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Carbon Hub

Estimating costs related to

- Carbon Capture
- Transportation
- Utilization
- Storage

Executive summary

The successful implementation of Carbon Capture, Utilization, and Storage (CCUS) technologies holds immense potential in mitigating carbon emissions and facilitating the transition towards sustainable energy systems.

Work package 3 focuses on estimating the costs associated with various aspects of the CCUS value chain, ranging from capture to storage, with a particular emphasis on the Oresund region and its potential to serve as a CCUS interconnecting hub.

Work package 3 underscores the importance of regional collaboration, infrastructure development, and technological innovation in advancing CCUS solutions. By addressing challenges and capitalizing on opportunities, stakeholders can expedite the adoption of CCUS, paving the way towards a sustainable, carbon-neutral future.

March 2024

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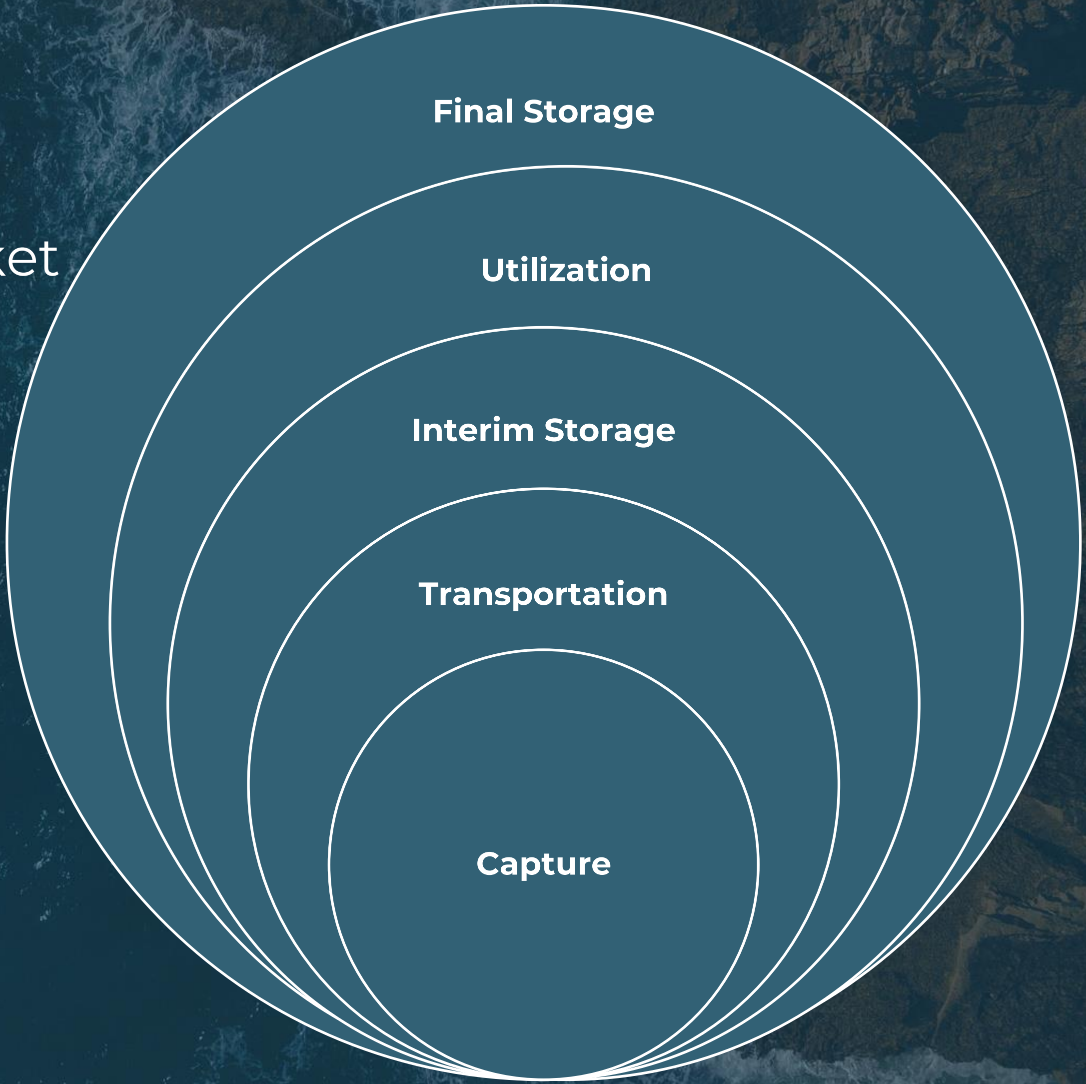
Total costs associated with Carbon Capture, Utilization and Storage (CCUS) can be reduced by

