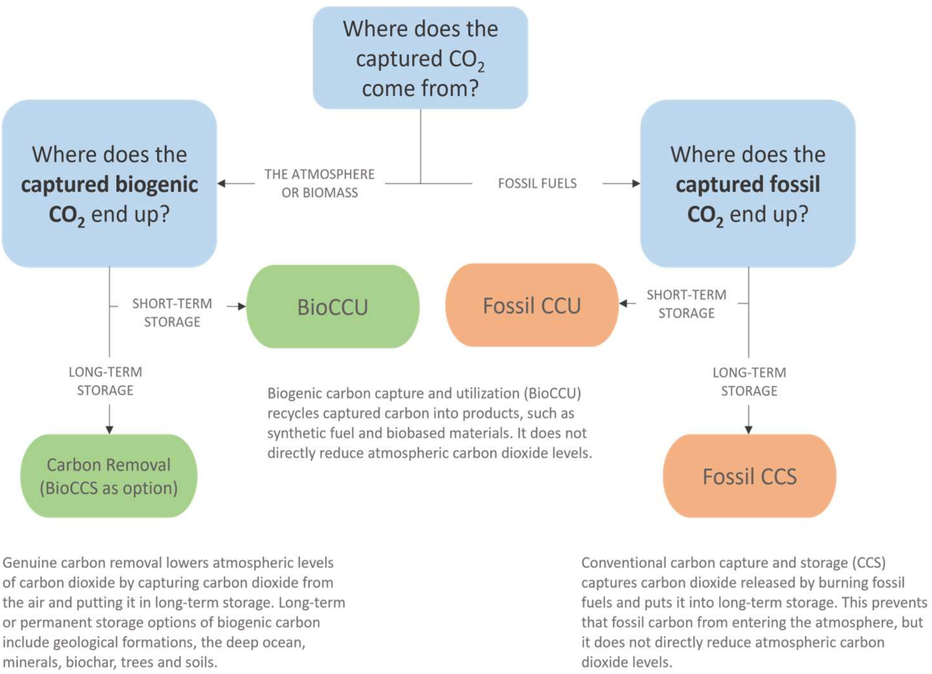
The trade-offs between utilisation and storage of captured biogenic CO_2

IEA Bioenergy: Task 40

March 2026

Note: The presented information dates back to November 2025. In the meantime, there have been new developments in particular with regards to legislation.



Own figure, based on Institute for Carbon Removal Law and Policy, 2020: Explainer: Carbon Removal.

The trade-offs between utilisation and storage of captured biogenic CO_2

Status of BECCS and BECCU deployment in selected EU countries
WP6 Report

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Contribution of IEA Bioenergy Task 40 & Task 45 to Strategic Inter-Task Project
Management of biogenic CO_2: BECCUS Phase 2

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Preface

Bioenergy combined with carbon capture and utilisation or storage, also known as bio-CCUS or BECCUS, is a concept that has been discussed in climate change mitigation research for quite some time. However, implementation has only become the subject of serious consideration within governments and private actors within the last 5 years or so. The reasons for this are largely related to four factors that are somewhat entwined: a) an emerging awareness of the need for BECCS and other negative emissions technologies if there is to be any chance for the Paris 1.5°C target to be reached, b) increased interest in buying carbon negative or neutral products including carbon removal certificates c) rising CO_2 prices, and d) the rapidly decreasing costs of electricity generation from solar & wind (and expectations of similar developments for electrolysers) that have made BECCU options based on power-to-X technologies more cost-effective.

In light of this, identifying and implementing approaches for how BECCUS systems can be deployed and integrated in ways that maximise benefits in terms of climate change mitigation - as well as in terms of energy system integration and sustainability ambitions more broadly - is highly important.

THE IEA BIOENERGY STRATEGIC PROJECT ON BECCUS

In 2019 the IEA Bioenergy TCP initiated a strategic project on bioenergy carbon capture, utilisation and storage (BECCUS) in order to understand the concept and opportunities for deployment. The project involves several of the IEA Bioenergy Tasks and is led by Task 40 (Deployment of biogenic value chains and carbon management)[1]. The project has evolved to a multi-annual research project, in which the findings of each project phase led to new research question for a next phase. Details on the project focus in the different phases are presented below, and more information on the BECCUS project can be found on Task 40's website[2].

Phase I (2019- 2021)

During 2019-2021, IEA Bioenergy Task 40 worked together with Task 36 (Material and Energy valorisation of waste in a Circular Economy), Task 44 (Flexible Bioenergy and System Integration) and Task 45 (Climate and Sustainability Effects of Bioenergy within the Circular Bioeconomy) on a strategic project called *Deployment of BECCUS value chains* that focused on understanding the opportunities for, and obstacles to, deployment of BECCUS in different sectors. Focus was on trying to cut across the full set of factors that determine successful deployment, from technology readiness, to business model viability and design of policy and regulatory frameworks.

Phase I findings

Factors determining successful deployment of BECUSS include technology readiness, business model viability, upstream supply chain set up, and current and expected public policy design. The investigations indicate that while the majority of the required individual BECUSS technology components can largely be considered proven, there is still R&D needed into finding models for on-the-ground deployment. Supply chain set up and possibly alterations of existing

[1] An overview of all Tasks of IEA Bioenergy TCP is found here: https://www.ieabioenergy.com/our-work-tasks/

[2] https://task40.ieabioenergy.com/inter-task-project-bioenergy-with-carbon-capture-storage/.

supply chain concepts are important. Many concepts are looking for viable business models for the captured carbon. Thus far, the focus is on utilising rather storing the carbon. Lack of governance with corresponding support measures and regulations for carbon storage pose a challenge. A synthesis report summarising phase I findings (Olsson, et al., 2022), as well as publications covering case studies topical reports, and system studies can be found on the IEA bioenergy, Deployment of BECCUS value chains website.[3]

Phase I suggestions for further work

Research and development are still required to identify models of on-the-ground deployment that make the most sense from techno-economic and climate perspectives. This includes aspects such as specific designs, deployment scales and choice of site locations. In addition, there are many questions remaining when it comes to process & supply chain integration as well as policy design and implementation. Answers to the above questions can assist in addressing key and most complex questions, i.e., *in a given situation should biogenic CO_2 be sequestered, or utilised? Which type of facilities (i.e., bioenergy installations) shall best provide BECCS and/or BECCUS under certain criteria (economics, CO_2 emissions mitigation potential etc.)? What are the main challenges for commercialising BECCUS projects and the lessons learnt thus far? How to monetise the carbon negative products that bioenergy can deliver? How to govern the different energy system services when targeting a high level of CO_2 emissions mitigation? And related to this, what factors and parameters should guide this decision-making process?*

Phase II (2022-2024)

Phase II of the BECCUS project is more diverse in its scope, with a stronger emphasis on cross-sector and cross-country learning about implementation of BECCUS projects using different energy conversion processes. A further goal is to shed some light on the effects of the integration of BECCUS facilities and systems within the overall energy system and its interaction with other energy system services. In addition, although we tend to refer to "BECCUS" as a unified concept, we also emphasise and analyse the important differences between BECCS and BECCU, not least from the perspective of potential business models and policy development. An understanding of the impacts of BECCUS on overall climate system in terms of potential for CO_2 mitigation is addressed and all different aspects covered are analysed jointly and policy recommendations provided. This approach allows for a systemic consideration of how to take different BECCUS applications to deployment, thereby building upon, but going beyond, Phase I. In this second phase of the BECCUS project, besides the Tasks already participating in Phase 1, Tasks focused on conversion technologies become involved as well: Task 32 (Biomass Combustion), Task 33 (Biomass Gasification) and Task 34 (Direct Thermal Liquefaction).

Phase III (2025-2027)

While the current report is part of the Phase II work, preparations for Phase III have been initiated. Overall biochar, biorefineries, first-of-its-kind projects, permanence of storage and the BECCS/BECCU potential and financing are foreseen as central themes. Further examples for case studies look to potentially include: BECCUS for biogas installations, BECCUS with novel capture technologies e.g. oxyfuel, H_2 from biomass with CCS, BECCS with decentralised storage solutions, BECCUS with mixed feedstocks, CCU from the chemical industry, and further small- to medium scale BECCS installations.

[3] https://www.ieabioenergy.com/blog/task/deployment-of-beccus-value-chains/

Executive Summary and key findings

This report examines the trade-offs between bioenergy with carbon capture and storage (BECCS) and bioenergy with carbon capture and utilisation (BECCU) — collectively referred to as BECCUS — and explores when captured biogenic CO_2 should be permanently stored versus when it should be utilised. The report synthesises insights from the case studies of Phase II of the IEA Bioenergy Inter-Task Project *Management of Biogenic CO_2*[4] and draws on recent developments across leading European countries.

CONTEXT AND PURPOSE

Bioenergy combined with carbon capture represents a critical pillar in achieving net-zero and ultimately net-negative emissions. BECCS offers permanent carbon removal, while BECCU contributes to fossil carbon substitution through the creation of renewable fuels and materials. Determining "when to store and when to utilise" depends on economic, policy, technological and infrastructural factors. The report analyses these dimensions from the perspective of CO_2-emitting sites, guided by emerging policy frameworks and early implementation experiences in Sweden, Denmark, and Norway.

CLIMATE AND POLICY DRIVERS

At the EU level, an evolving regulatory framework underpins BECCUS deployment:

- The EU Carbon Removal Certification Framework (CRCF) establishes the first EU-wide standard for certifying permanent carbon removals such as BECCS.
- The Industrial Carbon Management Strategy (2024) sets milestones for industrial CO_2 storage capacity (≥50 Mt/year by 2030) and aims for economically viable value chains by 2040.
- The Renewable Energy Directive (RED III), ReFuelEU Aviation, and FuelEU Maritime incentivise CO_2-based synthetic fuels through blending mandates and multipliers for renewable fuels of non-biological origin (RFNBOs).
- Emerging instruments, such as the Empowering Consumers for the Green Transition Directive and Green Claims Directive, will define what types of climate claims companies can make—critical for voluntary carbon markets and corporate offsetting.

These frameworks increasingly differentiate between storage and utilisation pathways, shaping the business case for BECCS and BECCU respectively.

NATIONAL DEVELOPMENTS AND CASE STUDIES

Sweden

Sweden's 2045 net-zero target explicitly includes BECCS to generate 3–10 Mt CO_2 removals annually. A BECCS support scheme (SEK 36 billion, 2026–2046) was launched using reverse auctions, awarding long-term contracts for lowest-cost negative emissions. The first award went to Stockholm Exergi, backed by both state support and a 3.3 Mt carbon removal purchase from Microsoft—the world's largest such deal (Beccs Stockholm, 2024). This deal was subsequently extended to over 5.0 Mt in May of 2025 (Stockholm Exergi, 2025). Sweden also

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[4] https://task40.ieabioenergy.com/inter-task-beccus-2-0/

sees multiple BECCU initiatives in e-methanol and e-aviation fuels, though several have been delayed due to market uncertainty.

Denmark

National focus in Denmark has recently shifted from BECCU to BECCS, reflecting stronger policy incentives for permanent removals. Anchored by its 70% emissions reduction target by 2030, Denmark is rapidly advancing large-scale CCS through state-funded tenders (a second tender round is currently underway, with a value up to EUR 3.8 billion to 2044). The first tender round resulted in Ørsted's Kalundborg Hub project, which is scheduled for completion in 2026 and will capture and store 430 ktCO_2/year, combining biogenic CO_2 capture with long-term offtake agreements for carbon removal certificates.

Denmark is also developing extensive onshore and offshore CO_2 storage infrastructure, positioning itself as a future storage hub for Northern Europe.

Norway

Norway, leveraging its oil and gas expertise, continues to pioneer CO_2 storage through projects such as Northern Lights. It is also undertaking first capture projects, for example at Hafslund Celsio, demonstrating operational and logistical lessons for BECCS deployment.

KEY DETERMINANTS OF WHETHER TO STORE OR UTILISE

There are a number of BECCUS projects that have recently been initiated either by larger utility companies or medium-sized enterprises in various countries. The majority of these initial projects are focused on CO_2 storage. In reviewing the development of ongoing and potential BECCUS projects in the selected leading countries above, there are a host of factors that determine whether to store or utilise captured biogenic CO_2. Some of the most important factors identified when whether to store or utilise captured biogenic CO_2 include:

- Site location & Production characteristics
- Government targets & relevant legislation
- Demand for end products

Site location and production characteristics

The physical location of the site where the CO_2 is captured is important for a number of reasons, including how it relates to access to CO_2 storage, the cost of exporting CCUS products, and potential heat integration and offtake options.

The location of the CO_2 emitting site relative to potential CO_2 storage options will determine the cost of CO_2 storage. Sites located by the sea will generally have access to a harbour, and therefore offshore storage options if an export terminal can be established. Sites located some distance from a CO_2 export terminal will have to establish a dedicated pipeline to the export terminal, or transport CO_2 to the terminal via trucks, with both options adding to the transport cost. Meanwhile, CO_2 capture sites located near an onshore storage facility, or dedicated pipelines to such facilities, can take advantage of the cost savings associated with onshore storage, which should on average be less expensive than offshore storage.

In Northern Europe, the first large-scale CO_2 storage facilities to be established will be offshore and it is unlikely that any onshore CO_2 storage options will be available prior to 2029 (at the earliest). Therefore, having a harbour from where the CO_2 can be exported from is a necessity.

This dynamic is exemplified by both the Kalundborg Hub and Stockholm Exergi projects, as they both have a harbour available for export of CO_2 via ship.

Another thing that these early BECCS projects have in common, is that the power plant units to which carbon capture are applied, have steam and/or district heating offtake contracts, thereby ensuring stable production, and the potential for utilisation of recouped heat from the carbon capture processes. Steady production, and many full load hours, are required in order to spread out the large CAPEX costs of carbon capture.

Government targets & relevant legislation

Government CO_2 emission reduction targets, particularly when backed by relevant legislation is a key driver in determining whether to store or utilise CO_2. Both Denmark and Sweden have ambitious climate targets, and their governments have concluded that negative emissions will be required in order to realise them. Both countries therefore launched schemes to provide significant economic incentives over a long time period to capture and sequester CO_2, thereby contributing to their respective countries' climate targets. These long-term schemes provide cost certainty for actors contemplating whether to utilise or sequester captured CO_2 and thereby tip in favour of the latter.

Demand for end products

Perhaps the most important factor in determining whether to sequester or utilise biogenic CO_2, is the demand for end products. For an actor deciding between the two, this is the demand for a sustainable product with CO_2, for example a green transport fuel, vs. the demand for carbon removal certificates. Based on the projects in focus within this report, it would appear that in a European context, the demand for carbon removal certificates (often combined with state subsidies) provides a more robust business case than that for green fuels.

Other factors

Other factors that can come into play when determining whether to utilise or sequester captured CO_2 can include access to low-cost electricity, particularly when the production cost of hydrogen is a driving factor. However, in the absence of significant demand for the end product (i.e., green aviation or shipping fuel) and/or government incentives to store captured CO_2, this factor is currently not significant enough to outweigh the others.

KEY FINDINGS AND RECOMMENDATIONS

- **BECCS is indispensable** for achieving net-negative emissions and offsetting residuals in hard-to-abate sectors.
- **Stable, long-term funding mechanisms**, such as reverse auctions or subsidies per tonne CO_2 sequestered, are critical to accelerate deployment. EU funding, for example EU Innovation fund or similar, can also provide vital revenue streams.
- **Private-public partnerships** are proving decisive -linking corporate offtakes with public support to unlock bankable projects.
- **Policy coherence** across the Carbon Removal Certification Framework (CRCF), EU Emission Trading Scheme (EU-ETS) and Renewable Energy Directive (RED), and industrial carbon management frameworks is essential to prevent conflicting incentives.
- **Cross-border CO_2 transport and storage agreements** (e.g. between Sweden, Denmark, and Norway) are enabling first regional BECCS value chains.

- **Various revenues streams** can support a successful realisation of BECCS projects, including: (1) Specific state support mechanisms (i.e. per tonne CO_2 subsides), 2) broader R&D support (i.e. EU Innovation fund), 3) voluntary carbon markets (i.e. CDRs)
- **Current business models favour BECCS.** BECCS can lead to clear climate mitigation via the capture and transfer of biogenic CO_2 from ecosystems to the underground, while BECCU provides transitional value and supports the circular carbon economy, particularly for producing e-fuels. However, relative to the revenue streams available to BECCS, sufficient willingness-to-pay for these e-fuels has yet to materialise, thus leaving BECCS as the preferred option for captured biogenic CO_2 given current market conditions.

