favor of CCS.

This is particularly because of the large amount of green power needed to produce e-fuels, which is then unavailable for other purposes such as direct electrification where it displaces fossil fuels from e.g. coal gas electricity, or direct electrification of industry, electric cars, or heat pumps, as shown in figure 3.

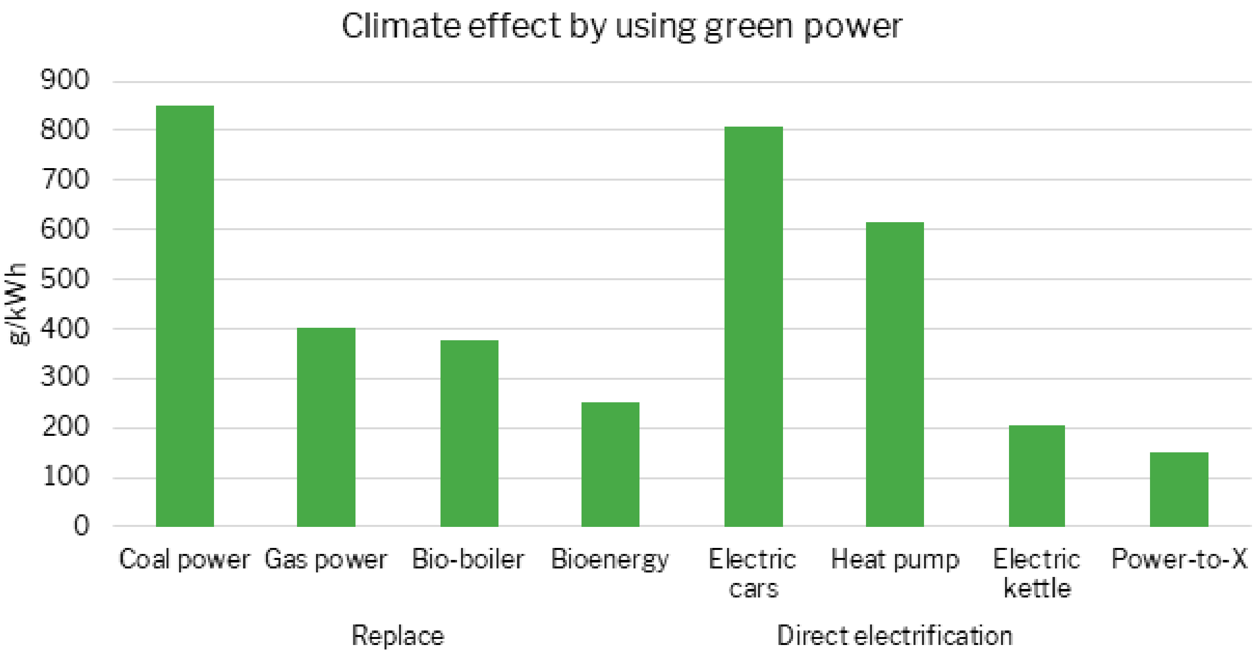
Until there is a significant surplus of green power, the climate effect is largest when using the power for direct electrification which displaces fossil fuels. This applies not only to fossil fuels, but also to biomass, as this is not in practice carbon neutral. The climate effect of displacing biomass is two to three times larger than displacing fossil fuels through e-fuels.

CO_2 will still be emitted to the atmosphere if it is used to produce e-fuels, just via ships or airplanes instead of e.g. the biomethane plant that supplied the CO_2.

With storage CO_2 transported directly to the underground and stored permanently, the green electricity saved from not making e-fuels can then be used to displace fossil fuels in other sectors – or used for carbon free Power-to-X, such as e-ammonia and green hydrogen.

The amount of energy used for CCU is a lot higher than CCS as shown in figure 4. In both cases, CO_2 is captured which is somewhat energy demanding, but the energy usage for synthesizing CO_2 into e-fuels is a lot higher than for transporting and storing it. Therefore, policy makers (and developers) should carefully consider how much the rely on e-fuels until there is a surplus of both green power and CO_2.

Figure 3: Climate effect from different use of green power. Own calculations.



