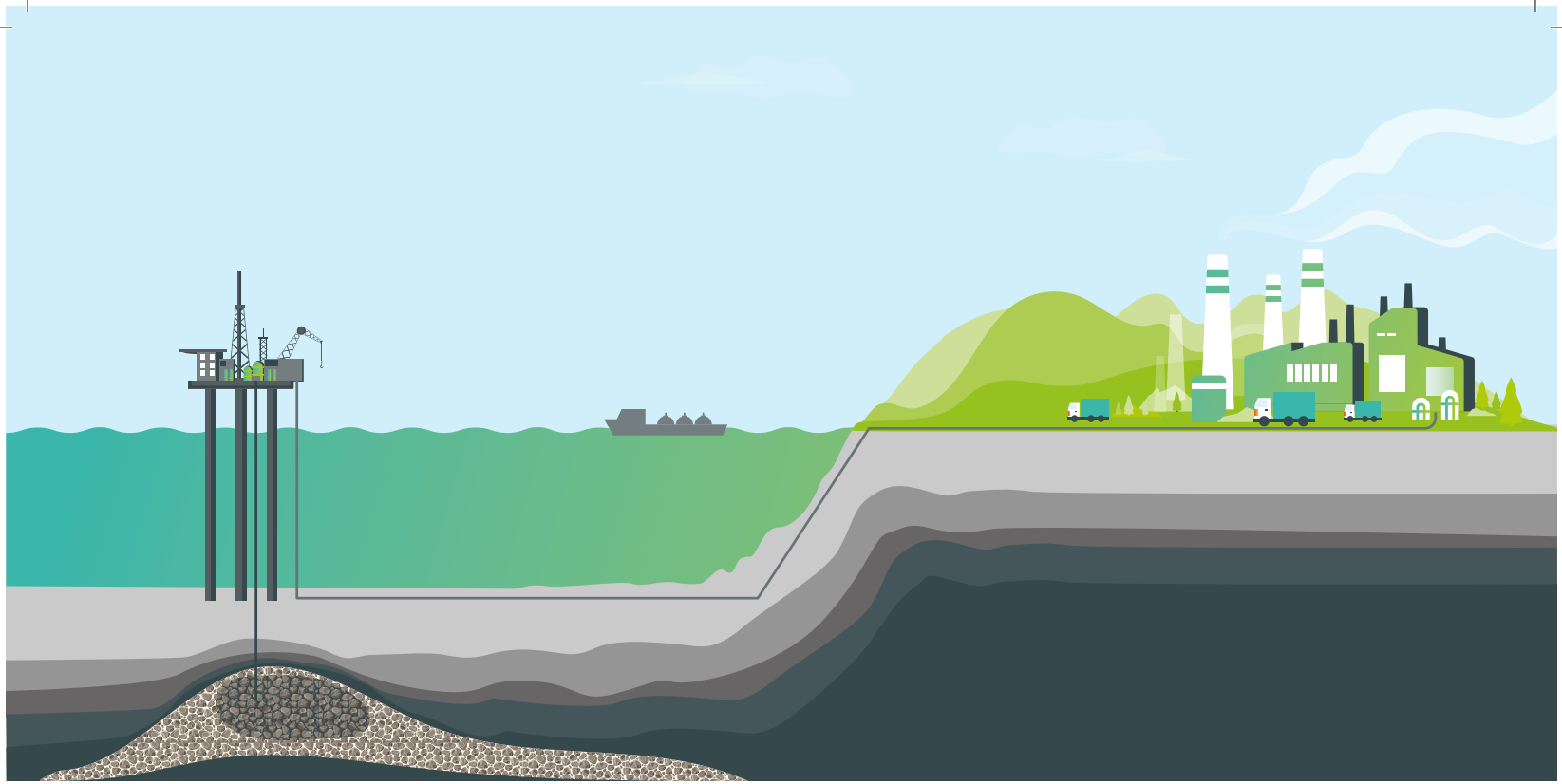


Carbon Capture and Storage

How Denmark can become the European hub for CO_2 storage

TotalEnergies

"Hidden beneath the Danish underground lies tremendous potential to contribute to solving the climate crisis. With Denmark's unique geology and proximity to European industry, Denmark can become a European hub for CO_2 storage."