CONCLUDING REMARKS

BECCS and BECCU will play complementary roles in Europe's path to climate neutrality. BECCS offers scalable, verifiable, and permanent removals—vital for achieving net-negative targets—while BECCU provides near-term opportunities for defossilising critical fuel sectors. The emerging European policy architecture, combined with pioneering national initiatives in Sweden, Denmark and Norway is establishing the foundations for commercial BECCUS deployment. As technology costs fall and regulatory frameworks mature, strategic coordination between storage and utilisation pathways will be central to maximising climate, economic, and system-wide benefits.

Introduction

While there are many potential benefits from both Bioenergy Carbon Capture and Storage (BECCS) and Bioenergy Carbon Capture and Utilisation (BECCU), the two are somewhat different pieces in the climate change mitigation puzzle. BECCS has the vital property that it can enable negative emissions, and thus provide products that have negative emissions, for example electricity and/or heat from biomass power and/or heat plants that implement carbon capture. Meanwhile, BECCU will in most cases at best be CO_2 neutral but can be an important pathway by which to produce carbon-containing fuels, chemicals and materials that are compatible with a zero-emission society. Furthermore, while BECCS implementation may in some contexts be limited by the complicated logistics and substantial economies of scale associated with transport and storage of CO_2, there are BECCU options that can be implemented in more decentralised situations. A vital question moving forward will thus be "when to store and when to utilise?", i.e., in what contexts is BECCS more preferable? Where on the other hand does BECCU make more sense? The current report attempts to fold out this discussion.

Biogenic CO_2 storage vs utilisation – Perspective matters

The question of whether to store or utilise captured biogenic CO_2 will depend on a number of site-specific factors, regulations and policies, climate protection aspects/targets but will also depend on whom poses the question. For example, a country or municipality wishing to meet its climate targets may prefer that captured biogenic CO_2 be sequestered in order to generate negative emissions. The same can be said for a private company wishing to purchase negative CO_2 emission credits. Meanwhile, a shipping or aviation company within the same country may prefer that the captured biogenic CO_2 be utilised to produce CO_2 neutral transport fuel for use in its ships or airplanes. Lastly, for the owner of a CO_2 emitting site, that is for example privately owned, the decision of whether to store or utilise will largely be a purely economic one.

When focusing on the overarching question of whether to store or utilise captured biogenic CO_2, the current report will primarily view this question from the perspective of the CO_2 emitting site. As will be demonstrated, this is of course often greatly affected by policies pursued by relevant governments. The initial results and insights from early movers provided here can therefore be useful for other governments when it comes to shaping policies and regulations regarding their preferred usage of the CO_2.

Theoretical approach and discussion

BECCS

Essentially, BECCS intercepts CO_2 captured from the atmosphere by photosynthesis, disrupting the natural carbon cycle which would otherwise release CO_2 back to the atmosphere through respiration or combustion. In this way, BECCS can achieve negative emissions, meaning that it removes more CO_2 from the atmosphere than it emits and storing it with high permanence. This is fundamentally different from CCS applied to fossil-based CO_2, which simply avoids (or delays) the transfer of carbon from geological storage to the atmosphere. Fossil CO_2 capture can avoid making the climate change problem worse; biogenic CO_2 capture can be part of the solution and actively remove CO_2 from the atmosphere. This principle is clearly explained elsewhere, e.g. (Olsson, Abdalla, Bürck, & Fehrenbach, 2022), (Hajian & Sedighi, 2022), (Institute for Carbon Removal Law and Policy, 2020). The fundamental principle of biogenic CO_2 capture and storage (BECCS or wider interpretation bio-CCS) and fossil CO_2 capture and storage is highlighted in Figure 1. Additionally, BECCS contributes dispatchable renewable energy during its operation, in contrast to other carbon dioxide removal (negative emission) technologies that typically consume energy (IPCC, 2023). Consequently, BECCS has the potential to lower the overall cost of carbon removal when compared to alternative technologies (Hayat, Alhadhrami, & Elshurafa, 2024). Furthermore, in contrast with widely established land-based Carbon Dioxide Removal (CDR) methods such as afforestation and soil carbon sequestration, BECCS involves the transfer of biogenic CO_2 from ecosystems (storage timescales of decades to centuries) to geological formations (storage timescales of millennia) (Geden, Smith, & Cowie). This is particularly important in the face of increasing climate volatility, and extreme weather events, which reduce the certainty of long-term storage in any given land-based CDR scheme.

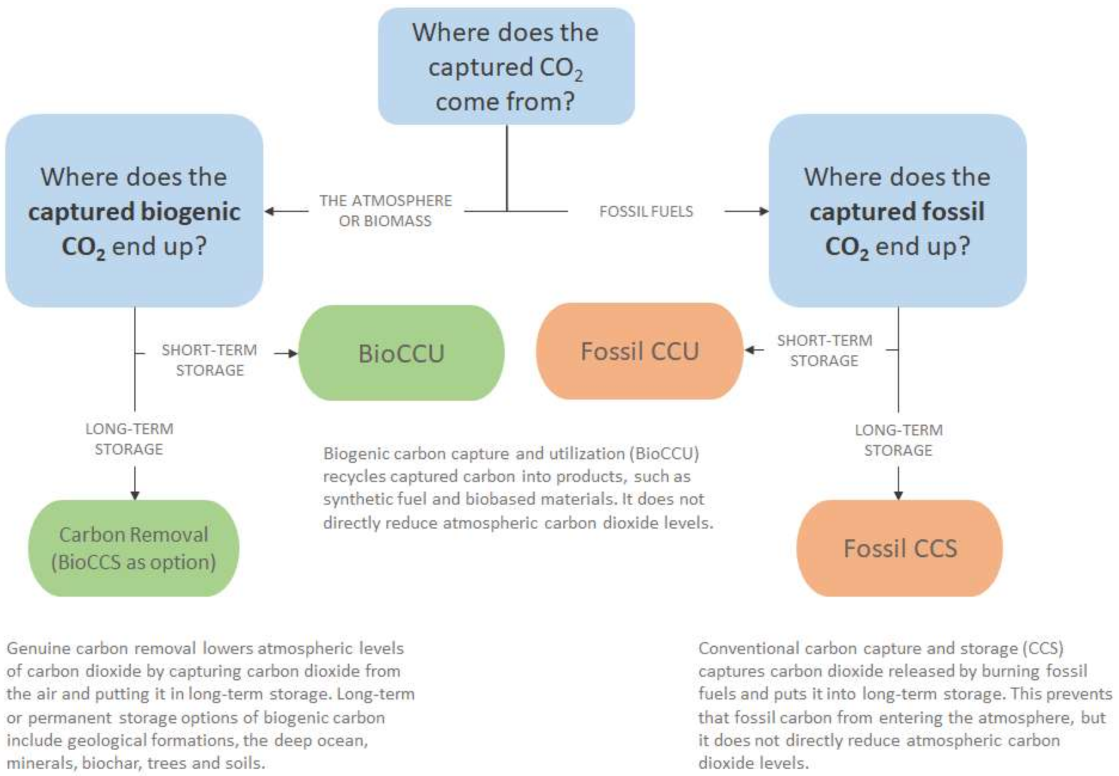


Figure 1: Distinguishing carbon dioxide capture and removal - biogenic CO_2 capture and fossil CO_2 capture (Based on: Institute for Carbon Removal Law and Policy, 2020).

In light of ongoing debate about the climate mitigation efficiency of harvesting forests to provide materials and bioenergy (Sohngen, Baker, Daigneault, & Favero, 2024), Figure 3 represents a "worst case" single use of wood harvested from a growing forest stand to supply a BECCS system. Typically, lower value forest or sawmill residues will be used for bioenergy, and the remainder of a forest harvest will go to higher value products such as sawn wood or particle board (Forster, Healey, Newman, & Styles, 2023). Nonetheless, the elaboration of this "worst-case" example is useful to demonstrate how the climate mitigation efficacy of BECCS depends on its influence across multiple carbon stores.

Compared with simple bioenergy generation without CCS, BECCS fundamentally changes biogenic CO_2 storage effects. At the forest stand level, carbon storage is dramatically reduced after harvest, from 5 down to 1 unit of CO_2, and slowly recovers over a period of 28 years. However, 3 units of biogenic CO_2 are transferred to geological storage, so that total (forest plus geological) biogenic CO_2 storage returns to the baseline level (BL) after just seven years (by 2034) and continuously exceeds the baseline level from 2041 onwards (Figure 2). By 2100, total biogenic CO_2 storage in the BECCS scenario is more than double the baseline (following three post-harvest transfers into geological storage). This cumulative “carbon pump” effect of BECCS could be particularly valuable for long-term climate stabilisation by: (i) providing an ongoing CO_2 sink beyond the point at which terrestrial carbon stores may saturate, and; (ii) de-risking the terrestrial carbon sink by transferring CO_2 storage away from climate-related risks (droughts, wildfires, pests & diseases, etc).

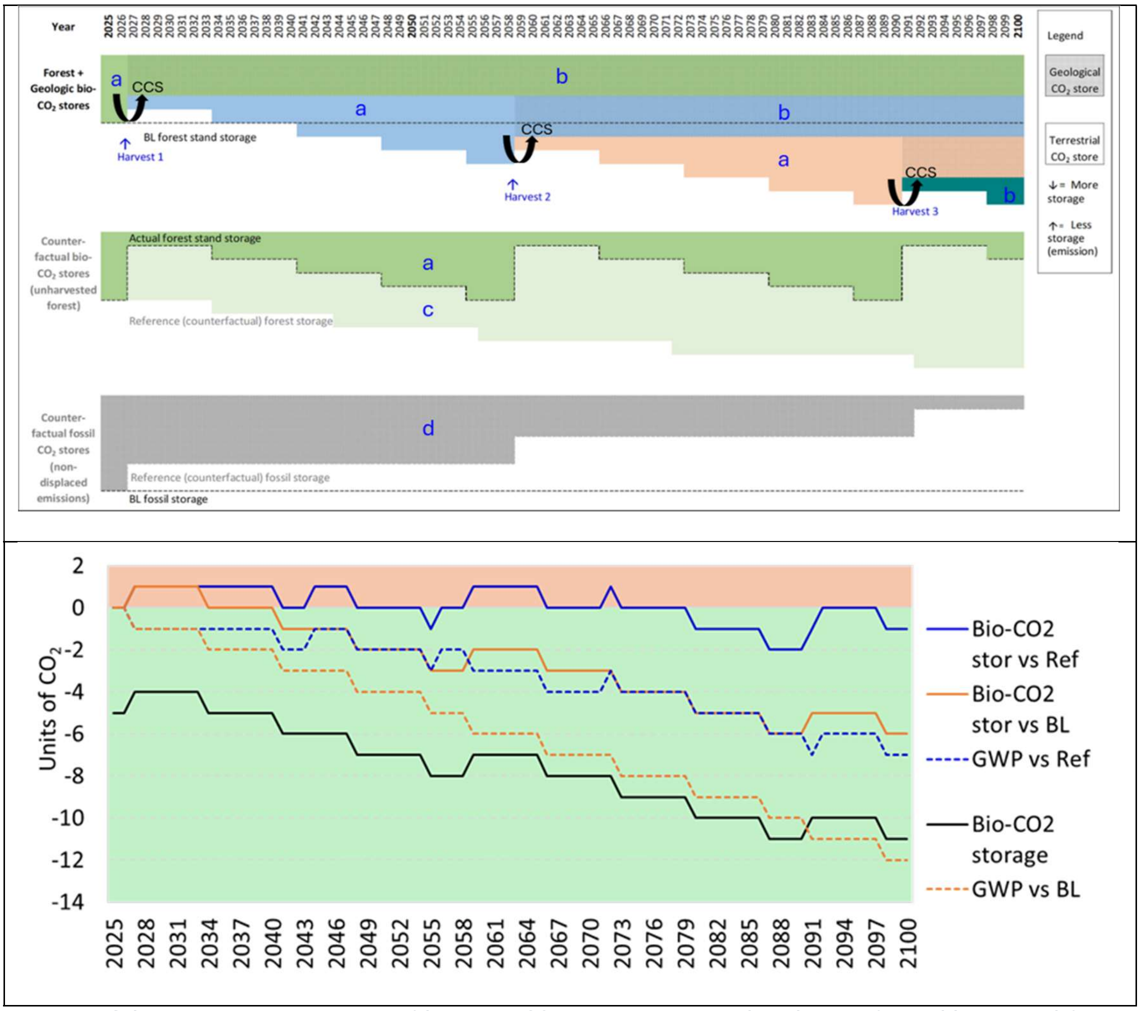


Figure 2: Schematic representation of biogenic CO_2 stores associated with use of wood harvested from a forest stand at year 32 of growth for BECCS, across three harvest cycles, based on conservative assumptions including: (i) a forest stand and single wood use perspective; (ii) 50% fossil CO_2 substitution efficiency; (iii) 75% carbon capture efficiency. Total biogenic CO_2 storage is the sum of evolving forest stand (a) and post-CCS geological storage (b). Flows from (a) to (b) in the upper panel arise via BECCS after harvest. References for the climate effects of BECCS include: (i) baseline forest stand biogenic CO_2 storage immediately prior to harvest; (ii) counterfactual evolution of (non-harvested) forest stand storage (c) based on a slowing growth rate, and; (iii) counterfactual cumulative fossil emissions, inversely related to fossil CO_2 storage (d). Net biogenic CO_2 storage and climate effects shown lower panel (negative values = climate mitigation).

Where things become more complicated in terms of assessing the net climate effect of BECCS is to understand what carbon storage (and conversely, net emissions) would have looked like in the absence of that BECCS system. This requires consideration of counterfactual carbon storage / emissions across systems influenced by the introduction of BECCS value chains. Here, we illustrate a simplified system boundary considering directly linked counterfactual processes, namely:

- Counterfactual forest growth and associated biogenic CO_2 storage (again, a "worst-case" assumption that assumes harvesting decisions are driven by BECCUS value chains, rather than higher value wood uses that could arise is cascading chains *before* BECCUS) Counterfactual reduction in fossil CO_2 storage (i.e. fossil emissions) displaced by first, and in case of BECCU second, bioenergy use.

Assuming a 50% substitution efficiency of fossil CO_2, the net climate effect of BECCS is beneficial right from harvest – because the avoidance of 2 units of fossil CO_2 emission (i.e. avoided depletion of fossil CO_2 storage in Figure 2) surpasses the initial 1-unit deficit in actual biogenic CO_2 storage in the first 7 years of forest regrowth. By the second harvest cycle, the additional 3 units of biogenic CO_2 storage in the geological pool (following BECCS transfer) surpasses the counterfactual increment in forest biogenic CO_2 storage that would have arisen had the forest not been harvested (Figure 2). The interaction between actual forest regrowth and periodic harvest, evolving (and slowing) counterfactual forest growth, periodic avoidance of fossil CO_2 release, and periodic increase in geological biogenic CO_2 storage, combine to generate an intermittent stepped increase in climate benefit through time, culminating in a 7-unit net benefit by 2100 (via a 2-unit benefit by 2050). Compare also (Bishop, et al., 2026).

BECCU

BECCU involves use of biogenic CO_2 to achieve another fossil CO_2 substitution and may or may not include longer-term biogenic CO_2 storage depending on what the CO_2 is used for, and the end-of-life management in case of a material. The underlying purpose with BECCU is the utilisation of the biogenic CO_2 and not its permanent storage for achieving negative emissions. Only where biogenic CO_2 is used to produce a material that is not incinerated (without CCS) at end-of-life, will the biogenic CO_2 be stored for some longer term. And often there is a trade-off between the additional fossil CO_2 substitution achieved by BECCU versus the additional actual long-term carbon storage (and negative emissions) achieved by BECCS. Figure 2 displays indicative carbon storage and substitution effects for a simplified assessment of a biogenic CO_2 to e-methanol value chain.