- Innovation and technology
- Time advances market maturity
- Economies of scale
- Shared infrastructure with 3rd party access
- Connecting CO_2 re-utilization cases to transportation chain
- Research & Development



Key Findings

Regional Targets and Opportunities
Denmark and Sweden have set ambitious CCS targets, viewing it as vital for achieving net-zero emissions. The Oresund Region, strategically located, presents unique opportunities for CCUS hubs, attracting investments.

Infrastructure and Innovation
Establishing the Oresund Region as a "carbon gateway" requires robust infrastructure and emphasizes innovation, offering prospects for CO_2 reutilization.

Challenges and Opportunities:
While CCS costs remain high, there's optimism for cost decline through investment and innovation. Challenges include design complexity and large-scale deployment obstacles.

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CCUS – the future weapon to combat climate change

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Political vision for CCUS in Denmark and Sweden

> **Denmark** has set a target of **reaching net zero carbon emissions in 2045** and sees carbon capture and storage (CCS) technology as key to reaching that target.

> **Sweden** has set CCS targets for 2030 (3.7 MtCO2e, of which 1.8 MtCO2 from BECCS - bioenergy with carbon capture and storage) and for 2045 (10.7 MtCO2e, 3-10 MtCO2 from BECCS)

The political ambition in Denmark is to build an entire CCS value chain and for Denmark to become a hub for onshore and offshore CO2 storage.

In 2021, the Swedish Energy Agency drafted a bilateral storage agreement with Norway. It aims at storing Swedish carbon dioxide offshore in the Norwegian North Sea

"The EU regards carbon capture and storage to be an important part of the EU's decarbonization effort." CCUS is listed as one of the key decarbonization technologies in the Net Zero Industry Act (NZIA)

Denmark has developed various support mechanisms for research and commercial sale CCUS projects, amounting to ~ EUR 5 billion in total

Carbon capture and storage (CCS) technology aims to reduce emissions by capturing carbon dioxide (CO2) and either burying it underground or utilizing it in other industrial processes. Some CCS technologies have been commercially used for several decades and were initially developed for capturing CO2 from natural gas production for enhanced oil recovery—a process in which CO2 is injected into aging oil wells.