Martin Rune Pedersen,
Country Chair Denmark, TotalEnergies Denmark

CO_2 storage is the next chapter in Danish climate history

Carbon capture and storage is a well-tested and secure way to reduce emissions – and it is needed.

Switching from fossil energy sources to renewables as well as increasing energy efficiency, is necessary to combat global warming. But unfortunately, that is not enough – more solutions are required.

The United Nations' Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA) assess that without large-scale implementation of Carbon Capture and Storage (CCS), achieving the 1.5-degree target is unlikely. When Denmark aims to become climate-neutral and even achieve 110% reductions, CCS will play a central role.

This makes CCS a central part of Denmark's next climate chapter. At TotalEnergies, we would like to contribute to making CCS a position of strength for Denmark.

Denmark has an ideal starting point

Up to 22 billion tons of CO_2. This is the assessment of the Geological Survey of Denmark and Greenland (GEUS) on the capacity of the Danish subsoil. With emissions of around 40 million tons of CO_2 in 2022 and 24 million tons in 2030, the capacity is much greater than Denmark will ever need. By upscaling CCS, Denmark can assist the rest of Europe in CO_2 storage.

This is possible because Denmark has a geographical advantage. Denmark is located close to major emitters in Germany, Poland and Sweden. According to the German Energy Agency, Germany needs to store 30-70 million tons of CO_2 annually, and according to the European Commission, the EU will need to use CCS technology for the reduction of up to 550 tons of CO_2 annually by 2050. At the same time, Denmark has an experienced offshore industry with the competencies necessary to successfully store CO_2. This makes Denmark an obvious choice to become a European CCS hub.

What it takes

Policy makers and the industry play a crucial role in shaping the energy supply of the future, and CCS has the potential to help society move towards a sustainable and climate-neutral future.

At TotalEnergies, we want to work with legislators, the industry and civil society to achieve 100% carbon reductions by 2045 and 110% by 2050. Together, we can find solutions to build – and invest in – infrastructure and to ensure incentives for carbon capture. At the same time, a large effort should be made to establish international agreements and pipelines for CO_2 for large-scale transport.

In the first pages of the publication, you can find an overview of how CCS works. Next, we describe how CCS benefits both the climate and Danish society. The final pages present the challenges and barriers that limit large-scale CCS deployment. We combine this with specific proposals for how the political framework can support future development.

Happy reading.

Martin Rune Pedersen, Country Chair,
TotalEnergies Denmark

How Carbon Capture and Storage works

CCS is about capturing CO_2 that would otherwise be emitted into the atmosphere and storing it safely underground. The phases are: carbon **capture**, **transport**, and ultimately, **safe** storage.

Capture

When CO_2 is emitted, it can be captured. You can do this with a flue gas system. The gas is treated in a so-called scrubbing process, where CO_2 is separated from the other molecules in the gas. With current technology, it is possible to capture more than 90% of the CO_2 from the flue gas.

Capture can either take place where CO_2 is emitted (called the point source) or by capture from the atmosphere (called DAC – Direct Air Capture). Point source capture technology is the most mature and cheapest technology available today.

Transport

The gas is compressed into a liquid, as it takes up less space and is easier to transport. CO_2 can then be transported through pipelines or in large tanks on trains, lorries and ships.

Storage

CO_2 is permanently stored in suitable geological structures in the subsurface, selected for their storage capacity and ability to seal CO_2. In Denmark, there are two types of geological storage: depleted oil or gas fields and aquifers.

How to store CO_2 in the North Sea subsoil

The CO_2 is extracted from the flue gas.

The CO_2 is converted into a liquid, making it easier to transport.

The liquid CO_2 is transferred into pipelines.