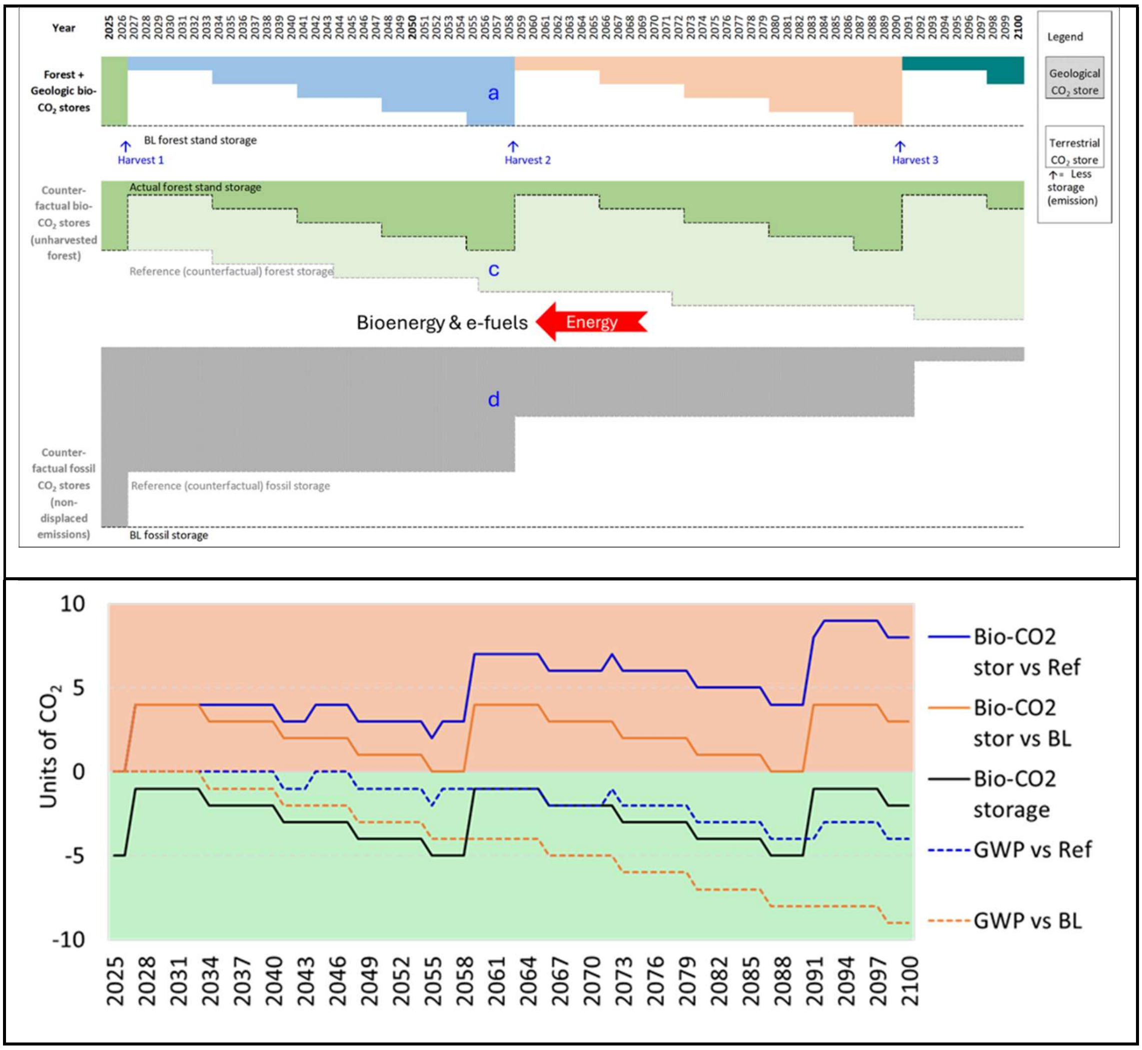
Compared with BECCS, BECCU incurs a larger fossil CO_2 emission avoidance credit, so that twice as much fossil CO_2 storage depletion (in other words, emission) is avoided, but also incurs a larger biogenic CO_2 storage deficit versus counterfactual (unharvested) forest growth (Figure 3). Total biogenic CO_2 storage remains below the baseline level until 2055 in the case of BECCU. Compared with the reference counterfactual situation, BECCU results in a small climate benefit (1 unit CO_2) by 2050, increasing to 4 units of CO_2 by 2100. However, unlike BECCS, a substantial energy input is implied to generate the hydrogen needed for e-methanol production. The presented CO_2 balances imply that this energy comes from independent non-fossil and non-bio (renewable) sources and therefore does not significantly impact CO_2 stores.

It is important to note that the figures in Figure 2 represent a "worst-case" perspective in that they consider a single forest stand, and a single use of wood for BECCUS purposes. If analysis was instead undertaken at the level of a sustainably managed forest, where annual harvest volumes are within annual growth increments, then forest biogenic CO_2 storage would effective remain constant at the baseline level, whilst geological CO_2 storage would accumulate. Modelling full Harvested Wood Products (HWP) breakouts would introduce additional temporary

CO_2 storage effects and substitutions not shown here (see e.g. Forster, Healey, Dymond, & Styles, 2021).

Implied climate trade-offs

BECCUS can substantially improve the climate mitigation efficacy of bio-based value chains by increasing either cumulative biogenic CO_2 storage potential, and/or fossil CO_2 substitutions for every molecule of harvested biogenic carbon. BECCS can also be deployed after more conventional cascading use of biomass – e.g. after use of wood in construction, or after a few cycles of paper or particle board recycling (Forster, Healey, Newman, & Styles, 2023). There are many possible deployment options for BECCU at different stages of cascading bio-based value chains that could enhance the substitution and/or biogenic CO_2 storage value of biogenic carbon, beyond the simple double bioenergy use considered here. For example, BECCU could "upcycle" biogenic CO_2 to form bio-plastic polymers that could provide fossil substitution and (temporary) storage benefits – these storage benefits could be extended to become effectively permanent depending on end-of-life management (which could include incineration with CCS).[5]



[5] Further info: Styles, D. et al: BECCUS Science and policy. WP7 Summary Report. BECCUS Phase 2. https://task40.ieabioenergy.com/wp-content/uploads/sites/29/2025/05/IEA-Bioenergy_Intertask_BECCUS_Phase2_Science-and-Policy-Report_final.pdf

Figure 3: Schematic representation of biogenic CO_2 stores associated with use of wood harvested from a forest stand at year 32 of growth for BECCU (bioenergy followed by use of biogenic CO_2 for methanol production), across three harvest cycles, based on conservative assumptions including: (i) a forest stand and single wood use perspective; (ii) 50% fossil CO_2 substitution efficiency from first bioenergy; (iii) 75% carbon capture efficiency; (vi) 67% fossil CO_2 substitution efficiency for e-fuel. References for the climate effects of BECCU include: (i) baseline forest stand biogenic CO_2 storage immediately prior to harvest; (ii) counterfactual evolution of (non-harvested) forest stand storage (c) based on a slowing growth rate, and; (iii) counterfactual cumulative fossil emissions, inversely related to fossil CO_2 storage (d). Net biogenic CO_2 storage and climate effects shown in lower panel (negative values = climate mitigation).

BECCS can lead to clear climate mitigation through a “carbon pump” effect that enables continuous uptake by, and transfer of biogenic CO_2 from, ecosystems. It offers a pathway to secure long-term storage of biogenic CO_2. However, it is less flexible than BECCU in that it represents the end of a value chain – the carbon can’t be used in the technosphere (economy) after being injected into geological storage. BECCU options incur high energy costs and incur a deficit in biogenic CO_2 storage versus alternative ecosystem management, so that climate mitigation effects are potentially less robust. However, BECCU options are more versatile, and can fit along various steps of bio-based value chains and represent a pathway to biogenic CO_2 upcycling. BECCU options are likely to make most sense in situations where fossil carbon can’t be directly substituted with clean energy. Further work is needed to explore how BECCUS can be integrated in a way that maximises the contribution of the future bioeconomy to circularity and climate-neutrality.

Regulatory status at EU level

There are several policy instruments, regulations, processes and proposals at EU level, affecting the conditions for the deployment of BECCUS in different ways. Important examples are listed in Table 1.

Table 1: Examples of current policy instruments, regulations and processes and proposals that affect the conditions for BECCS and BECCU.

Mainly influencing BECCS	Mainly influencing BECCU
EU Carbon Removal Certification Framework	Renewable Energy Directive (RED)
Empowering consumers for the green transition	FuelEU Maritime Regulation
Green Claims Directive	ReFuelEU Aviation
CCS Directive, Offshore Directive, Helsinki Convention, London Protocol	Circular Economy Action Plan (CEAP)
Industrial Decarbonisation Accelerator Act	Packaging and Packaging Waste Directive
CDR purchasing programme	
European Climate Law and the negotiations on the EU's 2040 climate target	
EU ETS Directive	
Industrial Carbon Management Strategy	
Net-Zero Industry Act	
EU Innovation Fund	
Industrial Decarbonisation Bank	

CLIMATE GOALS WITHIN EU

Under the European Climate Law, which is the heart of climate legislation on EU level, the EU is committed to achieving climate neutrality by 2050, with an interim goal of reducing net greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels. To support this, the EU introduced in 2021 the Fit for 55 package, designed to help reach the 2030 targets. In February 2024, the European Commission released a comprehensive impact assessment, examining various approaches to meet the 2050 climate-neutrality target (European Commission, 2024a). Based on this assessment, the Commission recommended a 90% reduction in net GHG emissions by 2040 compared to 1990. The proposal is expected in spring 2025. Once adopted, the 2040 target will guide the EU's updated nationally determined contributions under the Paris Agreement.

THE ROLE OF BECCS

The European Commission’s scenario analysis, "A Clean Planet for All", explores pathways for the EU to achieve climate neutrality by 2050 (European Commission, 2018). In scenarios where net zero emissions are reached, emissions are cut by over 90%. Achieving net zero involves balancing residual emissions in 2050 with an equivalent amount of carbon capture, using technologies like BECCS or DACCS, combined with the EU's total net removals in the LULUCF (land use, land-use change, and forestry) sector. This approach would result in a total of 500-600 million tonnes of CO_2 removed. In these scenarios, BECCS and DACCS are expected to capture between 207 and 486 million tonnes of CO_2 by 2050, with storage ranging from 80 to 298 million tonnes. Other CDR options like biochar or enhanced weathering for negative emissions are not considered within these scenarios due to further research needs regarding the efficiency and scalability of their capacity for CO_2 absorption and storage. This highlights the significant role of BECCS being a readily available CDR technology at the current point in time.

REPORTING OF AND INCENTIVES FOR PERMANENT NEGATIVE EMISSIONS

The approach for reporting permanent negative emissions, such as BECCS, within the EU remains undecided. Reporting could potentially fall under one of several existing frameworks: (i) the ETS Directive, which regulates the EU Emissions Trading System, (ii) the Effort Sharing Regulation (ESR), covering the non-traded sector, or (iii) the Regulation on Land Use, Land Use Change, and Forestry (LULUCF), which manages emissions and carbon removals related to forests and soils. Alternatively, a new, separate regulation specifically for negative emissions could be introduced. Including BECCS in the EU ETS would create economic incentives for negative emissions at the EU level. However, inclusion under the ESR or LULUCF frameworks would not automatically provide such economic incentives. In this case, additional policy instruments at either the national or EU level would be required (Fossil Free Sweden, 2024).

The ETS Directive states that the Commission shall, by the summer of 2026, submit a report on how negative emissions should be accounted for and how they could be covered by emissions trading. In the EU Industrial Carbon Management Strategy (see below), it is stated that policy instruments for industrial carbon storage shall be developed, including whether such storage should be reported within the EU ETS (European Commission, 2024b).

CRCF - CARBON REMOVAL CERTIFICATION FRAMEWORK

In February 2024, a provisional agreement was reached on a new EU regulation to establish the first certification framework for permanent carbon removals, carbon farming, and carbon storage in products (Council of the EU, 2024a). The regulation was finally approved and adopted late 2024 (Council of the EU, 2024b). The regulation supports activities in four main categories:

- **Permanent carbon removal**: Long-term atmospheric or biogenic carbon storage, including BECCS.
- **Temporary storage in products**: Carbon storage in durable products (e.g., wood-based materials) for at least 35 years, with on-site monitoring.
- **Temporary storage from carbon farming**: Initiatives like reforestation, wetland management, and seagrass restoration.
- **Reduction of land emissions**: Emission reductions from carbon farming practices.

This framework aims to ensure high-quality of the measures through criteria for quantification, additionality, long-term storage, and sustainability. Initially voluntary, the ambition is to eventually make it a guiding framework to be used both for certificate trading on the voluntary market and for other private as well as public financing of carbon sinks.

European Commission are currently (spring 2025) drafting methodologies with the first round including DACCS, BECCS and biochar carbon removal. The methodologies will be adopted Q4 2025 and implemented in 2026 (Harding, 2025).

EU INDUSTRIAL CARBON MANAGEMENT STRATEGY WITH FOCUS ON CCUS

In February 2024, the Commission introduced the EU Industrial Carbon Management Strategy, focused on CCUS (European Commission, 2024c), (European Commission, 2024b). It aims to create a comprehensive framework for industrial carbon management and an internal CO_2 market, emphasizing coordinated national strategies and strategic EU infrastructure planning. This strategy will complement existing EU policies and financing tools, including the CCS Directive, EU ETS, CRCF, and the EU Innovation Fund.

The strategy sets out three different steps in the development of industrial carbon management in Europe:

- 2030 - CO_2 storage capacity of at least 50 million tonnes per year, together with associated transport infrastructure.
- 2040 - value chains should be economically viable, up to one third of the captured CO_2 is estimated to be used and the remaining two thirds stored.
- After 2040 - industrial carbon management should be an integral part of the EU economic system, biogenic or atmospheric carbon should become the main source of carbon.

Uncertain carbon volumes, complex coordination, and lengthy licensing are key barriers to carbon transport investment. The Commission proposes preparatory work on a carbon transport regulation and an EU-wide planning mechanism with Member States, as well as support for Important Projects of Common European Interest in carbon transport and storage.

For CCU, it will assess options to increase sustainable carbon use in industry and develop a framework to support innovative applications. Furthermore, the Commission plans to evaluate an overall target for industrial carbon storage in line with the EU's climate ambition for 2040 and the climate neutrality target for 2050, with a view to achieving net negative emissions after that. Policy instruments for industrial carbon storage will also be developed, including how they are to be accounted for in the EU ETS. Support for research, innovation and early demonstrations of new industrial technologies to remove CO_2 within Horizon Europe and the Innovation Fund will also be strengthened.

EMPOWERING CONSUMERS FOR THE GREEN TRANSITION

The directive Empowering Consumers for the Green Transition (European Parliament, 2024) prohibits companies from making claims such as climate neutrality or climate positivity for products when such claims are based on offsetting emissions within their value chain. There remains uncertainty about the types of claims companies will be allowed to make at a broader corporate level using carbon offsets, and this will need to be clarified in forthcoming legislation, such as the *Green Claims Directive*. The kind of claims companies are permitted to make may significantly influence the demand for negative emissions credits on the voluntary carbon market.

RULES AND CONVENTIONS AS POTENTIAL BARRIERS TO CO_2 TRANSPORT AND STORAGE

There are existing regulations and international conventions that have been noted as potential barriers to the transport and storage of CO_2 (Fossil Free Sweden, 2024). Through an amendment to the London Protocol, the transport of CO_2 for offshore storage in another country is allowed, but the amendment has not yet come into effect as not enough countries have ratified it. However, the EU Commission believes that existing EU legislation is sufficient, though simpler agreements between countries need to be made, which has been done between several countries, such as Denmark and Belgium.

The CCS Directive does not differentiate between the origin of CO_2 molecules in mixed flows. Leakage of biogenic CO_2 during transport, for example, may require compensation under the EU ETS, which could complicate and increase the cost of BECCS. Furthermore, the CCS Directive does not permit storage sites extend into territories or economic zones outside European Union's territory, which is a potential problem for e.g. future sites for storage in Sweden.

RENEWABLE ENERGY DIRECTIVE (RED)

The purpose of the Renewable Energy Directive (RED) is to promote increased use of renewable energy and sustainable fuels within the EU. RED regulates the production and blending of sustainable fuels and specifies the greenhouse gas reduction quantification method to be used, depending on different feedstocks. The latest revision of the directive (RED III) was introduced in March 2023 (EU, 2023).

Renewable Fuels of Non-Biological Origin (RFNBO) are fuels produced by 1) converting renewable electricity through water electrolysis to produce hydrogen or 2) blending hydrogen with CO_2 to create hydrocarbons (e-fuels via, for example, BECCU). The term "synthetic fuels" is also used in ReFuelEU Aviation and FuelEU Maritime.