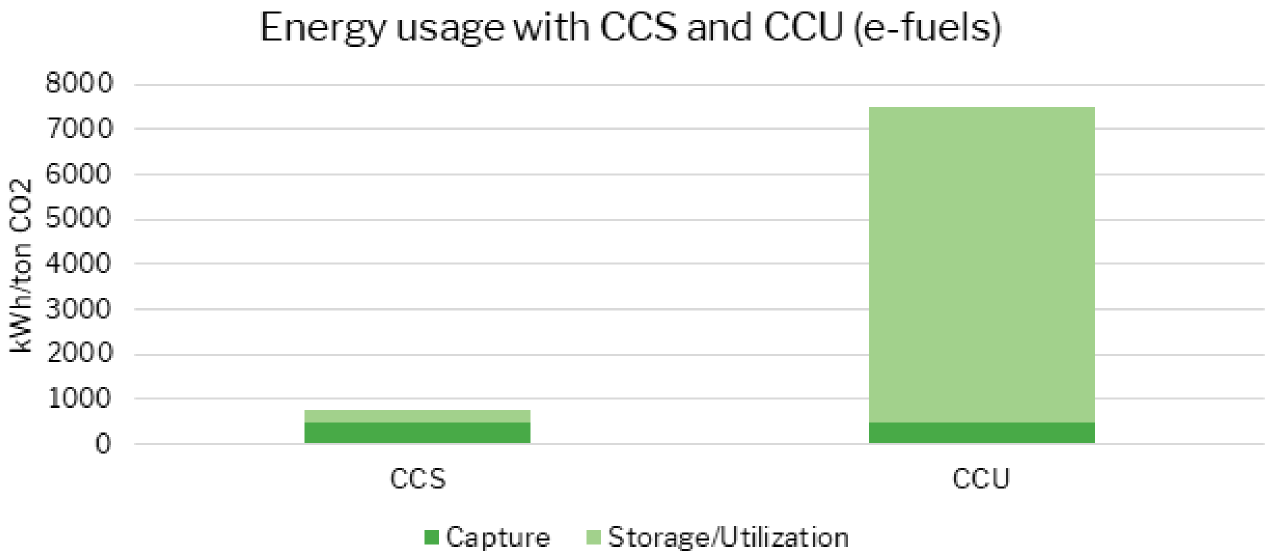


Figure 4: Energy usage with CCS and CCU.

Large scale negative emissions will be necessary

There will be a large demand for negative emissions in the future. Both to compensate for residual emissions in agriculture and land sector, in order to become climate neutral, and, following this, to become net-negative where more CO_2e is removed than emitted. This will put pressure on using biogenic CO_2 as for negative emissions.

As an example, The Danish government has announced a national Danish climate target of 110% in 2050. CONCITO estimates that Denmark will need negative emissions of around 14 Mt to achieve this target.

Taking into account that sustainable biomass is a limited resource, we estimate that up to 8 Mt of biogenic CO2 will be available for negative emissions in 2050 in Denmark, from WtE, biogas and biochar.

The remaining 6 Mt will then have to come from e.g. reforestation (which conflicts with other land-use cases such as food production) or new technologies such as direct-air-capture and storage (DACCS), which will probably be more expensive than negative emissions from biogenic sources. If e-fuel production thus demands a major part of the biogenic CO_2, society will have to pay more for negative emissions relying more on DACCS.

This calls for an effective carbon management strategy and careful consideration on how policy makers incentives the use of CO_2.

Appendix 1: Sustainable sources for carbon capture in Denmark

CONCITO has done a review of points sources and estimates a realistic potential of 5 Mt/year in 2030.

About two thirds of the 5 Mt of CCS potential is biogenic CO_2 and can therefore be counted as negative emissions in the Danish GHG-inventory. For biogas, all CCS would be included as negative emissions, as is the case for 3/4 of waste incineration in 2030. For industry, replacing natural gas with biogas and retrofitting with CCS, the result will be negative CO_2 emissions, e.g., from the production of cement.

Some of the Danish CCS potential may be realized with a high carbon tax on fossil CO_2. The national carbon tax and the EU ETS may be enough for realizing part of the potential. However, most of the CCS potential is on biogenic sources, which are not covered by the Danish carbon tax or the EU ETS. Therefore, a subsidy for these negative emissions is needed and CONCITO recommends Denmark to introduce a fixed negative carbon tax.