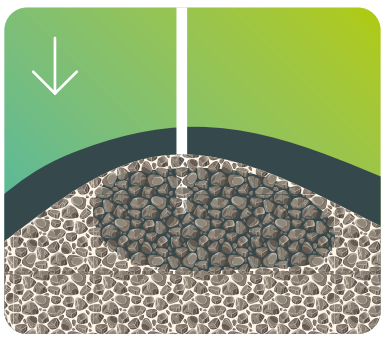
Depleted gas and oil fields

One type of storage is depleted oil or gas fields. There is thorough knowledge of the storage capacity of these old fields, and with some modifications, the infrastructure is in place. The pressure in the depleted reservoirs can be significantly below the original pressure, allowing large amounts of CO_2 to be injected before the original pressure is restored. The existing gas and oil wells are designed to seal the high pressure, and since the hydrocarbons were trapped underground for millions of years, it has also been proven that the reservoir seal can withstand the pressure needed to store CO_2 underground.

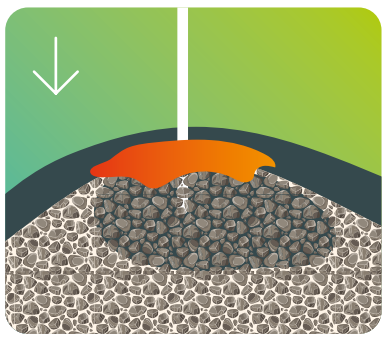
Aquifers

The second type of storage is aquifers, which refers to rock structures in the subsoil where water is found in the small cavities in the rock layer. An aquifer is typically located deep below the seabed. The storage capacity of aquifers is estimated to be enormous. The geological structures are isolated from groundwater. The aquifers in the Danish subsoil are still being fully explored.

On the platform, there will be a compressor that injects the CO_2into the reservoir. With only a few modifications, an existing platform can be used for carbon storage. It is also possible to construct a completely new compressor station.



The liquid CO_2 is injected into fields that previously stored oil or gas. It can also be pumped into so-called aquifers 1-2 kilometers below the seabed.



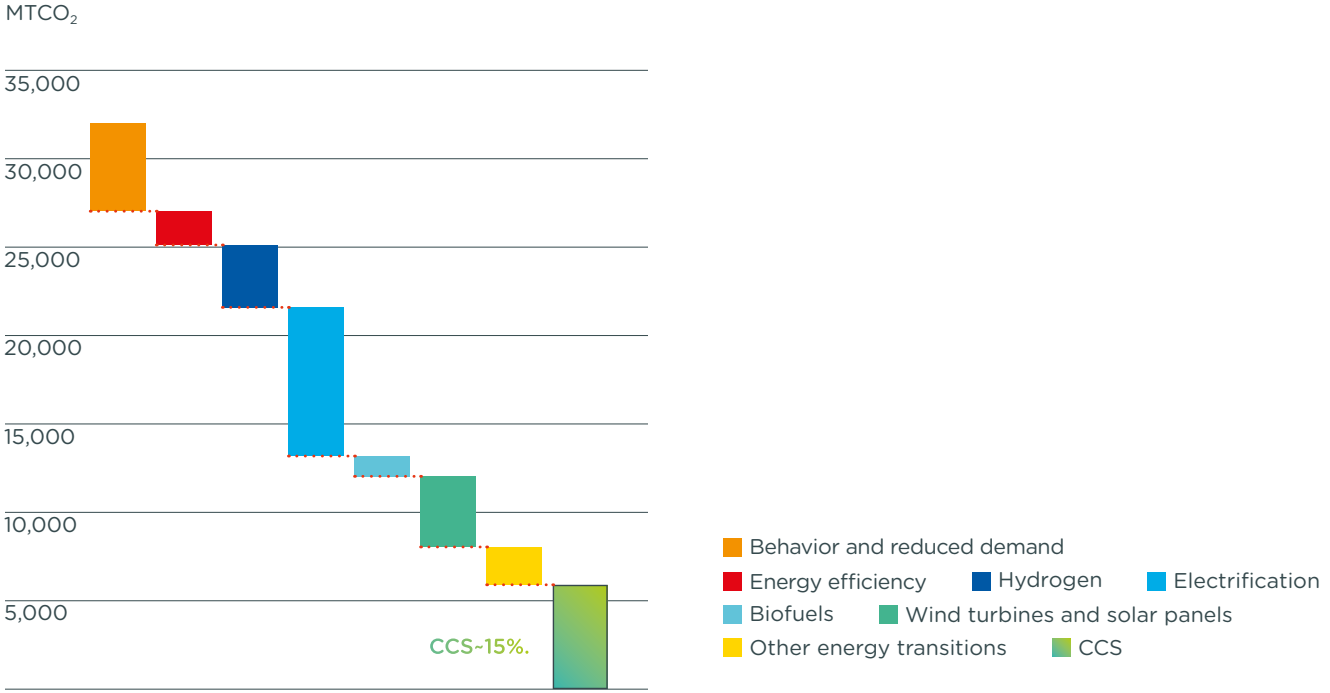
The CO_2 is trapped by the rock structure under a clay seal that prevents leakage. In addition, monitoring ensures that a potential leak can be detected and rectified quickly.