RED III includes a target of 5.5% for advanced biofuels, biogas, and RFNBOs, with at least 1% RFNBOs by 2030. According to the RED, advanced biofuels and biogas used in aviation and maritime transport shall be counted as 1.2 times their energy content, and RFNBOs as 1.5 times their energy content. In February 2023, two delegated acts to RED were adopted, including sustainability criteria and methods for RFNBOs (and RCF) (European Commission, 2023). These include e.g. (i) a minimum 70% greenhouse gas reduction compared to the fossil reference alternative and (ii) that non-renewable carbon sources will count as emissions after 2035 for power plants and after 2040 for other facilities. Furthermore, rules regarding how to account for the GHG intensity of used electricity are described.

REFUELEU AVIATION

In 2023, new targets for Sustainable Aviation Fuels (SAF) were adopted under ReFuelEU Aviation (The European Parliament, 2023a) (see Figure 4). The targets consist of quotas for SAF as a share of the future fuel mix, with specific sub-quotas for synthetic fuels. The levels in the short-term perspectives are low (e.g. 6% SAF, 1,2% synthetic fuels by 2030). By 2050, however, SAF is expected to account for 70% of the fuel mix, with a sub-quota of 35% for synthetic fuels. The sub-quota can be met by both RFNBOs and "synthetic low carbon fuels," which are fuels of non-biological origin whose energy content comes from non-fossil sources. This can include electrofuels where the electricity is generated from nuclear power.

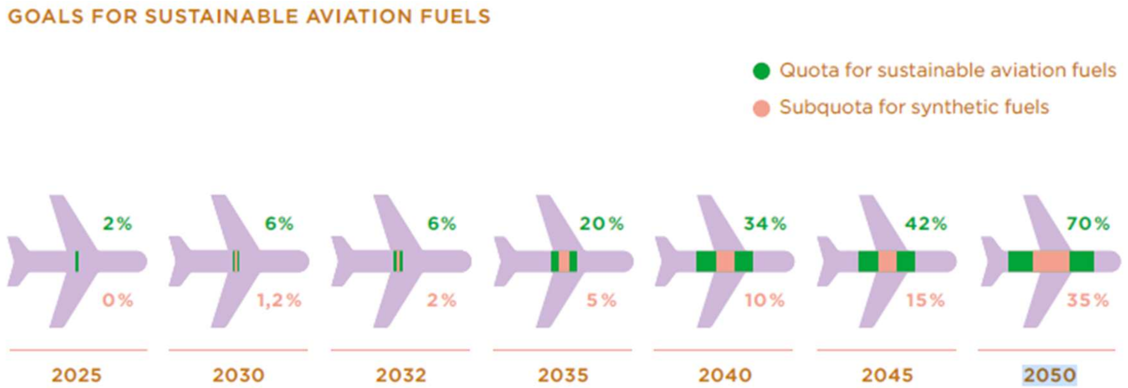


Figure 4: Targets for sustainable aviation fuels within the EU in the form of volume-based quotas (total for sustainable aviation fuels and with specific sub-quotas for synthetic fuels). Figure from Fossil free Sweden (2024).

FUELEU MARITIME

The FuelEU Maritime Regulation (The European Parliament, 2023b) requires ships over 5,000 gross tonnes calling at European ports to reduce the greenhouse gas intensity of the energy used on board by 80 percent by 2050, with interim targets as shown in Figure 5. A sub-quota (of 2%) will be introduced for synthetic fuels starting in 2034 if their total energy contribution to maritime transport is below 1% in 2031. The double counting (multipliers) specified for biogas, advanced biofuels, and RFNBOs in the RED are not included in the FuelEU Maritime Regulation. However, the multiplier for RFNBOs used in maritime transport will be 2 between 2025 and 2033, in order to stimulate the use of RFNBOs in shipping. A sub-quota (of 2 percent) will be introduced for RFNBOs starting in 2034 if their total energy contribution to maritime transport in 2031 is below 1 percent.

AVERAGE ANNUAL REDUCTION OF GREENHOUSE GAS INTENSITY COMPARED TO THE AVERAGE IN 2020

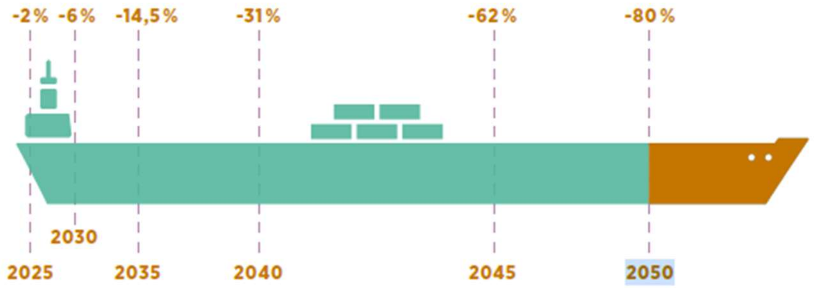


Figure 5: Targets for reducing the greenhouse gas intensity of the energy used on board vessels calling at European ports. Figure from Fossil free Sweden (2024).

THE ETS DIRECTIVE AND THE POSSIBILITY TO ALLOCATE CO_2 OF MIXED ORIGIN

One issue related to carbon capture from mixed CO_2 streams—such as those from waste—is the possibility of allocating carbon atoms. As a result of the cut-off date established in the RED for the use of fossil-derived carbon dioxide (see above), several waste-based CCU initiatives are based on the assumption that only the biogenic fraction will be utilized for CCU, while the fossil fraction is either not used or directed to CCS.

According to current regulations, including the EU ETS Directive and the Monitoring and Reporting Regulation, it is not permitted to claim that, for example, the biogenic portion of a stream is directed to CCU while the fossil portion is directed to CCS. If such allocation is not allowed, both the CO_2 stream going to CCU and the one going to CCS must be considered a mixture of fossil and biogenic carbon, based on the specific composition of the stream in question. This is determined using the mass balance principle. Consequently, the portion directed to CCU will partly be considered fossil-based and will therefore require emission allowances, which may present a barrier to investment.

However, this type of allocation appears to be permissible under the Renewable Energy Directive (RED), as indicated by the European Commission's response to questions regarding the interpretation of the delegated acts on RFNBOs (DG Energy, 2024) (Q&A 2024, Question 38).

Selected developments and case studies from leading European countries within BECCUS

The following chapter takes deep dives into two European countries that are leading the development of BECCUS solutions, namely Sweden and Denmark, as well as reflecting on Norway, which is a pioneer in CO_2 storage. This is eloquently exemplified by the fact that Denmark and Sweden are developing the two first large scale BECCS projects, and the storage destination for both projects is Norway.

SWEDEN

Climate goals

The Swedish Climate Policy Framework states that Sweden aims to achieve net-zero emissions by 2045 and have negative net emissions thereafter. Emissions are to decrease gradually, with interim targets for 2030 and 2040, to reach a reduction of at least 85 percent by 2045 compared to 1990 levels. To offset residual emissions and reach negative net emissions, so-called complementary measures are used. These include increased net carbon uptake and reduced emissions in forestry and land use, BECCS, and verified emission reductions through investments in other countries.

Governmental investigation - The pathway to a climate-positive future

In a governmental investigation from the beginning of 2020 - The pathway to a climate-positive future – the need for supplementary measures were pointed out (Statens offentliga utredningar, 2020). The indicative target is to implement complementary measures equivalent to 3.7 million tonnes of CO_{2eq} annually by 2030, with BECCS expected to account for 1.8 million tonnes. By 2045, the goal is to achieve complementary measures corresponding to at least 10.7 million tonnes of CO_{2eq} per year, with BECCS expected to contribute between 3 and 10 million tonnes. Some different measures were taken because of the investigation included BECCS becoming a part of big national program for research and innovation and an investigation of a support scheme for BECCS started (see below).

Fossil free Sweden's strategy for BECCUS

Fossil Free Sweden, initiated by the Swedish government in 2015, develops roadmaps, strategies, and political proposals in collaboration with stakeholders, which are then presented to the government to support Sweden's transition to a fossil-free future. In May 2024 the strategy for Biogenic carbon capture (BECCUS) was presented and handed over to the government (Fossil Free Sweden, 2024). Important starting points for the strategy include:

- Sweden has large (>100 kton per year) biogenic emission point sources of more than 32 Mton per year and a great potential for increased carbon utilization and to eventually become a significant net exporter of both sustainable carbon-based products and negative emissions.
- Negative emissions from BECCS must primarily be used to compensate for emissions that are otherwise difficult or very expensive to remove and is a measure to reach net negative emissions and reduce the amount of CO_2 in the atmosphere.
- For the production of sustainable carbon-based products, a broader perspective than pure CCU must be adopted since there are more efficient solutions for most applications in the long-term perspective.

The aim was to enable the necessary technology development for Sweden to achieve net negative emissions in the long term and to support the development of a new Swedish export industry for permanent negative emissions and sustainable carbon-based products. The focus was on how Sweden should act to remove obstacles, create conditions and incentives for the expansion of facilities for BECCUS. Some examples of suggestions from the action plan include that Sweden should work for:

- the introduction of separate targets for emission reductions and carbon storage, including a specific proportion of permanent negative emissions, both within the EU and at national level
- that a common definition is developed, for member states and companies within the EU, to standardize which residual emissions can be accepted in 2050
- that regardless of where reporting of permanent negative emissions will take place within the EU, ensure that these contribute to an increase in ambition in climate work
- that targets for recycled and/or renewable raw materials for chemicals and plastic products are introduced within the EU, including a common stop-year, suggested year 2040, for the intake of new virgin fossil raw materials

- to introduce a flexible and long-term policy instrument in the form of a revenue guarantee for domestic production of electrofuels and other renewable fuels.

The strategy also included suggestions regarding the design of the Swedish support scheme (which was not yet released at the time) including how the negative emissions should be used by Sweden. The strategy recommended that Sweden should only use permanent negative emissions to compensate for residual emissions of a maximum of 15% by 2045 so that the pace of continued emission reductions does not decrease.

BECCU plans in Sweden

Driven by the demand for electrofuels in aviation and maritime transport, and to some extent in the chemical industry, around ten large-scale CCU projects have been announced in Sweden (IEA Bionergy, 2024). The situation in Sweden, with a very high share of renewables in the electricity system, allows electrofuels (RFNBOs) to be produced using grid electricity without being attributed any greenhouse gas emissions from that electricity, in accordance with the RED framework. However, in certain parts of the country, agreements for the purchase of renewable electricity are required.

Ørsted had invested in what was to be Sweden's first BECCU facility in Örnsköldsvik and construction was set to begin in the near-term future. The project was however cancelled citing slow methanol market development (The Maritime Executive, 2024). Liquid Wind, which has developed the so-called FlagshipOne project in Örnsköldsvik, announced in early 2025 that it is resuming Ørsted's previously discontinued initiative (Howard, 2025). Once operational, the facility will produce approximately 100,000 tonnes of e-methanol per year, primarily for use in maritime transport.

Liquid Wind is also developing other e-methanol projects in collaboration with energy companies and technology providers in Sundsvall and Umeå. A similar project is being developed by Uniper at Jämtkraft's biomass fuelled CHP plant in Östersund.

Vattenfall, LanzaTech, and SAS are exploring the possibility of producing e-aviation fuel in Forsmark under the "HySkies" project. The project has been granted 80 million euros in support from the EU Innovation Fund, but no final investment decision has been made. St1 and Vattenfall are conducting a feasibility study on the production of e-aviation fuel based on electricity from offshore wind power. In Långsele, Uniper was exploring the possibilities for bioelectro-aviation fuel (implicit CCU by hydrogen boosted gasification) under the SkyFuel H2 project. In the autumn of 2023, a grant of 133 million SEK was awarded for planning and design from the Industrial Leap. In October 2024, it was however announced that the project is cancelled.

Several biogas producers are looking at opportunities to use the CO_2 from biogas production. Tekniska verken in Linköping is building a plant to recover and liquefy 20,000 tonnes of CO_2 from their biogas plant, with intended use in the food industry to replace the use of fossil CO_2. The plant will be ready in 2025. It will then be the first plant in Sweden to capture and use CO_2 from biogas plants. Another CCU application that has been in place for several years, is the usage of CO_2 for the beverage industry from an ethanol production plant in Norrköping (Fossil Free Sweden, 2024).

BECCS plans in Sweden

Several Swedish companies are developing plans for BECSS. The plans are mainly driven by the Swedish tentative targets for BECCS and the support scheme (announced in 2020), the specific interest from buyers on the voluntary carbon market for negative emissions and the development of storage locations for CO_2.

More than 30 different plants within the heat and power sector and pulp and paper industry have to different extent investigated the possibility of implementing BECCS. The Industrial Leap program supports innovative projects that can contribute to negative emissions (IEA Bionergy, 2024). Projects include mainly BECCS and cover the entire innovation chain, from research to investments. The budget for negative emissions within the program is around SEK 100 million per year.

Collaborative opportunities through regional CO_2 terminals, or hubs, at ports where CO_2 from various facilities is collected for joint liquefaction, interim storage, and further transport by ship to final storage are being explored in several locations in Sweden, such as Gothenburg (Cowi, 2021) and southern Sweden (VEAB, 2025).

Sweden has signed co-operation agreements on CO_2 storage with Norway and Denmark. There is also an ongoing investigation of suitable locations for permanent storage of CO_2 in Sweden. However permanent geological storage of CO_2 captured at Swedish facilities in the near- and medium-term future will have to be transported abroad for storage.

Since 2016, Stockholm Exergi has conducted various studies on BECCS (Beccs Stockholm, 2025). Among other things, they have a pilot facility to test capture technology connected to the biofuel-powered combined heat and power plant in Värtan, Stockholm. A BECCS facility is planned there, capable of capturing 800,000 tonnes of CO_2 annually. The project that was granted €180 million in support from the EU Innovation Fund in 2021, and in the beginning of 2025, it was announced that Stockholm Exergi was the winner of the first round of auctions in the Swedish support scheme for BECCS (see next section), enabling the final investment decision for the plant in Värtan to be taken by Stockholm Exergi in March 2025.

Other actors with well-advanced plans for BECCS include Öresundskraft (in Helsingborg), Sysav (in Malmö) and Växjö Energi. Vattenfall, who also had well-advanced plans for BECCS in Jordbro, suddenly announced in December 2024 that they put the project on hold (Plechinger, 2024).

The business model in near term future for most actors is based on combination of state support and selling credits on the voluntary carbon markets (Figure 6 presents potential financing models for BECCS over time). Deals with different companies regarding permanent carbon removals have been made. In May 2024, Stockholm Exergi announced a deal with Microsoft covering 3.33 million tonnes of permanent carbon removals from BECCS (Beccs Stockholm, 2024). The agreement represents the world's largest permanent removals deal to date.

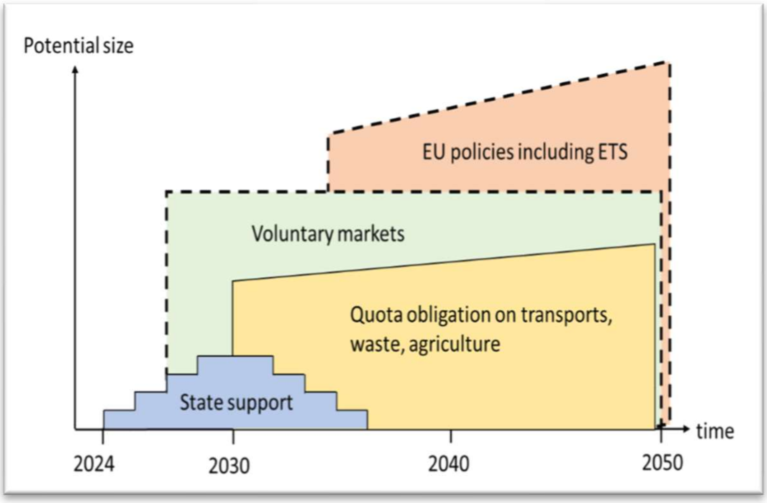


Figure 6: Financing models for BECCS. Figure from Zetterberg, Johnsson, & Möllersten, 2021.

Göteborg Energi has received investment support to realize one of the potentially first value chains for BECCS in the world. In connection with their biogas plant in Gothenburg, a plant is planned where approximately 7,000 tonnes of biogenic CO_2 will be liquefied and then transported for final storage. The business model is, in addition to the investment support, based on selling credits on the voluntary carbon market.