CO2 – from cradle to grave

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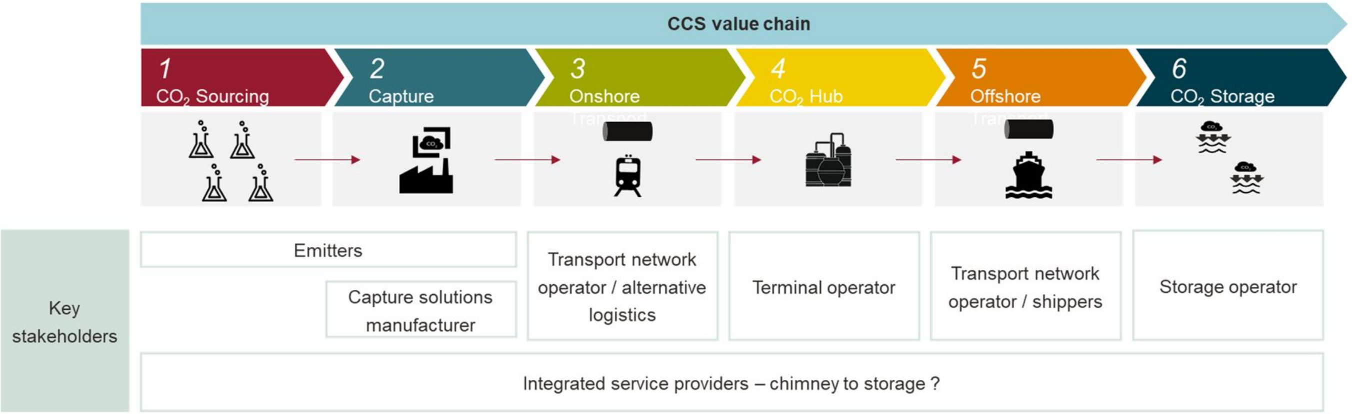
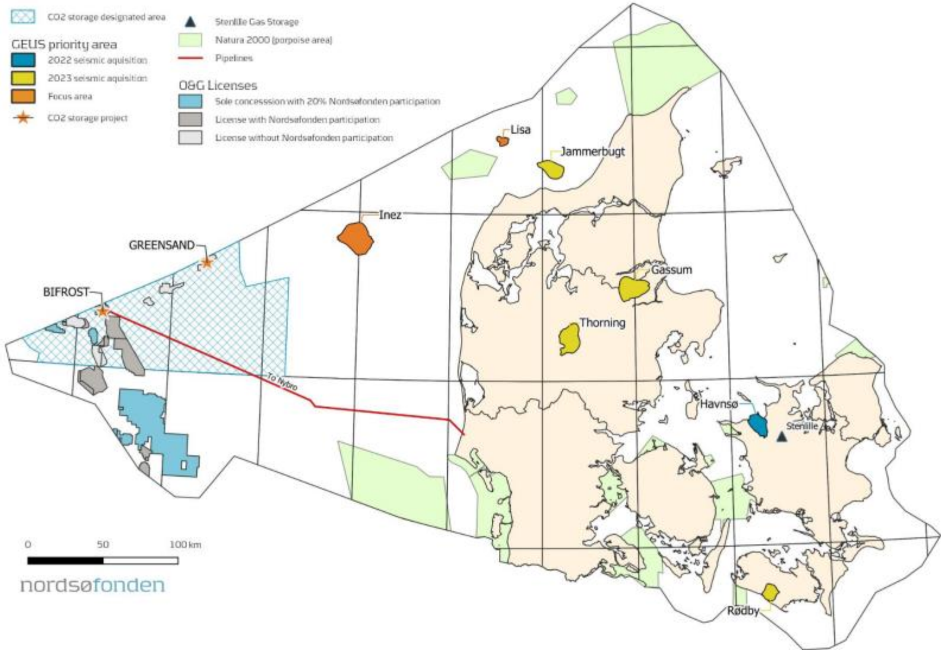
How does a CO2 value chain look like?

- A value chain consist of captured CO2 being transported to an interim storage from where the CO2 is either utilized, shipped, or piped to final storage
- A CO2 value chain can thus safely capture, transport, utilize and store CO2 . This represents a significant step to reduce CO2 emissions from nation-states.



Where will the captured CO2 be stored?



- Most CO2 is expected to be stored in the North Sea, Norwegian Sea, and close to shore in Denmark.
- The CO2 storage sites in DK are expected to store between 19-48 MtCO2 per year
- Storing CO2 has already begun and is a known technology today. Investments in storing CO2 in the North Sea is expected to increase significantly in the coming years.

Strong infrastructure projects and ideal location

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What needs to be true to develop the Oresund region as a CCUS interconnecting region?

Oresund region **importing CO2**

Creating **common CO2 hub(s)** enables connection and interconnection at **scale**

Political will and subsidy to advance infrastructure setups

Excellent port facilities

Shared CO2 infrastructure

High share of **biogenic CO2 in the region creating an incentive to utilize CO2 or trade with ETS credits**

Ideal underground, emitters proximity and shipping know-how.

- Preliminary analyses show that the North Sea can store 19-48 MtCO2/y due to **favorable natural conditions**
- Emitters are already **located in clusters** making it relatively inexpensive to collect CO2 compared to other regions
- Emitters are **relatively close to ports**
- **Existing maritime shipping experience** with resources such LNG, PLG, and oil/gas.