The road to climate neutrality in 2050 requires a multi-pronged approach

The figure shows that the path to climate neutrality requires many different solutions – and CCS is one of them. Tackling global warming is further complicated by the fact that demand for energy will increase due to demographic and economic developments.

The International Energy Agency (IEA) estimates that CCS must contribute 6.2 billion tons in carbon reductions annually by 2050 to achieve climate neutrality. This means that CCS will account for more than 15% of the total reductions in 2050.

Roadmap 2030-2050: CCS is one of the crucial tools for achieving global climate neutrality by 2050

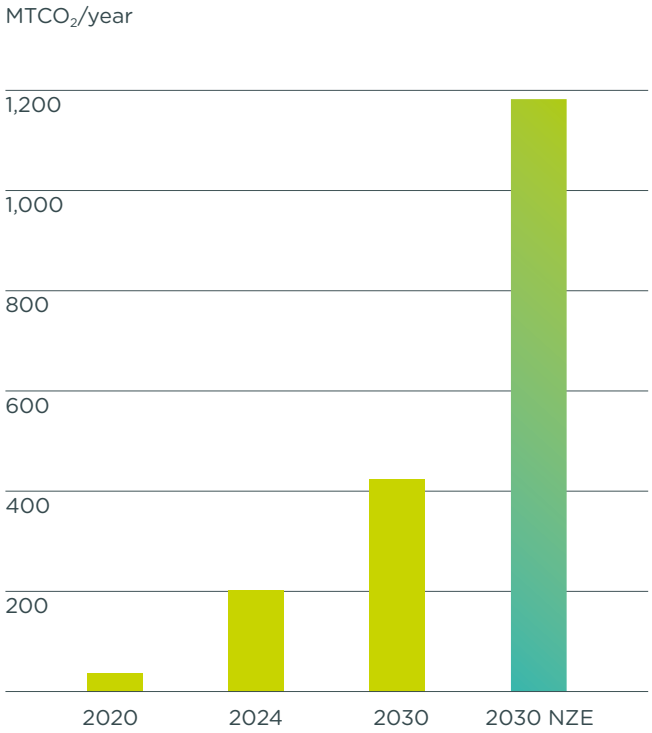


Source: The International Energy Agency (IEA).

Carbon storage capacity must increase fivefold by 2030 if the planet is to reach climate neutrality

The figure shows that we need to get moving. Worldwide, CCS projects are currently planned to capture around 420 million tons of CO_2 by 2030. If we are to be on track for climate neutrality by 2050, 1.2 billion tons of CO_2 will need to be stored every year by 2030.

Climate neutrality requires increased storage capacity



Source: The International Energy Agency (IEA). Data is updated per July 2023.

CCS on a global scale

- 30 carbon storage facilities in use
- 11 facilities are under construction
- 153 facilities are in development

Carbon storage capacity (required to stay on track for net-zero by 2050)

Carbon storage capacity (operational and planned)

NZE = Net Zero Emissions by 2050 Scenario. The NZE is a normative model that outlines a pathway for the global energy sector to achieve climate neutrality by 2050. Additionally, there are the Announced Pledges Scenario and the Stated Policies Scenario.

CCS can contribute carbon reductions in the short and long term

Since 1990, global annual greenhouse gas emissions have increased significantly. As a result, the atmosphere has gone from 350 parts per million (ppm) CO_2 in 1990 to more than 420 ppm CO_2 in 2023. Before the industrial revolution, the level was around 280 ppm.

CCS will be one of several measures to reverse this trend. The UN's Intergovernmental Panel on Climate Change, the International Energy Agency, the EU Commission, Concito and the Danish government unanimously agree on this.