Swedish support scheme for BECCS

During 2024 a Swedish support scheme for BECCS in the form of reversed auctions was introduced (European Commission, 2024d), (Energimyndigheten (Swedish Energy Agency), 2024). The state aid for BECCS was allocated through a competitive bidding process using a reverse auction mechanism. Companies that can capture, transport, and geologically store biogenic CO_2 at the lowest cost to public funds will secure funding. The aid will be disbursed over 15 years. Projects receiving support must begin delivering permanently stored biogenic CO_2 within three years of the funding decision. The scheme applies only to BECCS projects with the capacity to capture and store more than 50,000 tonnes of biogenic CO_2 annually. The total budget for the program is SEK 36 billion (€3 billion), to be distributed by the Swedish Energy Agency between 2026 and 2046.

Combining public support with private financing

In connection with the implementation of the Swedish support scheme and the growing trade in negative emissions on the voluntary carbon market, questions about ownership and who can claim the negative emissions have become highly relevant (Fossil Free Sweden, 2024). This includes determining what claims different actors should be allowed to make. Double claims arise when purchased negative emissions are used to offset the buyer's emissions and achieve the company's climate goals, while also being accounted for by the host country to meet its national climate targets. Opinions differ on the issue of double claims and whether it is problematic for a company and a nation to account for the same negative emissions, see e.g. (Möllersten & Zetterberg, 2023). At COP28 in Dubai in 2023, Belgium, France, and Germany, among others, signed a joint statement calling for carbon credit purchases on a voluntary market — intended by the buyer to offset greenhouse gas emissions — to be adjusted via a "corresponding adjustment" to avoid double claims (Government of the Netherlands, 2023). This recommendation applies to international trade. For trade within the EU, which has shared climate targets (NDC), national regulations may take precedence. Sweden was not a part of this joint statement.

After extensive discussions about how the Swedish support scheme should be designed, and whether funding from the voluntary carbon market could be combined with public support, the final design of the system allows for co-financing. This means that the bids submitted within the auctioning system are so-called net bids, where private financing has been deducted. Thus, if an actor's total cost is, for example, €250 per tonne of CO_2 and half of that cost, €125, is covered by revenues from the voluntary market, the actor may submit a bid equivalent to €125 per tonne of CO_2. The support scheme does not specify how buyers on the voluntary market may use the purchased carbon credits; thus, they may be used to offset the buyer's emissions while also being accounted for by the Swedish state (double claims). To prevent overcompensation under state aid regulations, all revenue and costs must be reported according to an open-book procedure. The aid received will be adjusted taking into account other public support received for the same project (e.g. from the EU Innovation fund).

First auction round

The first auction round took place during autumn 2024. Six different bids were submitted, of which two were not BECCS projects. Among the BECCS projects, however, Stockholm Exergi was the only one considered to have a realistic implementation plan. In early 2025 it was announced that Stockholm Exergi was awarded just over SEK 20 billion for the capture and storage of 800,000 tonnes of CO_2 per year over a period of 15 years. This means that the revenue from the support scheme is approximately SEK 1700 (~€150) per tonne of CO_2.

According to Stockholm Exergi, approximately 40% of the revenues over a 15-year period is from the support scheme (and EU innovation fund) and the rest, approximately 60%, are revenues from the voluntary carbon market. This indicates a total cost close to SEK 4000 (~€350) per tonne of CO_2.

Lessons learnt and next step

The first round of the Swedish support scheme for BECCS has provided several important insights (Flack, 2025). One of the key takeaways was that the costs of carbon capture and permanent storage were significantly higher than initially anticipated and that secondary revenues were an important advantage. In addition, the deadline (three years) for when to start permanent storage was hard to meet for the project developers and is under consideration for the second round of auctions.

As the scheme moves into its next phase, approximately SEK 15 billion remain in the budget. The Swedish Energy Agency is now actively working to map the level of interest among potential bidders. A critical condition for launching the second round is that the total volume of bids must exceed the available budget. This ensures a competitive process and optimal use of public funding. To maintain momentum, the Swedish Energy Agency aims to initiate the second auction round as soon as possible.

Key take aways from Sweden

Over the past five years, there has been significant interest in BECCS in Sweden. This has been driven by increased clarity regarding the future role and necessity of BECCS, as highlighted in the governmental investigation "The pathway to a climate-positive future", alongside the announcement of a forthcoming national support scheme for BECCS, and a growing interest from buyers on the voluntary carbon market, particularly for negative emissions. A wide range of actors—primarily in the heat and power sector—have investigated the possibility of BECCS.

These companies are often municipally owned, and negative emissions through BECCS are frequently integrated into broader strategies for achieving climate-neutral cities.

The pulp and paper industry, which is responsible for the largest concentration of large emission point sources in Sweden—amounting to over 22 million tonnes of CO_2 annually—has explored BECCS to a lesser extent, although interest has increased among several companies in recent years.

The BECCS project developed by Stockholm Exergi highlights the necessity of policy instruments to enable the realization of BECCS projects. Despite substantial revenues from the voluntary carbon market, public support proved essential to cover the total costs and to enable an investment decision. Assuming the same level of support per tonne of CO_2 in the next auction round, an additional 600,000 tonnes of BECCS per year (over a 15-year period) could be made possible. However, this would require an actor (or actors) with either substantial voluntary market revenues (as in the case of Stockholm Exergi), significantly lower costs, or a combination of both. One cost-driving factor for Stockholm Exergi is the plant's limited operating hours, expected to be around 6,000 hours per year.

To enable additional BECCS volumes, further policy instruments are needed. In the long term, the cost of negative emissions must be shifted away from the Swedish state, and new policy instruments must be developed at the EU or national level—such as the inclusion of BECCS in the EU ETS. Even with inclusion in the EU ETS, it may take time before the CO_2 price reaches a level sufficient to support investments in BECCS. The contribution of the voluntary carbon market remains uncertain, and within the EU, the demand could also be influenced by what kind of claims companies will be permitted to make—something that will be regulated under the forthcoming Green Claims Directive.

Several BECCU initiatives have also been announced in Sweden, primarily driven by the specific demand for electrofuels in aviation and maritime transport. However, many of these initiatives have been suspended or postponed over the past year, even though Liquid Wind recently resumed its e-methanol production project in Örnsköldsvik. No final investment decision for e-fuel production was made within the EU in 2024, suggesting that demand resulting from specific sub-quotas in aviation and shipping has not yet materialized to a sufficient degree.

Other potential barriers to BECCU investments also exist, including the fact that the ETS Directive does not currently allow the biogenic portion of a CO_2 stream to be allocated specifically to CCU applications. Instead, a mixed stream of biogenic and fossil CO_2 is treated as requiring allowances for the fossil portion. In Sweden, waste-based CHP plants often serve as baseload in district heating systems, operating year-round. This generally provides favourable conditions for cost-effective CCU, and several of the CCU initiatives are indeed located adjacent to waste-based CHP plants.

DENMARK

Denmark has been at the forefront of both carbon capture and storage the past years, particularly the capture of biogenic carbon. The following section will review the policies that have driven this development, provide an overview of current and upcoming projects, and reflect on modelling analysis that compared CCS and CCUS associated with a biomass-fired CHP plant.

Danish climate targets and highlighted government CCUS policies

In 2020, Denmark adopted the Danish Climate Act, which bound future governments to achieve a target of a 70% reduction in emissions by 2030 compared to 1990 levels, as well as climate neutrality by 2050. Danish emissions of CO_{2e} were roughly 45 Mt in 2020 and would therefore have to be reduced to roughly 23 Mt in 2030 to meet this 2030 target.

In order to roughly cut its emissions in half within a decade, Denmark foresaw that it would be necessary to rely heavily on CCS to achieve this target. Over the next 4 years, the Danish State thus launched a number of policies to support CCUS development. An overview of the key policies is displayed in Table 2.

Table 2: Danish climate targets and highlighted government CCUS policy

Year	CCUS policy, regulation or agreement
2020	The Danish Climate Act adopted a target of a 70% reduction in emissions by 2030 compared to 1990 levels and climate neutrality by 2050. The Danish State establishes a market-based “CCUS Fund” with DKK 16 bn* (EUR 2.1bn) to support execution of the Danish Climate Act targets. The CCUS Fund was at the time divided into two Tenders: 1) CCS (2023), and 2) CCUS (with the year TBD at a later point).
2021	In December of 2021, the Danish State introduced a market-based “NECCS Fund” with EUR 0.35 bn* dedicated to supporting the establishment of a value-chain for negative carbon emissions.
2022	In May of 2022, The Danish Energy Agency (DEA) launched the first tender from the CCUS Fund. With resources of EUR ~ 1 bn*, the objective was to achieve CO_2 reductions of 0.4 Mt annually from 2026 to 2045 via Carbon Capture and Storage (CCS). In August of 2022, the Danish Energy Agency launched the first tender for exploration permits for the offshore storage of CO_2 in the Danish subsurface in the North Sea.
2023	In August of 2023, the DEA launched the tender for the NECCS Fund. The goal was to achieve 0.5 Mt of negative emissions annually from 2025 to 2032 from the EUR 0.35 bn* fund. In September of 2023, a political agreement updating the CCUS fund was reached. By merging funds from another agreement, the pool grew to EUR 3.6 bn*. Via two separate tenders, the aim was to achieve CCS reductions of 2.3 Mt annually by 2029. (This was later updated to one tendering round, with 2.3 Mt/year by 2030). In December of 2023, the DEA launched the first licensing round in Europe for full-scale onshore licences for exploration and storage of CO_2. This Involves subsurface exploration of potential CO_2 storage in five designated areas: Gassum, Havnsø, Rødby, Stenlille and Thorning.
2024	In September 2024, the DEA opened a new tender round for exploration and use of the subsurface for storage of CO_2 at the previously tendered area at Thorning.

Year	CCUS policy, regulation or agreement
	In Oct of 2024, the DEA launched the CCS tender with the objective to realise reductions of 2.3 Mt of CO_2 annually from 2030-2044 via Carbon Capture and Storage (CCS).
2025	In January of 2025, the DEA launched the fourth tender round of permits for exploration and use of the subsurface for storage of CO_2, this tender deals with three coastal areas; Jammerbugt, Lisa and Inez, with a deadline of March, 2025. *Includes 25% VAT

The following sub-sections will describe how CO_2 capture and storage have developed in Denmark in response to the policies outlined in Table 2.

CO_2 capture in Denmark

Large-scale - First bidding round

In May of 2022, The Danish Energy Agency (DEA) launched the first tender from the CCUS Fund, and already one year later, in May of 2023, the winner of the tender was announced. The DEA awarded Ørsted a 20-year contract for its carbon capture and storage (CCS) project 'Ørsted Kalundborg Hub'.

Ørsted Bioenergy will capture and store 430,000 tonnes of biogenic CO_2 annually from 2026. It is estimated that roughly 280,000 tonnes of CO_2 will be captured annually from the woodchip-fired unit 6 at the Asnæs combined heat and power (CHP) plant, and roughly 150,000 tonnes of CO_2 from the straw-fired boiler at the Avedøre CHP plant (see Figure 7, next page). The captured CO_2 at Avedøre will be transported to the Asnæs site (initially via truck, until a pipeline across Zealand is established), whereafter the CO_2 from both sites will be transferred to a new CO_2 export terminal for shipping to Norway (Ørsted, 2024).

Ørsted will establish and hold responsibility for the entire CCS value chain. The main project partners are (Ørsted, 2024):

- Aker Carbon Capture, which will provide CO_2 capture, compression and liquification technology at the two sites
- Northern Lights, which will safely ship and permanently store the CO_2 at 2,600 meters under the seabed in the Norwegian portion of the North Sea
- Microsoft, with whom Ørsted has established a first-of-kind, large-scale agreement for the off take of carbon removal certificates. This is absolutely key to the project, as competing bids would have realised cost savings related to CO_2 quotas and taxes.

The project has initiated construction and will capture CO_2 and commence operations of the value chain from January of 2026.

Figure 7: Overview of Ørsted Kalundborg Hub project (Ørsted, 2024)

Large-scale - Second bidding round

In October of 2024, the DEA launched a CCS tender with the objective to achieve 2.3 Mt of CO_2 emission reductions and/or negative emissions by storing fossil CO_2 and/or biogenic CO_2 or atmospheric CO_2 from 2030-2044. All captured and stored emissions must contribute to Denmark's climate targets.

The original idea was to have two bidding rounds, one in 2024 and one in 2025, with full operations to be in place by Jan 1st, 2029. After receiving feedback from a number of stakeholders, the DEA merged the two rounds to one bidding round, with all projects having to be in place one year later, by Jan 1st, 2030.

Many of the original elements are in place:

- Ambition to achieve a minimum of 2.3 Mt of captured CO_2 annually
- 15-year contracts
- Can opt out to utilise CO_2 for CCUS instead
- Subsidy is paid per tonne CO_2 captured and stored

All contracts awarded will be on the basis of a competitive bidding process as follows:

1) Prequalification (March 2025), where all bidders must meet the following (among other) minimum requirements:
    - The operator shall ensure that the delivered quantity originates from (a) **carbon capture plant(s) placed in Denmark**
    - The operator shall ensure that the annual quantity of CO_2 which **as a minimum shall be 100,000 tonnes** of CO_2 is captured and stored each calendar year **from year 2030 and until and including 2044**.
- After prequalification, there is to be a maximum of 10 bidders that can proceed to the next round. The prequalification criteria if there are more than 10 bidders is based on:

    - Which candidates have demonstrated the most relevant experiences with planning and/or operating CCS activities (carbon capture, transport and storage), including e.g. demonstration projects, pilot projects and research projects, and
    - Which candidates have demonstrated the most relevant experiences with acquiring and establishing plants or platforms and/or modifying or expanding plants or platforms and commissioning hereof
2) Submission of the first Indicative Offer (August 2025)
3) Individual negotiations with the DEA
4) Submission of Best and Final Offer (December 2025)
5) Contract(s) awarded (April 2026)

In terms of the funding available:[6]

- Total maximum for the entire period is roughly €3.8 billion
- Annual maximum fund payout is roughly €240 million
    - To put this figure into perspective, €240 million / 2.3 million tonnes = €104/tonne. While some bidders may bid lower, and some higher, this value provides an indication of the average amount of subsidy the DEA foresees is required to bring about at least 2.3 million tonnes of captured CO_2 annually.
    - The maximum that can be bid is €235/tonne. Though, as noted above, if all bids were at this level, the total amount of reductions would barely exceed 1.0 million, thus it is not anticipated that many successful bids will be in this range.
- The above total and annual values include 25% VAT and potential derived tax losses in (Danish: "afledt afgiftstab")
    - These derived tax losses are a new interesting element that essentially ensure that the government's total cost of funding the pool (both directly, and indirectly), won't exceed €3.8 billion. The fund shall cover potential derived tax losses that stem from the award of contract(s) to tenderers who will avoid national CO_2 related taxes by capturing and storing their CO_2 emissions. As such, the total available annual funds depend on the composition of the final contract recipient(s). I.e., the greater the number of winning bidders that capture and store fossil CO_2, the greater the reduction in the overall size of the funding available.

Regarding the award criteria, the weighting is 80% based on the subsidy and 20% on project maturity. Regarding the latter, each offer will be awarded points in accordance with a qualitative evaluation of the project maturity. With respect to the subsidy evaluation, this will be evaluated according to an "Evaluation Amount", where:

- Evaluation Amount = Offered Rate + VAT of Offered Rate + evaluation-technical supplement
- The "evaluation-technical supplement" shall be added to the Offered Rate if the tenderer and/or an entity on which the tenderer bases the performance of the Contract is subject to (Danish) CO_2 Tax and/or Emission Tax
- Each offer will be awarded points based on the Evaluation Amount in accordance with a financial framework. The offer with the lowest Evaluation Amount is awarded the highest number of points on the scale (maximum points), i.e. 10 points.

[6] All figures below have been converted from 2025 DKK at a rate of 7.44 DKK/Euro.

A fictive example illustrating how this "evaluation-technical supplement" could be applied in the case of two bids, one based on biogenic CO_2, and the other on fossil-based CO_2 is as follows (Offered rate + VAT of Offered Rate + evaluation-technical supplement):

- Biogenic CO_2: 800 DKK/tonne + 200 DKK/tonne + 0 = 1000 DKK/tonne
- Fossil CO_2: 600 DKK/tonne + 150 DKK/tonne + 375 DKK/tonne = 1125 DKK/tonne

Thus, in this fictive example, if the fossil CO_2 tenderer would save 375 DKK/tonne in Danish CO_2 taxes and/or emission taxes (the biogenic CO_2 tenderer is currently not subject to such taxes), this value would be added to the bid when evaluating the bids. Thus, despite the fact that fossil CO_2 tenderer had an offered rate 200 DKK/tonne lower than the biogenic tenderer, when it comes to evaluating the bids, the biogenic tenderer would receive a higher subsidy score. It is important to note that in a situation where the fossil tenderer wins a contract, this evaluation-technical supplement does not affect the subsidy that they receive. I.e., they will receive their offered rate. However, as noted above, the size of the funding pool will be reduced. If the fossil CO_2 tenderer in the above example had a project that captured half a million tonnes of CO_2 per year, this would reduce the size of pool with 187.5 million DKK per year.