Waste incineration plants

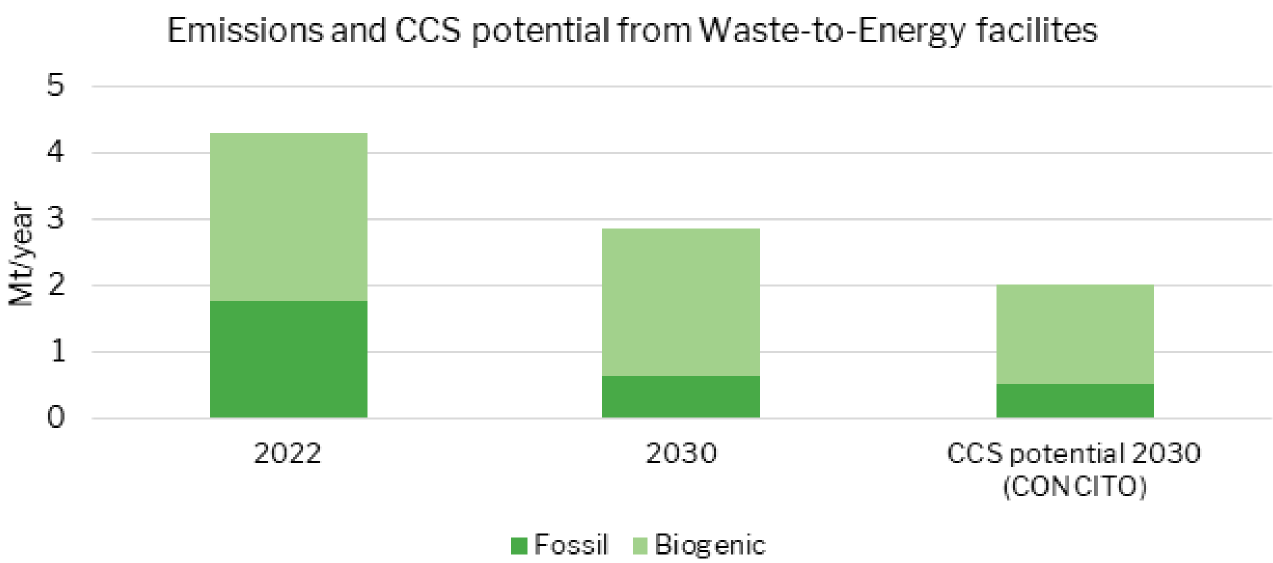
The Danish waste incineration plants are obvious sources for carbon capture, since they are operating almost all year around and emit relatively large amounts of CO_2 individually.

Even with an ambitious effort to improve recycling, not all waste can be reused, and there will most likely be waste for incineration for decades to come.

Currently, 3.7 Mt CO_2 are emitted from Danish waste incineration plants, which is expected to decrease to 2.4 Mt in 2030 with the implementation of current policies, where the incineration capacity must be reduced by 30%. Even if the capacity is reduced, there will still be large CO_2 emissions from waste incineration.

CONCITO recommends that Danish climate policies aim to install carbon capture at most of the Danish waste incineration capacity. CO_2 emissions from incinerations plants can be reduced by at least 2 Mt/year if CCS is applied to 90% of the emissions by 2030. To make this possible, CCS should result in reductions of at least 0.5 Mt, preferably by 2026. The consultancy firm Rambøll estimates that the cost of CCS on waste incineration is between 89-156 EUR/ton, where the lower cost is for onshore or coastal storage.

Figure 5: CONCITO's estimation of the realistic potential for CCS at waste incineration plants, for fossil and biogenic CO_2. Source: Denmark's Climate Status and Outlook 2022 (emissions) and own calculations (potential).



Emissions from waste incineration in Denmark is a mix of biogenic (e.g., biowaste) and fossil (e.g. plastic) CO_2, Today the split I closer 50/50 but the fossil share is expected to decline to about 1/4 in 2030 as more plastic is expected to be recycled. Our estimate of the CCS potential for waste incineration in Denmark and the split between fossil and biogenic CO_2 is shown in figure 5

Only the fossil CO_2 is accounted for in the GHG-inventory according to EU and UN procedures, but when CCS is applied the biogenic CO_2 this will result in negative emissions, and should be counted as such in the inventory.

Industrial processes

There is a large potential for electrification and energy efficiency in industrial processes. Green fuels and hydrogen can also play an import role to mitigate emission. Where electrification end fuel switch is not possible, CCS may be feasible.