Denmark's subsoil can store far more than its own emissions

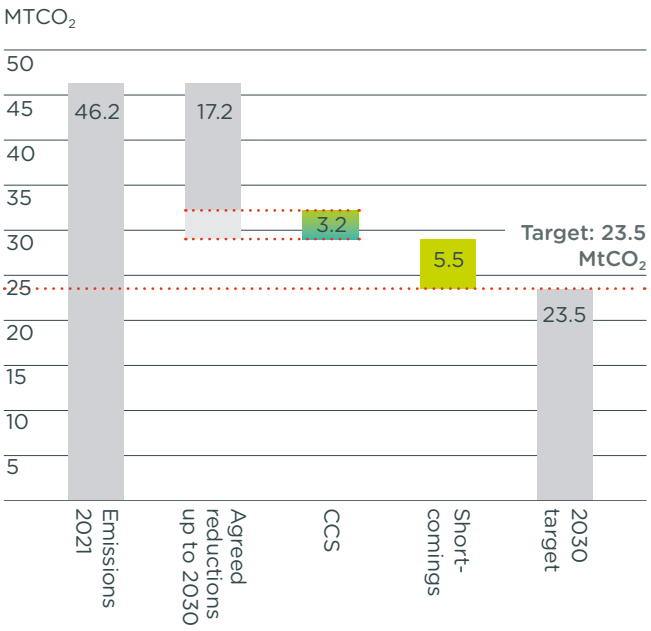
Carbon storage can take place both on land and at sea. GEUS estimates that the Danish subsoil has a storage potential of up to 22 billion tons of CO_2. This corresponds to around 500 times Denmark's annual CO_2 emissions at 2022 level. 22 billion tons is equivalent to removing the lifetime emissions from all Danish passenger cars 200+ times over. Because of our suitable subsurface, we can store CO_2 for other countries that do not have the same opportunities.

Together with Ørsted, DTU, BlueNord and Nordsøfonden, TotalEnergies has already explored the possibilities of storing CO_2 in the North Sea in the soon-to-be-depleted Harald gas field (the Bifrost project). The preliminary results are positive and establish the North Sea's extensive carbon storage potential with certainty.

On 6 February 2023, the Danish Energy Agency awarded three licenses to investigate full-scale carbon storage in the North Sea. TotalEnergies was awarded two of the licenses, and we are now in the process of investing and further investigating the subsurface in order to commission large-scale carbon storage in the North Sea. Nordsøfonden is co-owner of the projects.

Denmark has allocated funding for 3.2 million tons in carbon reductions by 2030. Concito estimates that CCS can help reduce Denmark's emissions by 5 million tons per year. Concito recommends that the reductions should be achieved through carbon storage rather than utilization, as storage is more energy efficient. So far, projects have been announced in the Danish part of the North Sea with a storage capacity of 13 million tons of CO_2 in 2030. This way, Denmark can reach its own 70% target and we can help our neighbors achieve their climate reduction targets.

CCS is necessary to reach 70% reduction in Denmark by 2030



CCS helps hard-to-abate sectors

All sectors must reduce their CO_2 emissions. CCS will reduce carbon emissions in sectors where green electrification or other direct decarbonization is not feasible – known as residual emissions. For example, CO_2 is released when limestone is heated and turned into cement. Here, CCS can play a crucial role in ensuring climate neutrality. The following is an overview of some of the major point sources of CO_2 in Denmark.

Industry

According to Statistics Denmark, industry emitted 5.9 million tons of CO_2e (carbon dioxide equivalent) in 2021. This corresponds to approximately 13% of total Danish emissions. A large part of these emissions are hard-to-abate. Denmark will also be able to store carbon from the heavy industry in our neighboring countries.

Utility sector

CHP plants have an important role to play in the energy supply of the future, despite the shift towards wind and solar energy. Carbon emissions that need to be captured and either stored or utilized for Power to X (PtX) will continue to exist. According to the Danish Energy Agency, the electricity and district heating sector has the largest carbon capture potential after industry.

Refineries

A major industrial emitter is refineries, which will continue to convert raw materials into processed products. Although energy consumption can be decarbonized, some chemical processes will continue to emit carbon.