Small-scale

In April of 2024, the DEA announced that the tender for the fund for negative CO_2 emissions (NECCS fund) had been completed. Contracts were awarded to three companies for new CCS projects. In total, 160,350 tonnes of biogenic CO_2 will be captured and stored annually during the period 2026 to 2032. All of the CO_2 will be captured and stored in Denmark. (DEA, 2024 c).

The table below displays the winning bidders, the quantity of CO_2 to be captured annually, and the support level granted per tonne of CO_2.

Table 3: Results of the DEA's tender for the NECCS fund (DEA, 2024 c)

Company	Annual capture quantity (tonnes CO_2)	Support level (EUR* per tonne of CO_2) *Assuming 7.45 DKK/Euro
BioCirc CO_2 ApS	130,700 t	130.0 EUR/t
Bioman ApS	25,000 t	150.0 EUR/t
Carbon Capture Scotland Limited	4,650 t	349.0 EUR/t
Total / Weighted average	160,350 t	139.5 EUR/t

Table 3 highlights the fact that the successful projects varied greatly in both their size and the amount of subsidy awarded. While it is a positive that 3 companies signed contracts with the DEA, it is also noteworthy that the total quantity of CO_2 to be captured annually (roughly 160,000 t), was well below the DEA's target of 500,000. As a result, the funds allocated to the fund were not utilised (an estimate based on the table above, points to less than half of the earmarked EUR 0.35 bn being distributed). According to the DEA, there are currently no plans for further NECCS bidding rounds (DEA, 2024 c).

The tender as a whole was not seen as a success, with some commentators going as far as to call it a flop. The energy minister, while recognising the actors that did bid, acknowledged that the bids as a whole were not in line with expectations. Furthermore, he stressed the importance of ensuring that the next tender results in all the allocated funds being utilised for CO_2 capture and storage. (Energy Watch, Danish CCS tender flops — hard, 2024)

CO_2 storage in Denmark

The figure below displays the Danish CO_2 storage licensing areas (dark blue), the CO_2 storage exploration licences awarded (yellow), and CO_2 storage areas currently under tender (aqua - as of early March 2025). They are essentially divided into 3 categories, offshore, onshore, and nearshore.

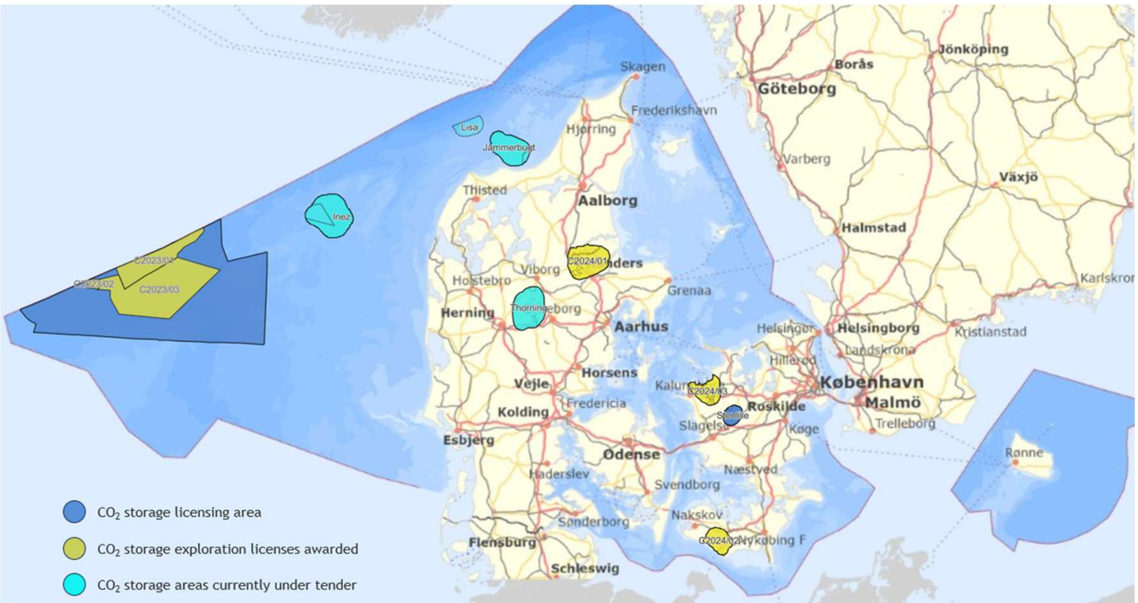


Figure 8: Danish CO_2 storage licensing areas (dark blue), CO_2 storage exploration licences awarded (yellow), and (in aqua) CO_2 storage areas currently under tender (as of early March 2025). (DEA, 2025 a)

Offshore storage is advantageous as geological characteristics of selected sites are well understood, often due to previous and/or ongoing oil and gas activities. They also benefit from the fact that they are located far away from population centres. In Denmark, offshore CO_2 storage options are thus some years ahead in their development relative to onshore.

Onshore storage development is largely driven by the assumption that onshore storage options will be less expensive. Generally speaking, any work undertaken offshore is more expensive, as it requires specialised transport to and from the site, specialised knowledge, often requires more robust materials, etc. In addition, if an onshore pipeline can be established from an emitter to the storage site, this can greatly reduce the transport cost relative to shipping.

Offshore

In February of 2023, three exclusive licenses for exploration and full-scale CO_2 storage in the Danish portion of the North Sea were granted (see Figure 9). Two permits were awarded to TotalEnergies (red and pink areas in Figure 9) and one to a consortium consisting of INEOS E&P

and Wintershall Dea International (light blue area in Figure 9). The Danish State (via Nordsøfonden) participates with a 20% ownership share in each license.

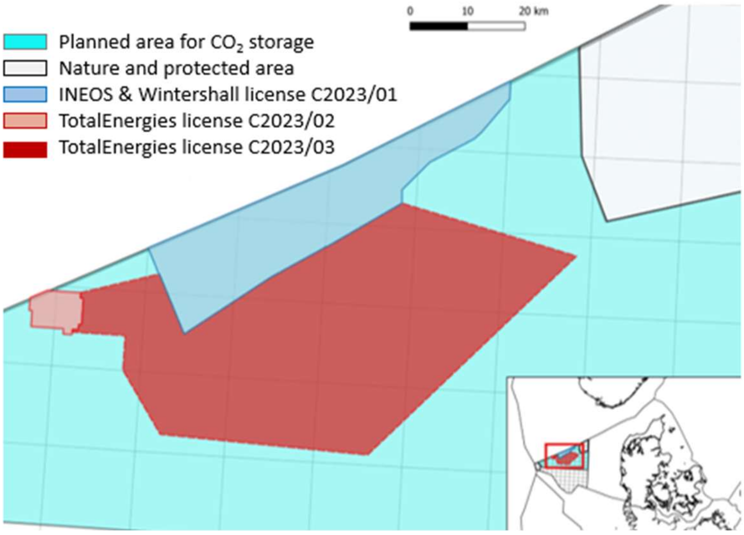


Figure 9: Map of planned areas for CO2 storage, nature and projected areas, and licenses C2023/01, C2023/02 and C2023/03. (DEA, 2024 a)

The licenses cover areas with depleted oil and gas fields, and geological areas that while yet to be investigated, are deemed to be well-suited to CO_2 storage. The specific storage projects must be approved by the Danish Energy Agency before establishment. Timing and design of the CO_2 storage facilities will depend on the upcoming investigations and analysis. The captured CO_2 will be transported either via purpose-built ships or through existing or new pipeline infrastructure.

Examples of projects within these areas include Project Greensand, and Project Bifrost:

- Greensand (Greensand, 2025)
    - Storage of CO_2 in the Nini oil field.
    - Technical verification by DNV and FID made in 2024.
    - Awaiting approvals for permanent storage.
    - Capacity to store 0.4 Mt/year (2025/2026) with plans to increase to 8.0 Mt/year by 2030
    - 23 partners form the consortium that is led by INEOS and Wintershall Dea.
- Project Bifrost (Bifrost, 2024)
    - Investigating the potential for storage in Harald West (a depleted gas field, pink box above)
    - Storage capacity estimated at several Mt/year
    - Partners: TotalEnergies, DTU offshore, Ørsted, DTU management, Nordsøfonden, BlueNord

Both of these projects are supported by the Danish state via the Energy Technology Development and Demonstration Programme (EUDP).

Onshore

In December of 2023, the DEA opened a licensing round for subsurface exploration of potential CO_2 storage under five designated areas: Gassum, Havnsø, Rødby, Stenlille and Thorning (see Figure 10). To ensure that any eventual storage takes place in an environmentally sound manner, strategic environmental assessments of the areas had already been carried out at the time of the launch.

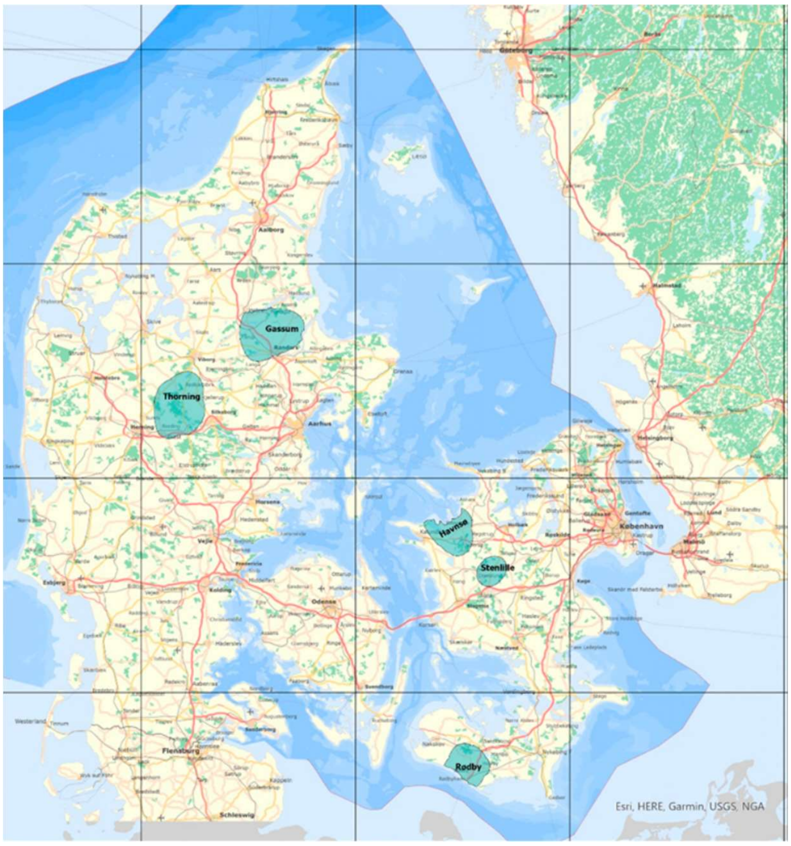


Figure 10: Overview of the five designated areas for potential onshore CO_2 storage (DEA, 2024 b)

The deadline for proposals was Jan 24th, 2024, and while this may sound like a short timeframe, potential bidders were aware that the licensing round was soon to be launched as the tender followed up on political agreements regarding the capture and storage of CO_2. For example, according to an agreement from September of 2023 “Aftale om styrkede rammevilkår for CCS i Danmark” (KEFM, 2023) (in English: Agreement on strengthened framework conditions for CCS in Denmark) a tender for onshore storage permits was to be opened before the end of 2023.

The tender stipulated that exploration licenses will be granted for up to six years, with the possibility of applying for extension up to a total of 10 years. The licenses will stipulate that Nordsøfonden is to participate on behalf of the State with a share of 20%. If the area fulfils all environmental requirements, and a suitable structure for CO_2 storage is proved, the licensee will have a preferential right to apply to have the license extended with an exclusive right to carry out storage activities for up to 30 years.

As a minimum requirement, bidders had to demonstrate that they have satisfactory technical and financial capacity. The assessment criteria thereafter were based on:

1. Data collection - “The extent to which the tendered work contributes to a greater understanding of the Danish subsoil and realisation of CO_2 storage potentials.” I.e., collection of new data, number of test wells drilled, etc.

2. Provability of storage potentials - “How much geological certainty and mapping of uncertainties and main risks an applicant can provide for a storage project in the area applied for”. I.e., by carrying out 3D seismic surveys, etc.
3. Timetable - “A shorter period of time until commencement of the work tendered will be weighted higher than a longer period of time. The timetable must be realistic.”

In conjunction with the tender launch for the 5 onshore areas, the DEA also announced that applications for 3 nearshore areas would await the completion of a maritime spatial plan.

Results

In June of 2024, based on 8 received bids, the DEA announced that it had awarded 3 exploration licenses for onshore geological storage of CO_2, at Gassum, Havnsø and Rødby (see Figure 11).

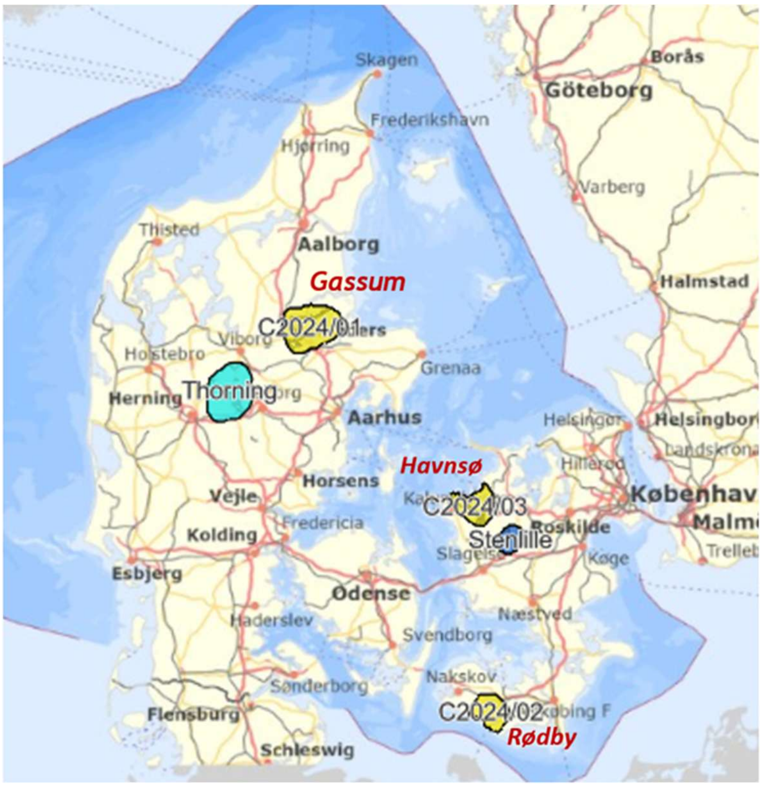


Figure 11: Results of onshore CO_2 storage tender from June of 2024. CO_2 storage exploration licences awarded (yellow), CO_2 storage area currently under re-tender (aqua - as of early March 2025), and Stenlille, for which no licence was awarded. (DEA, 2025 a)

The Gassum site went to a consortium consisting of Wintershall Dea International GmbH and INEOS E&P A/S, and the project will be called “Greenstore”. With a 40% ownership share is Wintershall Holding GmbH, Germany's largest crude oil and natural gas producer, and a wholly owned subsidiary of BASF. INEOS Energy Denmark comprises what was previously state-owned Dong’s oil and gas assets. Now owned by the INEOS Group (a large multinational – and also one of the largest global chemical companies), it will also have a 40% ownership share (recall that Nordsøfonden maintains a 20% ownership stake in each project).

The Havnsø site went to consortium consisting of Equinor Low Carbon Solutions Denmark A/S and Ørsted Carbon Solutions A/S. Equinor is a Norwegian energy company (primarily oil and gas) and they have a 60% ownership stake. As previously described above, Ørsted is a Danish energy company (primarily renewables), and they will have a 20% ownership stake.