The Oresund Region has a unique location connecting the Baltics and the North Sea.

- **Import scenario** (Huge amounts of CO2 is expected to pass through Oresund each year)
- **Biogenic CO2 export and use** (potentially a scare resource)
- Support **e-methanol and e-SAF production** in the region

Pioneering Oresund as Europe's carbon gateway

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CCUS in Oresund serves both Danish/Swedish interests and the Baltic's interest

- Establishing one of the continent's first hubs could promote Oresund as a "carbon gateway" attracting investments in CCUS.
- If a levelled CO_2 price is negotiated between emitters and off-takers, CO_2 would become a market commodity leading the captured CO_2 to the cheapest storage option.
- Innovation, technology and R&D are all strong in the Oresund region providing great opportunities of reutilizing CO_2 under the right circumstances.

Country name	MtCO2
Germany	53.584
Poland	16.729
Sweden	15.913
Denmark	12.143
Belgium	10.722
Finland	10.365
France	8.735
Czechia	5.120
Lithuania	1.970
Estonia	1.400
Latvia	0.520

All hard-to-abate sectors – 137.2 $MtCO_2$

What is needed to be the Baltic's carbon gateway ?

- High level of supporting infrastructure
- Port's ability to receive and load CO_2
- Development of carbon hubs ready to receive imported CO_2 from the Baltics
- Utilization perspectives such as e-methanol, E-SAF, etc.
- Mature final storage options nearby or in connection to hubs.

Expected key requirements:

- Receiving facilities exceeds contemporary CO_2 transport volumes
- Port depth of minimum 9,5 (LCO_2 ship with standard storage as 7500 m3)
- Substantial investments in supporting CO_2 infrastructure setup (e.g. pipelines and hubs)
- Available port space
- Connection to a final storage or utilization site

But everything comes with a price….
If the prices are economically viable, the Oresund region could be a pivotal player in the CCUS value chain, both in terms of importing but also as a utilizer of CO_2 to produce fuels transforming the blue industry.

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Estimating costs associated with CCUS by triangulation method

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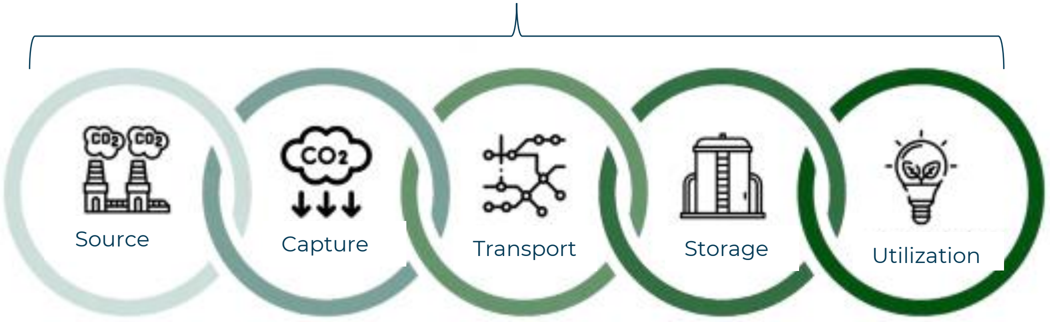
The CO2 follows the cheapest price to final storage or utilization

- Emitters interested in getting rid of captured CO2 thus choosing the cheapest option for storage
- Shipowners of LCO2 tankers compete on price lowering transportation costs
- Implementing efficient storage technologies, optimizing operational processes, and leveraging economies of scale, storage facilities can offer competitive pricing for CO2 storage services

Total Costs of CCUS



Which data are used in the triangulation method to calculate associated costs?

Based on 4-5 sources it has been possible to break down costs associated with CCUS. 4 interviews with CCUS experts have confirmed the suggested average price on each CCUS element but admitting that some of the estimated costs are relatively pricy compared to their existing knowledge.

Triangulation **involves using multiple sources of data to study costs in the CCUS value chain.** For example, the working group has gathered data through interviews, documents, or reports etc.. By using different data sources, it has been possible to cross-validate findings and gain a more comprehensive understanding of costs associated with CCUS.