Biogas

CO_2 is emitted when biogas is upgraded to biomethane. The CO_2 must be captured and can either be stored as negative emissions or used to produce PtX. Biogas itself is recognized as CO_2-neutral due to its biogenic origin.

Denmark can become a European hub and create thousands of jobs

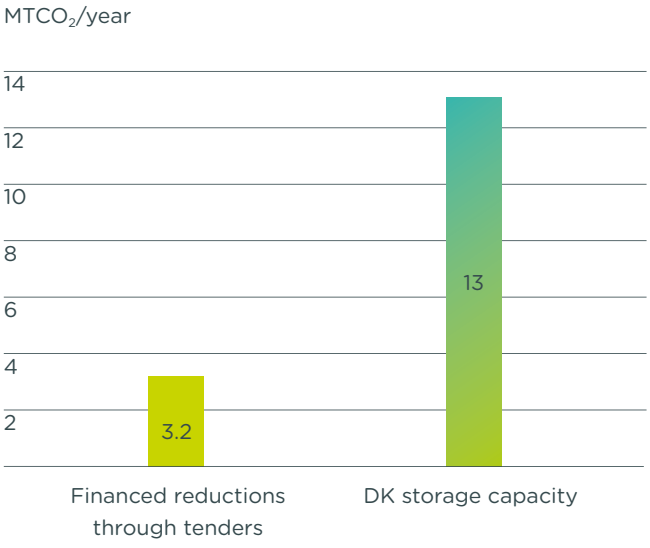
Denmark has the opportunity to become a hub for European carbon storage. This will create growth and jobs, but it is not a new oil and gas venture. Technicians will be needed on the platforms, craftsmen for construction, engineers for planning, scientists for researching and so on. Kraka estimates that the CCS industry in Denmark could directly and indirectly employ up to 17,000 people.

Denmark can store more than we need. The excess capacity can make Denmark a European hub for carbon storage, benefiting the climate, growth and jobs.

Located close to heavy industry in Germany, Sweden and Poland, Denmark has the opportunity to help these countries move in a greener direction. This can be made possible through coordination of the CCS value chain and international cooperation.

But Denmark is not the only country that has realized the potential of CCS. Others are also in the process, which is why Denmark must get started now and establish the necessary framework.

As early as 2030, Denmark will have surplus offshore storage capacity



Only projects awarded a license are included in the graph. The figures are the announced storage estimates from Greensand and TotalEnergies.

By 2030, the EU Innovation Fund will invest €38 billion in green energy innovation, including at least €3 billion in CCS.

Norway's project Langskip aims to promote CCS in a collaboration between companies, authorities and universities.

Germany is in the process of developing a national strategy on how to implement CCS to create the best synergies.

In 2022, the Netherlands increased its budget from €5 billion to €13 billion for its Sustainable Energy Transition Subsidy Scheme (SDE++), through which CCS projects can be subsidized.

The US Inflation Reduction Act provides significant tax credits for CCS, including a Direct Air Capture (DAC) credit of $180/ton.

Mapping the future: TotalEnergies' vision for Northern European CCS infrastructure

Those that emit carbon need to be connected to the storage sites. The larger the emissions, the greater the benefit of pipelines. Therefore, the greatest effect can be achieved with a pipeline between Esbjerg and Fredericia and down to Germany. This would connect Denmark with German industry as well as with industry from the Baltic Sea region, which will unload CO_2 by ship in Fredericia. From Esbjerg, the CO_2 will be piped to the storage facilities in the North Sea, where it will be injected into the subsoil.

Three steps to make Denmark a CCS leader

The CO_2 exists. The technology for large-scale safe storage of CO_2 has been extensively tested for more than 20 years. In Denmark, billions of Danish kroner have been allocated to reduce 3.2 million tons of CO_2 per year through CCS. Yet an efficient value chain is missing, which is a prerequisite for driving down the price of CCS and achieving significant emission reductions. However, through three steps, the creation of the value chain can be facilitated:

1 ECONOMIC

Create incentives for negative emissions

One ton of CO_2 in the atmosphere has the same effect whether it comes from fossil or biogenic sources. To minimize CO_2 in the atmosphere, there must be an economic incentive to reduce CO_2emissions, regardless of whether the source is fossil or biogenic. Therefore, there must also be a price for capturing and storing biogenic CO_2. The price should be negative.