Lastly, the Rødby site, went to CarbonCuts A/S, with the project to be named “Ruby”. CarbonCuts is a daughter company of BlueNord (a Norwegian listed oil company) and will have an 80% ownership share.

As can be seen from the winning bids, they are dominated by the oil and gas sector, which reflects the fact that within this field, much of the technical knowledge and experience, as well as capital, is in the hands of oil and gas companies. This is a fact that governments, companies, and planners will have to take into account, particularly when it comes to potential issues such as public resistance to onshore storage.

With respect to the Thorning site, in an interview with DR (in English, the Danish Broadcasting Corporation), the DEA stated that it had only received one bid for Thorning, but that the bidder decided to not accept the offer from the DEA. The DEA did not elaborate as to why. In the same article, the DEA stated that a new bidding round for Thorning will be launched (which as of early March 2025 is underway). (DR, 2024)

As for Stenlille, the DEA did not immediately comment as to why no license was awarded. Gas Storage Denmark (which is owned by the Danish TSO, Energinet) currently stores natural gas at Stenlille and has been undertaking preparations for CO_2 storage for quite some time. They stated that they are in dialogue with the DEA to learn more about the background for the rejection, but that one concern could be the coexistence between their natural gas storage and a CO_2 storage. (DR, 2024)

Nearshore

On January 9th, 2025, the DEA opened for applications for exploration and use of the Danish subsoil for CO_2 storage in 3 nearshore areas: Inez, Lisa and Jammerbugt (see Figure 12, next page).

The deadline for application was March 6th at noon, and on the following day, the DEA announced that it had received two applications. The two bidding entities were:

- CarbonCuts A/S
- TotalEnergies EP Danmark A/S and Mitsui & Co. Ltd.

The DEA stated that they will in the coming period assess the applicants' technical and financial capacity as well as the work programs that the companies have submitted in their applications. Before a permit is granted, the Minister for Climate, Energy and Utilities, Lars Aagaard, must present a report to the Danish Parliament's Climate, Energy and Utilities Committee on which permits are to be issued. (DEA, 2025 b)

In addition, any granting of permits for exploration does not guarantee a right to store CO_2, as the subsoil must first be thoroughly investigated to determine whether CO_2 storage can be carried out safely and in an environmentally sound manner in the respective areas (DEA, 2025 b)

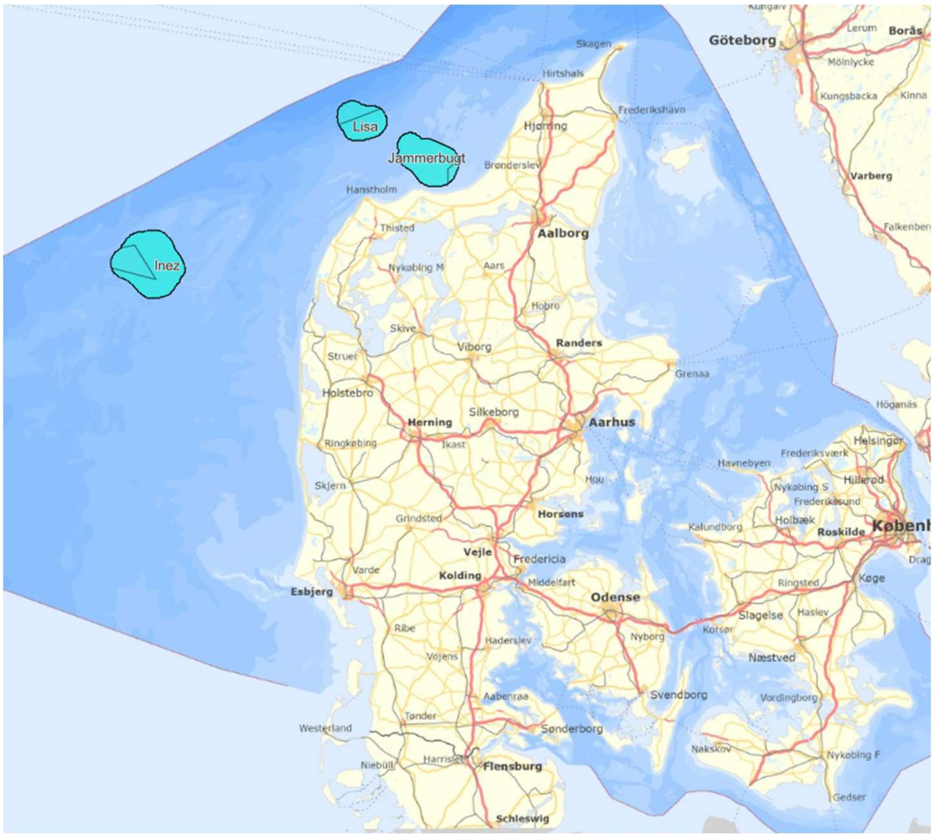


Figure 12: Overview of nearshore CO_2 storage areas that were opened to tender on January 9th, 2025 - Inez, Lisa and Jammerbugt (DEA, 2025 a)

CCS vs CCUS case study

In light of Denmark's above-mentioned climate goals, which mandates a 70% reduction in CO_2 equivalent emissions by 2030 compared to 1990 and aims for climate neutrality by 2050, the imperative to explore innovative solutions has become paramount. One of the key questions has become how to rely on CCS vs CCUS going forward, and how this will affect the power and heat system.

To get some insight into this issue, it was deemed relevant to model the interaction between a biomass Combined Heat and Power (CHP) plant and Carbon Capture and Storage (CCS) or Carbon Capture and Utilization (CCU). The Skærbæk Combined Heat and Power Plant in Denmark was identified as a pertinent case study for this investigation. The study aims to scrutinise the full-scale implementation of CCUS technologies. By delving into these technologies within the context of a biomass-fired CHP plant, the analysis seeks to elucidate the consequences of adding these technologies to the operation of the plant and the district heating system.

The Skærbæk CHP plant is located in the Western part of Denmark where it delivers heat to one of Denmark's largest district heating systems, the TVIS system that supplies heat to the towns of Vejle, Kolding, Fredericia and Middelfart. Today, the Skærbæk CHP plant delivers app. 50% of the heat and the remaining part is delivered mainly by surplus heat from the local refinery and by the waste incineration plant in Kolding supplemented by peak load boilers based on oil or natural gas. The Skærbæk plant today uses approximately 550,000 tonnes of wood chips per year.

The aim of the study is to analyse the consequences of investment in CCUS technology at the Skærbæk plant. The study analyses the following three scenarios for development of the plant:

- **BAU.** In this scenario, the setup is a continuation of the current situation, a business-as-usual scenario. The Skærbæk Power Station has the option to produce heat and electricity, either in combined generation or a separate generation. The other heat production units in the district heating system are assumed to continue operation with the same capacity as today.
- **CCS.** This scenario considers the inclusion of a CO_2-capture system (CC-plant), which aims to capture and store carbon dioxide deriving from the woodchip boiler for potential future storage (S). In the analysis two different versions of the CCS-Scenario are analysed: one version with capture of a fixed yearly amount of CO_2 (CCS fixed) and one version with optimization of the sale of CO_2 against an assumed market price for CO_2 (CCS Market).
- **CCUS.** This scenario entails the incorporation of carbon capture, storage, and utilisation at the Skærbæk Power Station. Unlike the 'CCS-scenario', where CO_2 is captured and stored for potential sale, all or part of the CO_2 can be directed to an electricity-powered methanol production facility with hydrogen provided by a large electrolyser. The capacity methanol process is dimensioned to match the CO_2-production from the biomass boilers at full capacity. The amount of methanol produced over the year is assumed to be fixed and based on 4,500 full load hours operation of the methanol plant. However, it can be chosen to run the biomass boilers for more than 4,500 full load hours to provide more and heat and power. Also, during this operation, CO_2 could be captured and sold at an assumed market price.

The analyses of the scenarios focus on the year 2035.

The energy market model Balmorel has been applied to analyse the different scenarios. The district heating system is modelled on an hourly basis with individual representation of all production units and an hourly consumption profile for the heat demand. Also, a large heat storage is part of the system and is modelled as part of the optimisation. For modelling the CCUS technologies at the Skærbæk plant, the advanced OptiFlow module of the Balmorel model has been applied. This allows for modelling of energy and mass balances of the different process of the CCUS technologies (carbon capture, heat pumps, electrolysers, methanol synthesis etc.).

An overview of the production from the Skærbæk CHP plant is shown in Table 4.

Table 4: Overview of the production from the Skærbæk CHP plant in the analysed scenarios in 2035.

Skærbæk plant (GWh)	BAU	CCS Fixed	CCS Market	CCUS
Wood chip consumption	2,091	2,204	2,486	2,486
Net electricity generation	558	409	317	-2,615
Condensing	178	256	375	543
Backpressure	385	314	219	54
Bypass	-5	-1	-1	-0
CC plant		-56	-97	-97
CC heatpump		-86	-148	-148
CO2 storage		-17	-30	-13

Skærbæk plant (GWh)	BAU	CCS Fixed	CCS Market	CCUS
Electrolyzer				-2,916
Methanol plant				-31
H2 storage				-6
District heating generation	1,214	1,368	1,477	1,690
Flue gas condensation	135	142	160	160
Backpressure	769	627	437	108
Bypass	310	81	79	0
CC plant		86	149	149
CC heatpump		432	746	746
Electrolyzer				464
Methanol plant				439
Cooling	0	0	-93	-374

The main results and conclusions from the analyses are:

- In the BAU-scenario, the operating hours of the Skærbæk CHP plant increases compared to today. With the assumed development in fuel and power prices and the development of the framework for waste plants in Denmark, Skærbæk CHP becomes more competitive and increases the heat production from app. 3.5 PJ today to 4.5 PJ in 2035. Also, the plant is competitive in the power market when power prices are moderate and high, and the plant produces app. 230 GWh of power in condensing mode.
- In the CCS-scenarios, the operation of the plant is further increased, especially in the CCS Market Scenario. The district heating generation increases further, and a significant part of the district heating generation is delivered as surplus heat from the CC-facility.
- In the CCUS-scenario, a significant shift is observed in the dynamics of net electricity production, transitioning from positive to negative on average over the year. District heating generation is further increased and in this scenario the heat production from the Skærbæk plant can cover almost all the district heating demand in the TVIS area. Most of the heat generation is delivered as surplus heat from the CC-plant, the electrolysers and the methanol plant, while the CHP plant delivers process heat for the CCUS-processes and increases power production in condensing mode.
- Hydrogen production is optimized for periods when the electricity value is low, while district heating demand proves significant only in winter months.

For more details on the case study, please see the full case study report “Modelling full-scale implementation of CCUS at large wood chip fuelled CHP plant in Denmark - Skærbæk CHP plant” (Bornak, 2025).

Denmark - CCS drivers and key takeaways

Key driver: Climate targets combined with fully funded policies

The deployment of carbon capture and sequestration in Denmark has largely been driven by the Danish climate targets, in particular the 2030 targets. Fundamental for this deployment, is that these targets have been followed up by fully funded policies that provide an economic and stable incentive for actors to participate. A prominent example of this is regimes that involve payments per tonne of CO_2 sequestered lasting 15 to 20 years. Thus far, the key mechanism has been bidding rounds, both for capture and/or storage of CO_2. An important aspect of these bidding rounds, in particular those that have been successful, has been ongoing dialogue with market actors, thereby allowing the DEA to make adjustments and learn from the subsequent tender rounds.

Coupling Danish CO_2 capture with Danish CO_2 storage

The majority of onshore projects described above have publicly announced anticipated start dates in, or prior to, 2030. At first glance, the 2025 CCS tender can perhaps therefore provide opportunities for utilising Danish onshore storage within their project, as the final bids are scheduled to be delivered in December of 2025. However, even if onshore storage can be online in 2030, it is problematic for storage developers to enter into contracts with potential bidders in 2025 given that all geological tests and the issuance of a storage permit by the DEA, are unlikely to have been completed by the end of 2025. This could potentially result in CCS bidders in 2025 relying on offshore storage solutions, at least for the initial years of the project, and/or "locking in" to these solutions for a long period of time.

Looking longer term, depending on site location and development of CO_2 pipelines, onshore (and potentially nearshore) storage options are likely to be the most cost-effective options for many Danish projects, but also other European countries looking to export and sequester CO_2 in Denmark. In this respect, Denmark could become particularly relevant for countries that want to implement CC but have local opposition to storage. A perfect example of this is Germany, which could look to export its captured CO_2 to Denmark.

Recent years have seen a shift from CCUS to CCS

From a government perspective, CCS, provides a cost-effective option for national, regional and municipal governments to meet their climate targets, for example the national 2030 target. With negative emissions, i.e., when biogenic CO_2 is captured, it allows the government to offset emissions from sectors that are either difficult to abate, and/or may be politically sensitive to address.

Meanwhile, there are also many private companies that require high quality negative emissions in order to meet their own stated climate targets. Some of these corporate targets cover emissions that are difficult to reduce, while other companies are looking to offset historic emissions.

The result of the above, is that there is a strong willingness to pay from both governments (via subsidies, etc.) and companies (negative emission credits) for biogenic based CCS. Simultaneously, a correspondingly strong willingness to pay for large quantities of green fuels (i.e., green methanol based on captured biogenic CO_2) has not yet materialised, which has unfortunately resulted in several green fuel projects recently being scrapped. It is therefore not surprising that, within recent years, the focus in Denmark has shifted from CCUS to CCS.

NORWAY

Background

Within CCS, Norway has long been a CCS pioneer, largely driven by its oil and gas industry. A prominent example is the Sleipner CCS project, where Equinor (previously Statoil) has been sequestering CO_2 into the Norwegian portion of the North Sea since 1996 (Dickson, 2024).

Norway has leveraged this development into one of the first large-scale CO_2 storage projects, the aforementioned Northern Lights project.

Case study - Hafslund Celsio full-scale CCS project

A short case study on the Hafslund Celsio full-scale CCS project at their Klemetsrud WtE plant in Oslo, Norway presents the latest developments in the project (Becidan, Full-scale Waste-to-Energy CCS in Norway - Oslo CCS Hafslund Celsio, WP2 Case Study Report, 2025). This section provides a brief summary of the case study. For more details, please see Becidan, M. 2025.

The purpose of the case study is to present the different stages and challenges and to derive lessons learnt of developing this kind of BECCS project. Thereby the case study builds on the presentations within the case study report by Becidan, M. 2021 (Becidan, Deployment of bio-CCS: case study on Waste-to-Energy. Fortum Oslo Varme (FOV), Oslo, Norway, 2021) as part of the BECCUS Inter-Task Project Phase I and tells the developments over the past 4 years by presenting the events in a chronological order.

The project was initiated in 2015 and went through different stages of project realisation since then. The first-of-its-kind full-scale CCS project at a WtE plant has progressed despite numerous challenges, thanks to the commitment of those involved. Key lessons learnt include the importance of perseverance, patience, and thorough evaluation. Infrastructure and organizational needs are often underestimated. Especially the provision of electricity, transport, the significant need for space (especially challenging in urban settings) and a temporary storage at the harbour. Political or societal resistance may arise. Integrating new systems into existing operations proves to be complex, and managing various levels of process maturity is challenging. In this particular case, a bold cost-cutting phase helped to revitalize the project. From the above it has to be noted that some of the challenges encountered are not inherent to BECCUS projects however can apply in general when developing a new project.

Summary on key determinants of whether to store or utilise

There are a number of BECCUS projects that have recently been initiated either by larger utility companies or medium-sized enterprises in various countries. The majority of these initial projects are focused on CO_2 storage. In reviewing the development of ongoing and potential BECCUS projects in the selected leading countries above, there are a host of factors that determine whether to store or utilise captured biogenic CO_2. Some of the most important factors identified when whether to store or utilise captured biogenic CO_2 include:

- Site location & Production characteristics
- Government targets & relevant legislation
- Demand for end products

Site location and production characteristics

The physical location of the site where the CO_2 is captured is important for a number of reasons, including how it relates to access to CO_2 storage, the cost of exporting CCUS products, and potential heat integration and offtake options.

The location of the CO_2 emitting site relative to potential CO_2 storage options will determine the cost of CO_2 storage. Sites located by the sea will generally have access to a harbour, and therefore offshore storage options if an export terminal can be established. Sites located some distance from a CO_2 export terminal will have to establish a dedicated pipeline to the export terminal, or transport CO_2 to the terminal via trucks, with both options adding to the transport cost. Meanwhile, CO_2 capture sites located near an onshore storage facility, or dedicated pipelines to such facilities, can take advantage of the cost savings associated with onshore storage, which should on average be less expensive than offshore storage.