- Reports
- Data & Statistics
- Interviews
- Scientific articles

Breaking down costs in the CCUS value chain

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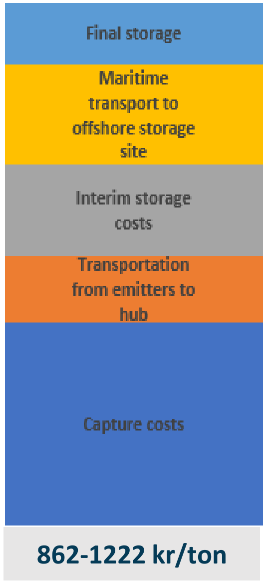
For an assessment of pricing, it is necessary to consider the entire value chain from emitter to storage. For CCUS to make commercial sense, the total expenses throughout this chain must be covered by the tax and quota savings resulting from not emitting CO2. In other words, the total costs (including expected profits) for capture, transportation, and storage must not exceed the tax and quota savings.

(kr/ton CO2)	Capture costs	Transportation from emitters to hub	Interim storage costs	Maritime transport to offshore storage site	Final storage	Total costs (estimated on different reports
N/A	-	Pipeline: 195	180-200	50-159	50-60 (onshore)	475-614 (% capture costs
C4 (2023)	-	Pipeline + liquefication: 159-305 Truck: 50	159-250	250-350	-	409-705 (From capture to ship loading)
Energistyrelsen / Ramboll (2021)	-	Pipeline: 30 -150	-	75-225	-	N/A
Maersk / Teknologisk Institut (2022)	300-500	Pipeline: 80-200 Truck: 150 Train: N/A	100-200	100 – 375	50-300	Short term: 1000-1700 Long term: 600-1000
DNV (2024)	-	-	-	127,5 – 375	141	N/A
Average	**400**	**Pipeline: 116-170 Truck: 100 Train: N/A**	**146 – 216**	**120 – 270**	**80 – 166**	**862-1222 kr/ton**

WP2 – costs findings



Northern Lights (Norway)

What determines costs?

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Understanding the factors that determine costs is crucial in assessing the feasibility and sustainability of CCUS technologies. It is relevant to explore four key components that significantly influence the costs associated with CCUS: CO2 capture, CO2 transport, CO2 interim storage, and CO2 utilization. By examining these elements, it is possible to gain insights into the economic considerations shaping the deployment and scalability of CCUS solutions.

CO2 Capture

- Capture Technology & Energy Price
- CO2 Concentration in Flue Gas
- Scale of Capture Facility
- Feedstock Characteristics

CO2 Transport

- Geographical Context
- Transportation Modes
- Infrastructure Development
- Compression and Pumping Costs

Interim Storage

- Storage Duration
- Import Oriented
- Storage Capacity
- Safety and Security Measures
- Site Location

CO2 Utilization

- Utilization Technology Used
- Scale of Utilization Plant
- Energy Requirements
- Market Demand

Why the cost of carbon capture and storage remains persistently high and varies greatly

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The cost of CCS is currently high and varied, yet CCS proponents speculate that costs will decline as more investment drives innovation and learning. While this logic applies to many technologies, whether it applies to CCS is questionable due to its complex functional requirements and constraints.

Costs remain high because of:

Relatively **low experience rate**.

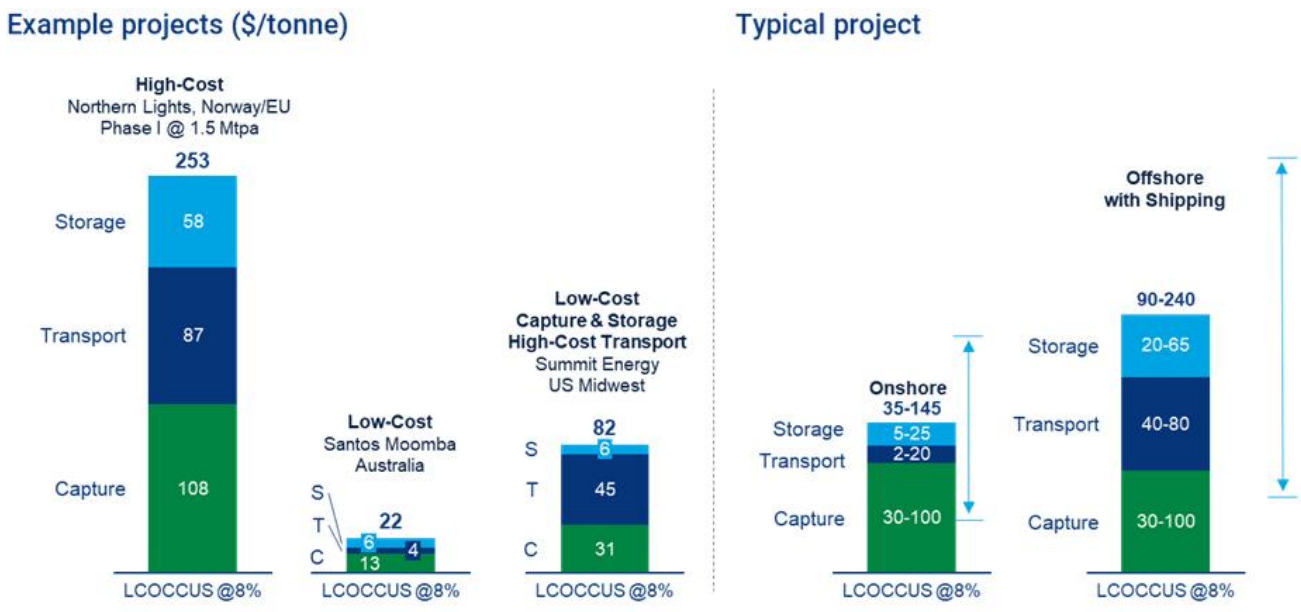
High design complexity and high need for customization—which present obstacles to technological advancement.

Technological innovation is more difficult, leading to a **highly iterative process** with a high risk of bottlenecks and dead ends.

Challenging to **achieve large-scale deployment,** limiting innovation acceleration, and, therefore, impeding cost reductions

The overall process of CCS is projected to be standardized, however some **components will still need to be tailored to specific applications, geological conditions, and local supply chains**

Costs vary greatly, but capture is usually the costliest in the CCUS value chain:



Source: Wood Mackenzie Lens CCUS Valuations

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Developing carbon hubs expands re-utilization perspectives potentially reducing CCUS costs

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Implementing CO2 re-utilization cases can help bring down costs associated with CCUS by creating additional revenue streams. Re-utilization cases create a demand for captured biogenic CO2 raising the price on biogenic CO2 thus creating an extra incentive for emitters to capture and “sell” their CO2.

The Oresund region has a great potential to accelerate the green energy transition

Develop hub(s) for storage and export of green fuels.

Can facilitate locally produced and sustainable fuel for green shipping and aviation.

Commercialize the potential as a CCUS infrastructure hub.

How to leverage the potential?

Governments need to provide economic incentives, such as tax credits, grants, or subsidies, to support CO2 re-utilization projects.

Scaling up CO2 re-utilization processes can lead to economies of scale, driving down production costs and improving competitiveness in the market.

Collaborating with industry partners, research institutions, and government agencies can facilitate knowledge sharing, technology transfer, and cost-sharing opportunities.

Potential results

Enjoy a competitive advantage in current CCUS market by having exclusive access to the market and can set the standards for others to follow.

Attracting investments, talent and knowledge to the region.

Establishing the region as an interconnected epicenter in CCUS connecting emitters and off-takers from the Baltics and Scandinavia.

Different ways to reduce costs in the CCUS industry

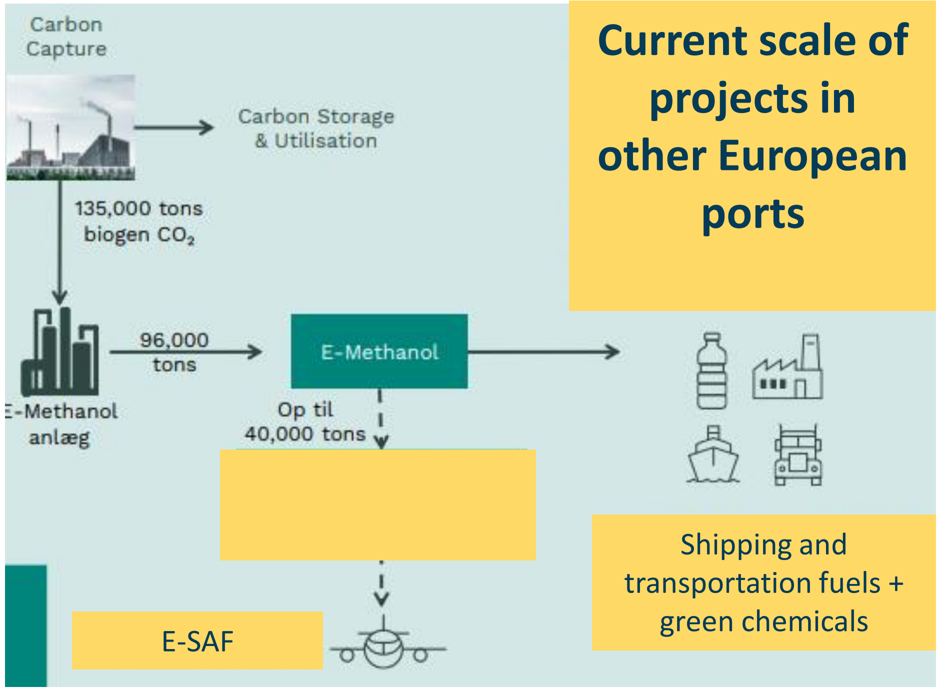
Create **3rd party access** in future CO2 infrastructure setup to reduce overall transportation costs.

Developing pipelines will require significant effort. However, pipelines can greatly reduce CCUS infrastructure OPEX and de-risk storage projects, such that more storage projects can be developed, and regional transport and storage infrastructure could gain a competitive edge compared to other European storage projects .

Points of constraints

- Big investments needed and comes with high risks
- Who should pay for shared infrastructure?

Develop a regional demand for biogenic CO2 through e-methanol and e-SAF production.



Points of constraints

- Electricity capacity and price are limiting factors
- Limited space in regional ports
- Limited e-fuel demand for shipping and aviation industry.
- Relatively little fuel produced compared to energy intensity

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Recommendations

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- **Explore Carbon Hub Development**: Invest in the development of carbon hubs with excess interim storage capacity, strategically positioning regions like the Oresund as a "carbon gateway." These hubs can serve as centralized points for CO2 capture, transportation, and storage, offering economies of scale, infrastructure sharing, and efficient logistics for multiple emitters.
- **Enhance Third-Party Access**: Ensure that CO2 infrastructure, including pipelines and storage facilities, allows for third-party access. This promotes competition, fosters innovation, and reduces costs by encouraging multiple users to share infrastructure resources and operational expenses.
- **Encourage Early Investment:** Encourage both public and private sector investment in CO2 infrastructure at an early stage.
- **Promote Feasible Utilization Cases:** Develop and promote feasible utilization cases for captured CO2 to lower costs and create additional revenue streams. Explore opportunities for converting captured CO2 into value-added products, such as fuels, chemicals, construction materials, and agricultural inputs, attracting investment and market demand.
- **Facilitate Collaboration**: Foster collaboration among industry partners, research institutions, and government agencies to facilitate knowledge sharing, technology transfer, and cost-sharing opportunities. Collaborative efforts can accelerate innovation, reduce duplication of efforts, and address common challenges more effectively.

For further information

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Disclaimer

All data is treated with respect without additional calculations. However, each source has different calculation methods and assumptions when estimating costs.

The sources used, perform their calculations based on a regional context with offset in Scandinavia and the North Sea

Costs are highly volatile to specific regional situation, technology advancements, macroeconomic trends, policies etc. But not expected to decrease with time.

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