Equalize the value of negative and fossil emissions – preferably at the EU level

- Negative emissions should be included in the CO_2 tax rules to ensure equal incentives for storage.

2 REGULATORY

Enable free trade of CO_2 across borders.

The atmosphere does not recognize state borders, but international trade of CO_2 for offshore storage requires a bilateral trade agreement or a project exemption. This delays the deployment of CCS.

Allow free trade of CO_2 for offshore storage

- Ratification of Article 6 of the London Protocol of 1996 would authorize the trading of CO_2 for offshore storage. Ratification must be done at the intergovernmental level; in the meantime, bilateral agreements must be made with countries such as Germany, Sweden and Poland.

Tender more areas for CO_2 storage in the North Sea

- Prioritize tenders for new areas in the Danish part of the North Sea to clarify the real potential and create more capacity for storing CO_2 in Denmark.

3 PHYSICAL

Pipelines ensure scale and flexibility

CO_2 pipelines are necessary to scale CCS. Pipes will provide cheap, safe and stable transport from emitters to storage. As with oil and gas, transport via pipelines is much more efficient. There are four reasons why:

- **Transmission:** Pipelines can transport large amounts of CO_2 at a time
- **Costs:** At the required scale, pipelines are cheaper per ton of CO_2 transported
- **Energy efficiency:** Pipelines have lower energy consumption per unit of CO_2 transported
- **Stability:** Offshore storage pipelines can transport CO_2 regardless of weather conditions

Some of the existing gas pipelines can be reused for transporting CO_2, while others need to be established. Ships, lorries and trains will help create flexibility when transporting CO2 from emitters to a central compressor plant connected to the pipeline. The "lower t" is especially important.

The state takes an active role in the expansion of CCS infrastructure

- The government should support coordination of the entire CCS value chain – from point sources to storage facilities. It is important that all links in the chain are in place. This is done through appropriate tender design and similar approaches.
- The government should identify and plan the most central CO_2 pipelines in Denmark. Pipelines between Fredericia and Esbjerg and down to Germany should be prioritized.
- The state should contribute with the necessary risk tolerance to ensure that central CO_2 pipelines are established. For example, this can be done through the involvement of state-owned companies in the establishment of the pipelines. TotalEnergies is in a position to co-operate with such state-owned companies. If, instead, the construction of large pipelines is left to the market, the dimensioning of the pipes will follow individual projects and become too small for society's future needs.

CCS scaling requires experience – and TotalEnergies has just that

Developing and implementing CCS projects involves complex challenges, and TotalEnergies has more than 20 years of experience in building and operating CCS facilities. This section summarizes some of TotalEnergies' past and upcoming CCS projects.

Previous projects

Sleipner in Norway

In 1996, the world's first large-scale commercial carbon storage project was initiated. In connection with gas extraction on the Norwegian continental shelf, CO_2 was captured and stored offshore – close to the gas field. During TotalEnergy's participation in the project, which ran until 2016, more than 16 million tons of CO_2 were stored. The Sleipner field continues to store CO_2.

Lacq in France

In 2007, a milestone was reached when the capture and storage of CO_2 took place at separate locations, for the first time requiring dedicated CO_2 transport infrastructure. TotalEnergies was the operator of the entire project.CO_2 was captured from a natural gas plant, liquefied and sent through 27 kilometers of pipeline from Lacq to Rousse, where it was stored onshore in a depleted gas reservoir. From 2010 to 2013, more than 51,000 tons of CO_2 were stored.

Under construction or in development

Bifrost in Denmark

In 2021, Project Bifrost was initiated in a collaboration between the Dansk Undergrunds Consortium (TotalEnergies, BlueNord and Nordsøfonden), Ørsted and DTU, with support from EUDP. The feasibility studies investigate the possibility of creating a CCS value chain by transporting CO_2 to the Harald field. This is either performed by ship, using a floating offshore unit to inject the CO_2, or by reusing an existing gas pipeline to transport CO_2. In February 2023, TotalEnergies was awarded two licenses covering the Harald field and a nearby saltwater aquifer. Together with state partner Nordsøfonden, the ambition is to store more than 5 million tons of CO_2 per year from 2030. Read more at www.bifrost-ccs.com

Northern Lights in Norway

From 2024, companies in Europe can store their CO_2 via the Northern Lights project. CO_2 will be transported via pipes to the platform and stored in an aquifer. The project is a joint venture between Equinor, TotalEnergies and Shell, and the Norwegian state has provided important support. The project will be expanded to store 5 million tons in subsequent years.