In Northern Europe, the first large-scale CO_2 storage facilities to be established will be offshore and it is unlikely that any onshore CO_2 storage options will be available prior to 2029 (at the earliest). Therefore, having a harbour from where the CO_2 can be exported from is a necessity. This dynamic is exemplified by both the Kalundborg Hub and Stockholm Exergi projects, as they both have a harbour available for export of CO_2 via ship.

Another thing that these early BECCS projects have in common, is that the power plant units to which carbon capture are applied, have steam and/or district heating offtake contracts, thereby ensuring stable production, and the potential for utilisation of recouped heat from the carbon capture processes. Steady production, and many full load hours, are required in order to spread out the large CAPEX costs of CC.

Government targets & relevant legislation

Government CO_2 emission reduction targets, particularly when backed by relevant legislation is a key driver in determining whether to store or utilise CO_2. Both Denmark and Sweden have ambitious climate targets, and their governments have concluded that negative emissions will be required in order to realise them. Both countries therefore launched schemes to provide significant economic incentives over a long time period to capture and sequester CO_2, thereby contributing to their respective countries' climate targets. These long-term schemes provide cost certainty for actors contemplating whether to utilise or sequester captured CO_2, and thereby tip in favour of the latter.

Demand for end products

Perhaps the most important factor in determining whether to sequester or utilise biogenic CO_2, is the demand for end products. For an actor deciding between the two, this is the demand for a sustainable product with CO_2, for example a green transport fuel, vs. the demand for carbon removal certificates. Based on the projects in focus within this report, it would appear that in a European context, that the demand for carbon removal certificates (often combined with state subsides) provides a more robust business case than that for green fuels.

Other factors

Other factors that can come into play when determining whether to utilise or sequester captured CO_2 can include access to low-cost electricity, particularly when the production cost of hydrogen is a driving factor. However, in the absence of significant demand for the end product (i.e., green aviation or shipping fuel) and/or government incentives to store captured CO_2, this factor is currently not significant enough to outweigh the others.

References

Beccs Stockholm. (2024, May 6). *Stockholm Exergi announces permanent carbon removal agreement with Microsoft, world's largest to date* . Retrieved from Beccs Stockholm: https://beccs.se/news/stockholm-exergi-announces-permanent-carbon-removal-agreement-with-microsoft-worlds-largest-to-date/

Beccs Stockholm. (2025, April 18). *Beccs Stockholm*. Retrieved from Beccs Stockholm: https://beccs.se/

Becidan, M. (2021). *Deployment of bio-CCS: case study on Waste-to-Energy. Fortum Oslo Varme (FOV), Oslo, Norway*. IEA Bioenergy.

Becidan, M. (2025). *Full-scale Waste-to-Energy CCS in Norway - Oslo CCS Hafslund Celsio, WP2 Case Study Report*. IEA Bioenergy.

Bifrost. (2024, 6 12). *About Bifrost*. Retrieved from Bifrost: https://bifrost-ccs.com/

Bishop, G., Colm, D., Berndes, G., Brandão, M., Cowie, A., Healey, J. R., . . . Styles, D. (2026). Cascading wood use into bioenergy with carbon capture and storage ensures continuous and enduring temperature reduction. *Nature Communications Earth & Environment*.

Bornak, L. P. (2025). *Modelling full-scale implementation of CCUS at large wood chip fuelled CHP plant in Denmark. Skærbæk CHP plant, WP2 Case Study Report*. IEA Bioenergy. Retrieved from https://task40.ieabioenergy.com/wp-content/uploads/sites/29/2025/12/IEA-Bioenergy_ITP_WP2_Skaerbaek_final-report.pdf

Council of the EU. (2024a, March 8). *Climate action: Council and Parliament agree to establish an EU carbon removals certification framework*. Retrieved from Council of the EU: https://www.consilium.europa.eu/en/press/press-releases/2024/02/20/climate-action-council-and-parliament-agree-to-establish-an-eu-carbon-removals-certification-framework/

Council of the EU. (2024b, November 19). *Council greenlights EU certification framework for permanent carbon removals, carbon farming and carbon storage in products*. Retrieved from Council of the EU: https://www.consilium.europa.eu/en/press/press-releases/2024/11/19/council-greenlights-eu-certification-framework-for-permanent-carbon-removals-carbon-farming-and-carbon-storage-in-products/

Cowi. (2021). *CinfraCap – Gemensam infrastruktur för transport av koldioxid*. Göteborg: Cowi. Retrieved from https://www.goteborgshamn.se/globalassets/dokument/cinfracap-forstudie-23-april-2021.pdf

DEA. (2024 a, 10 18). *Tilladelser til efterforskning og lagring af CO2 og miljøhøringer*. Retrieved from Første licensrunde 2022-2023 (offshore i den Danske del af Nordsøen): https://ens.dk/ansvarsomraader/ccs-fangst-og-lagring-af-co2/tilladelser-til-efterforskning-og-lagring-af-co2-og

DEA. (2024 b, 01 25). *Ni selskaber vil lagre CO2 i den danske undergrund*. Retrieved from Danish Energy Agency: https://ens.dk/presse/ni-selskaber-vil-lagre-co2-i-den-danske-undergrund

DEA. (2024 c, April 17). *Danish Energy Agency*. Retrieved from Three new CCS projects have been pledged support to capture and store biogenic CO2: https://ens.dk/en/press/three-new-ccs-projects-have-been-pledged-support-capture-and-store-biogenic-co2

DEA. (2025 a, March 05). *Danish Energy Agency*. Retrieved from CO2 storage Denmark: https://energidata.maps.arcgis.com/apps/instant/sidebar/index.html?appid=7493a78f50f7428e9bc3f5def191d560

DEA. (2025 b, March 07). *Danish Energy Agency*. Retrieved from To selskaber vil lagre CO2 i de kystnære områder på havet: https://ens.dk/presse/selskaber-vil-lagre-co2-i-de-kystnaere-omraader-paa-havet

DG Energy. (2024, December 4). *Q&A implementation of hydrogen delegated acts*. Retrieved from European Commission: file:///C:/Users/cb/Downloads/Q&A_implementation_of_hydrogen_delegated_acts.pdf

Dickson, D. (2024, February 26). *Norway's Sleipner: Where CO2 has been buried in the rock since 1996*. Retrieved from Vattenfall: https://group.vattenfall.com/press-and-media/newsroom/2024/norways-sleipner-where-co2-has-been-buried-in-the-rock-since-1996

DR. (2024, June 20). *DR.DK*. Retrieved from Staten vil have olieselskaber til at lagre CO2 i Danmark: https://www.dr.dk/nyheder/viden/klima/staten-vil-have-olieselskaber-til-lagre-co2-i-danmark

Energimyndigheten (Swedish Energy Agency). (2024, August 22). *Investerings- och driftstöd för bio-CCS*. Retrieved from Energimyndigheten: https://www.energimyndigheten.se/utlysningar/investerings-och-driftstod-for-bio-ccs/

Energy Watch. (2024, April 17). *Danish CCS tender flops — hard*. Retrieved from EnergyWatch: https://energywatch.com/EnergyNews/Renewables/article17027181.ece

EU. (2023, October 18). *Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council* . Retrieved from EU: https://eur-lex.europa.eu/eli/dir/2023/2413/oj/eng

European Commission. (2018, November 28). *In-depth analysis in support on the COM(2018) 773: A Clean Planet for all - A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy*. Retrieved from European Commission: https://climate.ec.europa.eu/system/files/2018-11/com_2018_733_analysis_in_support_en.pdf

European Commission. (2023, February 10). *COMMISSION DELEGATED REGULATION (EU) 2023/1185*. Retrieved from European Commission: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R1185

European Commission. (2024a, Feb 5). *Commission presents recommendation for 2040 emissions reduction target to set the path to climate neutrality in 2050*. Retrieved from European Commission: https://ec.europa.eu/commission/presscorner/detail/en/ip_24_588

European Commission. (2024b, Feb 6). *Questions and Answers on the EU Industrial Carbon Management Strategy*. Retrieved from European Commission: https://ec.europa.eu/commission/presscorner/detail/en/qanda_24_586

European Commission. (2024c, February 6). *Towards an ambitious Industrial Carbon Management for the EU*. Retrieved from European Commission: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52024DC0062

European Commission. (2024d, July 2). *Commission approves €3 billion Swedish State aid scheme to support the roll-out of biogenic carbon dioxide capture and storage*. Retrieved from European Commission: https://ec.europa.eu/commission/presscorner/detail/en/ip_24_3583

European Parliament. (2024, December 15). *Empowering consumers for the green transition*. Retrieved from European Parliament: https://www.europarl.europa.eu/legislative-train/theme-a-european-green-deal/file-consumers-in-the-green-transition

Flack, M. (2025). Financing Swedish bio-CCS Through Reverse Auctions: Status and Next Steps. *BioCCUS Conference 2025, April 1-2,*. Stockholm, Sweden.

Forster, E., Healey, J., Dymond, C., & Styles, D. (2021, June 22). *Commercial afforestation can deliver effective climate change mitigation under multiple decarbonisation pathways*. Retrieved from nature communications: https://www.nature.com/articles/s41467-021-24084-x#citeas

Forster, E., Healey, J., Newman, G., & Styles, D. (2023, October 25). *Circular wood use can accelerate global decarbonisation but requires cross-sectoral coordination*. Retrieved from nature communications: https://www.nature.com/articles/s41467-023-42499-6#citeas

Fossil Free Sweden. (2024). *Strategy for fossilfree competitiveness - Biogenic Carbon Capture*. Fossil Free Sweden.

Geden, O., Smith, S., & Cowie, A. (n.d.). Retrieved from https://pure.iiasa.ac.at/id/eprint/19787/1/The-State-of-Carbon-Dioxide-Removal-2Edition.pdf

Greensand. (2025, 1 15). *Greensand*. Retrieved from Greensand: https://greensandfuture.com/

Hajian, C., & Sedighi, M. (2022). A Critical Survey of Bioenergy with Carbon Capture and Storage (BECCS). In *Synergy Development in Renewables Assisted Multi-carrier Systems* (pp. 255-278). Springer.

Harding, E. (2025). CDR & BioCCS: navigating EU policy & funding. Presentation at the BioCCUS Conference 2025. *BioCCUS Conference 2025: April 1-2*. Stockholm, Sweden.

Hayat, M., Alhadhrami, K., & Elshurafa, A. (2024). Which bioenergy with carbon capture and storage (BECCS) pathways can provide net-negative emissions? *International Journal of Greenhouse Gas Control, 135*.

Howard, G. (2025, Februray 12). *Liquid Wind picks up suspended Swedish e-methanol project, doubles capacity*. Retrieved from Seatrade Maritime News: https://www.seatrade-maritime.com/alternative-fuels/liquid-wind-picks-up-abandoned-swedish-e-methanol-project-doubles-capacity

IEA Bionergy. (2024). *IEA Bionergy Country Reports. Implementation of bioenergy in Sweden – 2024 update*. Retrieved from IEA Bionergy: https://www.ieabioenergy.com/wp-content/uploads/2024/12/CountryReport2024_Sweden_final.pdf

Institute for Carbon Removal Law and Policy. (2020, March 10). *Explainer: Carbon Removal*. Retrieved from https://www.american.edu/sis/centers/carbon-removal/upload/carbon-removal-explainer_icrlp_accessible.pdf

IPCC. (2023). *AR6 Synthesis Report: Climate Change 2023*. Retrieved from IPCC: https://www.ipcc.ch/report/sixth-assessment-report-cycle/

KEFM. (2023, 9 20). *Danish Ministry of Climate, Energy and Utilities*. Retrieved from Aftale om styrkede rammevilkår for CCS i Danmark: https://www.kefm.dk/Media/638307862071081909/Aftale%20om%20styrkede%20rammevilk%C3%A5r%20for%20CCS%20i%20Danmark%20af%2020.%20september%202023.pdf

Klima-, Energi- og Forsyningsudvalget. (2021). *Non-paper on Carbon Capture and Storage (CCS)*. Retrieved from Folketinget: https://www.ft.dk/samling/20201/almdel/KEF/bilag/87/2288136.pdf

Ministry of Economic Affairs and Climate Policy. (2024, June). *Update of the National Energy and Climate Plan 2021-2030*. Retrieved from Ministry of Economic Affairs and Climate Policy: https://commission.europa.eu/document/download/b6d21e56-4297-4b91-a692-300716209f72_en?filename=NL_FINAL%20UPDATED%20NECP%202021-2030%20%28English%29.pdf

Möllersten, K., & Zetterberg, L. (2023). *Bringing BECCS credits to voluntary carbon markets - A policy brief by Sustainable Finance Lab (Sweden)*. © Sustainable Finance Lab. Retrieved from https://www.sustainablefinancelab.se/wp-content/uploads/sites/14/2023/08/Bringing-BECCS-credits-to-voluntary-carbon-markets_web.pdf

Olsson, O., Abdalla, N., Bürck, S., & Fehrenbach, H. (2022). *Carbon accounting in Bio-CCUS supply chains – identifying key issues for science and policy*. IEA Bioenergy.

Olsson, O., Becidan, M., Bang, C., Abdalla, N., Bürck, S., Fehrenbach, H., . . . Hennig, C. (2022). *Deployment of BECCUS value chains - From concept to commercialization - Synthesis Report*. IEA Bionergy.

Ørsted. (2024, November 10). *Carbon capture and storage*. Retrieved from What we do: https://orsted.com/en/what-we-do/renewable-energy-solutions/bioenergy/carbon-capture-and-storage

PBL. (2024, October 24). *Reaching 2030 climate goal becomes extremely unlikely; extra policy with rapid effect is needed*. Retrieved from PBL Netherlands Environmental Assessment Agency: https://www.pbl.nl/en/latest/news/reaching-2030-climate-goal-becomes-extremely-unlikely-extra-policy-with-rapid-effect-is-needed

Plechinger, M. (2024, December 02). *Vattenfall puts major CCS project on hold*. Retrieved from Energy Watch: https://energywatch.com/EnergyNews/Cleantech/article17691839.ece

Sohngen, B. L., Baker, J., Daigneault, A., & Favero, A. (2024, August 11). *Why Modeling Forests Requires Integrated Biological and Economic Modeling: A Response to Tim Searchinger and Steven Berry*. Retrieved from SSRN: https://ssrn.com/abstract=4927778 or http://dx.doi.org/10.2139/ssrn.4927778

Statens offentliga utredningar. (2020). *Vägen till en klimatpositiv framtid (The pathway to a climate-positive future)*. Retrieved from Government Offices of Sweden: https://www.regeringen.se/contentassets/1c43bca1d0e74d44af84a0e2387bfbcc/vagen-till-en-klimatpositiv-framtid-sou-20204/

Stockholm Exergi. (2025, May 6). *Stockholm Exergi extends landmark carbon removal agreement with Microsoft*. Retrieved from Stockholm Exergi: https://www.stockholmexergi.se/nyheter/stockholm-exergi-extends-landmark-carbon-removal-agreement-with-microsoft/?utm_source=chatgpt.com

The European Parliament. (2023a, September 20). *European Parliament, »Regulation of the Europan Parliament and of the council on ensuring a level playing field for sustainable air transport (ReFuelEU Aviation*. Retrieved from European Union: https://data.consilium.europa.eu/doc/document/PE-29-2023-INIT/en/pdf

The European Parliament. (2023b, July 13). *Regulation of the European Parliament and of the Council on the use of renewable and low-carbon fuels in maritime transport, and amending Directive 2009/16/E*. Retrieved from European Union: https://data.consilium.europa.eu/doc/document/PE-26-2023-INIT/en/pdf

The Maritime Executive. (2024, August 15). *Ørsted Pulls Plug on Shipping E-Methanol Fuel Project Citing Slower Demand*. Retrieved from The Maritime Executive: https://maritime-executive.com/article/oersted-pulls-plug-on-shipping-e-methanol-fuel-project-citing-slower-demand

VEAB. (2025). *Växjö energi, »Sydsvenskt projekt för att fånga in koldioxid*. Retrieved from VEAB: https://www.veab.se/om-oss/satsningar-och-projekt/cnetss/

Zetterberg, L., Johnsson, F., & Möllersten, K. (2021). *Incentivizing BECCS - A Swedish Case Study*. Frontiers in Climate, 3. Retrieved from https://doi.org/10.3389/fclim.2021.685227

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