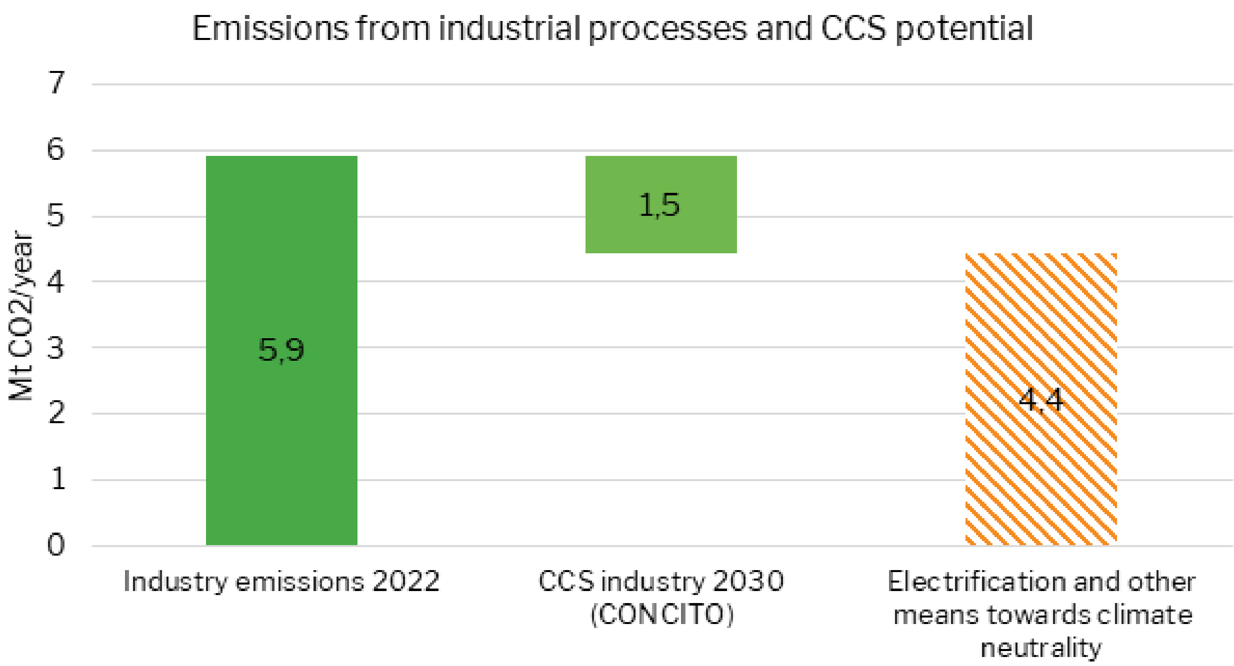
In Denmark, a few companies, mainly one cement producer and two refineries, make up the majority of industry related emissions.

These are obvious candidates for carbon capture since they meet the three criteria mentioned above, with no feasible alternative, long lifetime, and high operating hours as well as high climate benefit from CCS.

Switching to green fuels does not exclude carbon capture. Biogas or biofuel also emits CO_2 when burned. If CO_2 from biogas or biofuel is captured and stored, it will be possible to achieve negative emissions. Negative emissions will require an incentive scheme not provided by a national carbon tax on fossil CO2 or the EU ETS.

A rough estimate shows that CCS can contribute with a yearly reduction of at least 1.5 Mt CO_2 from industries in Denmark, at a cost less than 200 EUR/ton. The industrial processes emitted 5.9 Mt CO_2 in 2022, so the reduction from CCS is only part of the necessary transition towards a climate neutral industry, as shown in figure 6.

Figure 6: Industrial emissions and reduction strategies. Source: Denmark's Climate Status and Outlook 2022 (KF22) and own calculations.



Biogas plants

There is a large potential for further reductions of CO_2 emissions at biogas plants. A large amount of CO_2 is emitted from biogas plants that upgrade biogas to natural gas quality. This has gained little attention since the emissions are biogenic and do not count in the Danish GHG-inventory. However, avoiding biogenic CO_2 in the atmosphere is just as important as avoiding fossil CO_2.

An upgrading plant separates CO_2 from biogas. Most biogas plants in Denmark already have upgrading plants, or will have in the future, in order to convert and sell biogas via the existing gas grid. Since carbon capture will be established at many biogas plants towards 2030, the next step is to clean, compress and possibly cool down the $CO_{2,}$ so it can be transported through pipes. Since almost all biogas in Denmark is expected to be upgraded, it should be realistic to capture 0.5 Mt in 2025 and 1.5 Mt of CO_2 every year from 2030.

There are challenges for biogas production in Denmark due do methane leakages and the use of energy crops, which new regulation is aiming to solve. Hence, for biogas to have an actual climate benefit methane leakage must be kept below 1% and the use of energy crops in biogas production must be avoided.

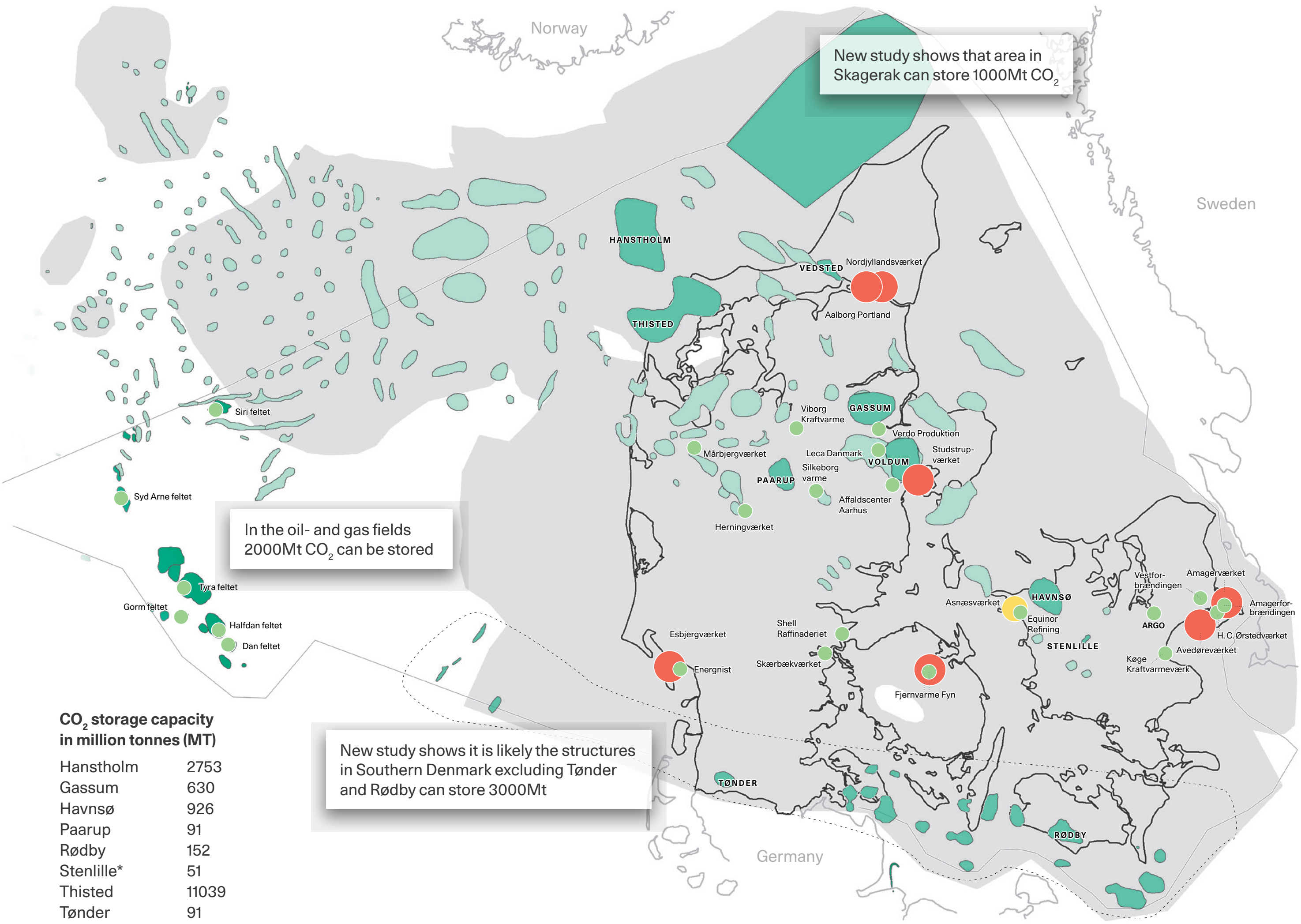
Appendix 2: Storage capacity and sites areas under development

Figure 7 shows the storage potential from various geological structures in Denmark. GEUS estimates the Danish storage capacity to 22Gt with a majority being onshore or nearshore. The map also shows the current point source emissions.

Currently, eight potential sites for storage nearshore and onshore are being explored by GEUS as shown in figure 8. The four onshore formations below, excluding Stenlille, has potential to store 1.800 Mt.

Figure 7: Storage capacity in Denmark. Source: [State of Green 2022]

Denmark from above



CO_2 storage capacity in million tonnes (MT)

Hanstholm	2753
Gassum	630
Havnsø	926
Paarup	91
Rødby	152
Stenlille*	51
Thisted	11039
Tønder	91
Vedsted	162
Voldum	288
Syddanmark	3000
Olie-gasfelter	2000
Skagerrak	1000
Sum	22.183

*In use as natural gas storage

The largest point sources for CO_2 emissions in Denmark

Fossil fuels and biomass

- 100.000 - 500.000 tonnes
- 500.000 - 1.000.000 tonnes
- > 1.000.000 tonnes

Geological structures

- Investigated areas
- Unexplored areas
- Sandstone 800-3000m
- Oil-gas fields

Figure 8: Potential storage sites explored by GEUS. Note that the Thorning site is reffereded to as Paarup in figure 7.