Aramis in the Netherlands

A newly built terminal in Rotterdam will receive CO_2 from industry in the Netherlands and then send the CO_2 out via pipeline to former oil and gas platforms. The project is being developed in partnership with EBN, Shell and Nederlandse Gasunie. The storage takes place in a decommissioned gas field, 3-4 kilometers below the seabed. Phase 1 will begin in 2027, and the ambition is to store more than 5 million tons annually.

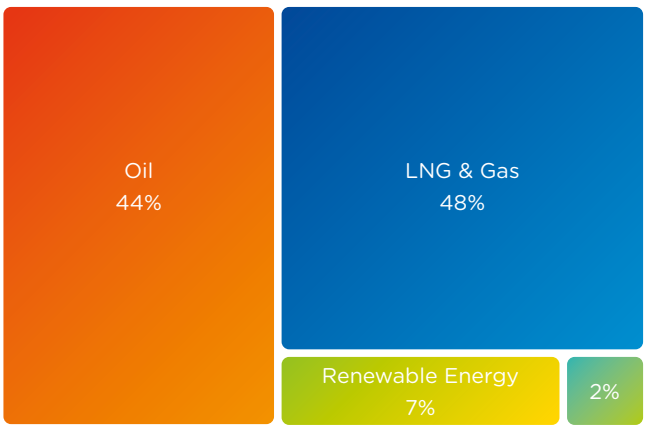
Northern Endurance Partnership in England

The Northern Endurance Partnership is a project that will store CO_2 from energy supply and industry in the Teesside and Humber region. By 2026, 4 million tons of CO_2 will be stored, which will increase to 10 million tons by 2030, aided by an efficient pipeline infrastructure. The storage will take place in an aquifer that is estimated to have a storage capacity of 450 million tons of CO_2. This corresponds to more than 10 times Denmark's annual CO_2 emissions at 2023 levels.

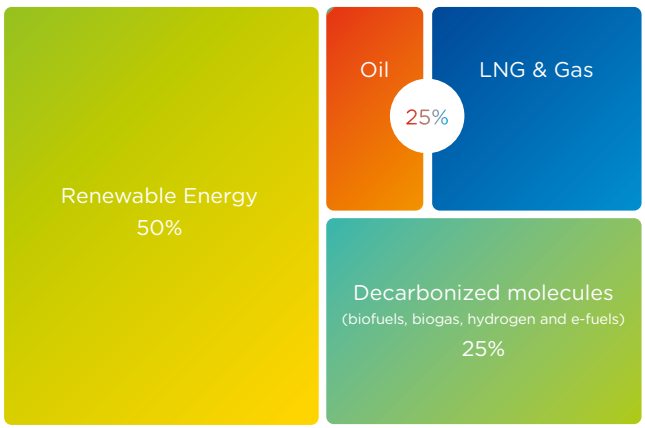
TotalEnergies is a global energy company with more than 100,000 employees, including around 1,300 in Denmark. TotalEnergies' activities in Denmark date back more than half a century and represent an important contribution to Denmark's economy, energy supply and employment. TotalEnergies is transforming its business towards climate neutrality by 2050.

Today, TotalEnergies is one of the world's largest oil and gas companies. In the future, TotalEnergies will be among the world's largest developers and operators of renewable energy. Our ambition for climate neutrality includes scope 1, 2 and 3 emissions. We want to contribute with solutions that make energy climate-neutral, affordable and accessible to all. Read more about TotalEnergies' transition to net-zero: "Sustainability & Climate 2023 Progress Report"

2021 energy mix



2050 energy mix



CCS 50-100 $MTCO_2e$/year

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For more on TotalEnergies' development of CCS, please scan the QR code: