ENE425 Sustainable Energy and App Development

Mario Blázquez de Paz

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Contents

Chapter 10

Sustainable Energy. Carbon Capture

10.1 Introduction

Two good videos to frame the discussion:

Money Is Pouring Into Carbon Capture Tech, But Challenges Remain

Carbon Capture - Humanity's Last Hope?

10.2 The role of Carbon Capture

As he have studied in the previous chapters, the **use of renewables** alongside **efficiency improvements** can deliver most of what is needed, providing 80% of the required CO2 emissions reductions. **Renewable sources**, including renewable power generation sources and the direct use of renewable heat and biomass, would contribute to 25% of CO2 emissions reductions, an additional 25% of CO2 reductions would come from the **reduced demand compared to the baseline scenario, efficiency improvements and circular economy**. The **electrification of transport and heat applications** would account for 20% of CO2 emissions reductions, while the use of **hydrogen and synthetic fuels and feedstocks** would enable 10% of CO2 emissions reductions.

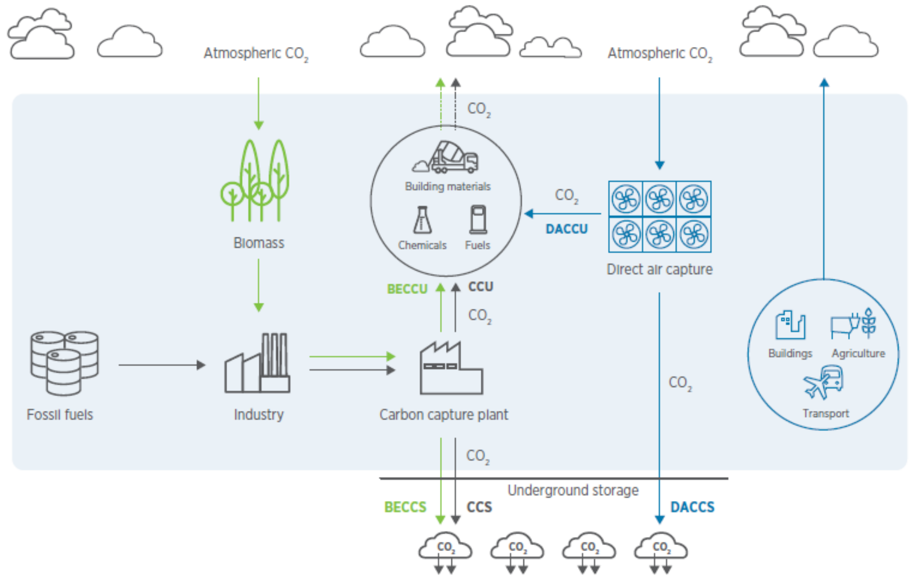
However, the scale of the challenge, the relatively limited time available, the legacy of systems built around fossil fuel use, and the complexities of some industrial processes mean that even a very aggressive ramping up of renewables will not be sufficient to address all emissions. Some fossil fuel use will remain in 2050 and some industrial processes will produce CO2 emissions irrespective of the energy source.

There is a targeted role, therefore, for a combination of **carbon capture and storage (CCS)** processes that reduce emissions released into the atmosphere, for **carbon capture and utilisation (CCU)** processes that might reduce emissions, and for **carbon dioxide removal (CDR)** processes which, combined with long-term storage, can remove CO2 from the atmosphere, resulting in negative emissions.

There are different types of carbon capture technologies (figure 10.1):

- **Carbon Capture and Storage (CCS)** refers to processes that directly capture CO2 emissions from "point sources" – i.e. from fossil-fuel use or industrial processes with the CO2 subsequently stored in ways that lock it away for long periods. If effectively implemented, the process reduces most of the CO2 emissions being released into the atmosphere, although usually not all.

Figure 10.1: Carbon cycle



Source: IRENA (2021)

- **Carbon Capture and Utilisation (CCU)** refers to processes that directly capture CO2 emissions from "point sources" – i.e. from fossil-fuel use or industrial processes – but then utilise that CO2 in secondary processes such as producing synthetic fuels, chemicals and materials. As with CCS, if effectively implemented, CCU reduces some CO2 emissions being immediately released into the atmosphere but, depending on the life-cycle of the products produced, some or all of the utilised CO2 may be subsequently released into the atmosphere. The impact of CCU on emissions is complex therefore and must be carefully managed.

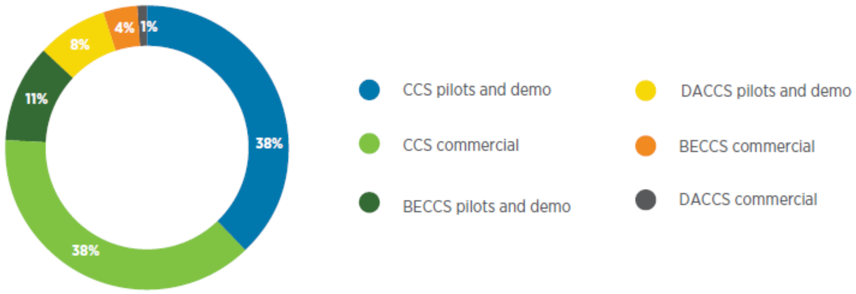
- **Carbon Dioxide Removal (CDR)** refers to processes that actually "remove" CO2 from the atmosphere rather than simply reduce what is added. If combined with long-term storage, these can result in negative emissions. These technologies and practices are sometimes therefore called negative emissions technologies (NETs) and include natural approaches such as afforestation or reforestation and technological or engineered approaches such as the use of bioenergy coupled with CCS (BECCS) or direct air capture and storage (DACCS).

CDR Technologies Remove CO2 from the atmosphere.

- **BECCS (bioenergy with carbon capture and storage)** When growing, biomass captures CO2 from the atmosphere. In power or industrial processes, the biomass (or fuels derived from the biomass) is combusted, releasing CO2. In BECCS the majority of that CO2 is captured and then stored. BECCS applies the same technology as CCS with the difference that it uses biogenic feedstock/fuels.

- **DACCS (direct air carbon capture and storage)** Instead of capturing CO2 from point sources such as relatively high concentration flue gas streams, the CO2 is separated from ambient air. The low concentration of CO2 in ambient air requires a higher surface area of solvents or sorbents in their liquid or solid form in contact with the input air stream, as well as a large amount of energy.

Figure 10.2: Share of commercial CCS, DACCS and BECCS



Source: IRENA (2021)

10.3 The current status of carbon capture, transportation, utilisation and storage

As of early 2021, **24 commercial fossil fuel-based CCS and CCU facilities** were in operation globally with an installed capacity to capture around 0.04 Gtpa of energy- and process-related CO2 emissions.

Of these **CCS and CCU facilities**, 11 are **natural gas processing plants** (where CO2 needs to be removed anyway to produce natural gas that meets specific standards) and one is a **coal-fired power plant**. **Chemical plants** (mostly for ethanol production), **hydrogen production in refineries**, and **iron and steel plants** account for the remainder. Three plants were operational but are now closed or suspended. An additional 30 plants are at various stages of development. A further 16 small scale pilot and demonstration plants are operating, 19 are at various stages of development, and 24 have been completed and closed (figure: 10.2).

If all 30 commercial plants under development are completed, the capture capacity would rise to approximately 0.1 Gtpa.

There are currently three operational commercial facilities that use **bioenergy with CCS (BECCS)** and seven commercial plants are in development. The current capture capacity of operational commercial BECCS plants is very small at 1.13 Mtpa, which would rise to 9.7 Mtpa if all plants under development reach operation. A further nine smaller scale BECCS pilot and demonstration plants are operational – six completed and four in different stages of development.

There are currently **two facilities that use DACCS**, with one in development, plus 15 pilot and demonstration plants in operation or development; however, collectively their capture capacities are quite small.

10.3.1 Costs are uncertain and vary by application

The costs of CCS, CCU and CDR will be a crucial factor in decisions on their future roles; however, **cost estimates vary widely**, with **future projections having a high degree of uncertainty**.

CCS is capital intensive and, in some cases, has significant operating costs. In general, **capture costs** dominate but in some cases **CO2 transportation costs** can be significant. Actual costs are site specific and differ significantly depending on the technology used. Capture costs are mainly dependent on CO2 concentration and pressure, and transport cost on volume and distance.

While the costs of capture in CCU are fairly well understood, the **costs of converting CO2 into products** such as fuel, fertilisers, building materials, etc. are less clear and require further research and analysis. The **costs of CDR**, and particularly BECCS, depend on biomass feedstock, while the costs of DACCS as a novel technology are currently very high with an uncertain cost reduction trajectory.

Many cost estimates focus only on capture costs and either do not include costs for compression/liquefaction, transportation and storage (including assessment and monitoring costs) or treat transport and storage as lump sums.

Cost estimates tend to focus on large-scale CCS facilities with large CO2 volumes (such as gas plants) that can justify dedicated transport and storage infrastructure, rather than smaller industrial plants that emit lower CO2 volumes per year (such as cement plants) and will therefore have to rely on clusters, hubs and transportation networks to benefit from economies of scale. The same applies to CDR facilities. The calculated costs in feasibility studies also tend to be much lower than the costs of actual projects that have been implemented.

When discussing and comparing costs, therefore, the project specifics and the full end-to-end project costs need to be considered.

As CCS applied to fossil fuel processes results in additional energy use, it can in turn lead to additional CO2 emissions and the difference can range from 10 to 25%. To account for that, cost per tonne of CO2 avoided (and not cost per tonne of CO2 captured) is the best measure to compare CCS with renewable options.

10.3.2 Transportation costs

Transporting relatively small quantities of CO2 is an established process and there are a few larger projects, mostly located in the US, which involve the pipeline transportation of CO2 for enhanced oil recovery (CO2- EOR) or EU regional transport by ships.

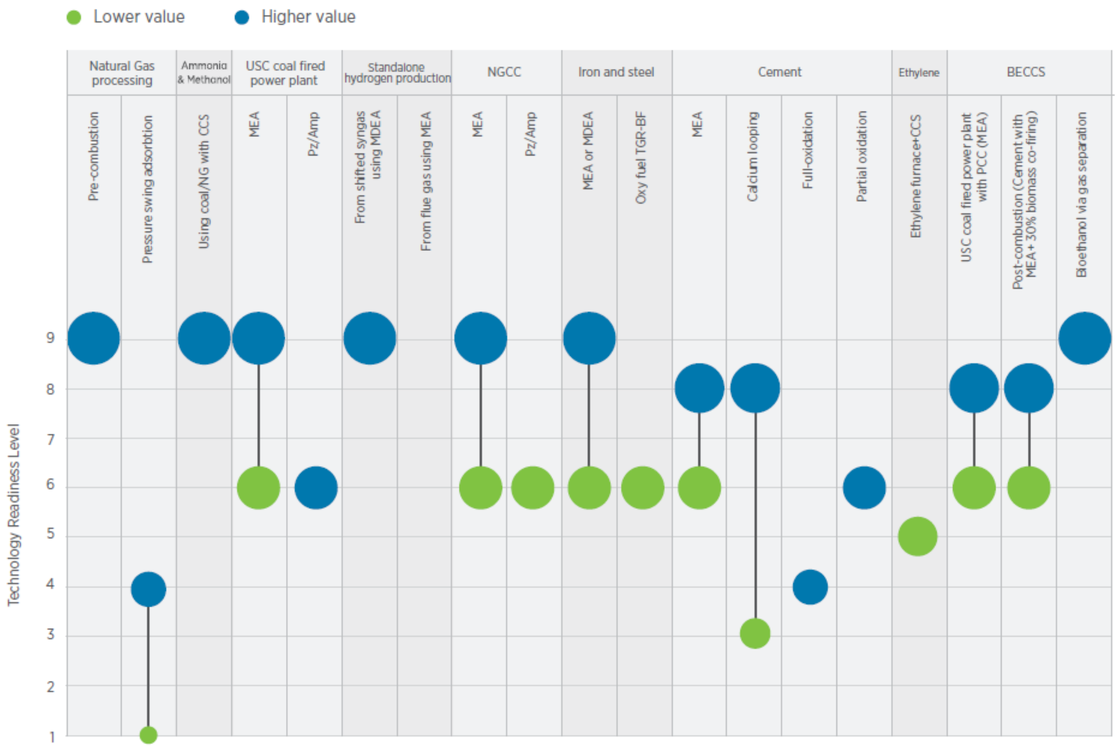
With experience of transporting other more volatile gasses, the safe transportation of CO2 is not likely to be barrier to CCS uptake, although public acceptance may remain a concern, particularly for onshore transportation options.

There is a lack of detailed data on costs. Transport and storage costs are often modelled in the integrated assessment models as lump sums at USD 10/tCO2 and disregard the flowrate, distance to storage and utilisation sites, transport mode and storage type, as well as the variability in geographical, geological and institutional settings. The models also focus mostly on large-scale plants with high volumes of CO2. There are a few more detailed studies that focus on a handful of countries with established infrastructures.

Based on current estimates, for pipelines the **capital expenditure** (CAPEX) is the major component amounting up to 90% of total transport costs. For transporting CO2 by ship, the situation reverses and the major component is **operating costs** (OPEX) for liquefaction, fuels, loading/unloading and temporary storage.

Based on current estimated costs for capacities of 2.5 to 20 Mtpa CO2 for distances between 180 km and 500 km, **onshore pipeline** has the lowest costs at USD 1.7–6.1/tCO2, followed

Figure 10.3: Technology readiness levels of CO2 capture technologies



Source: IRENA (2021)

by **offshore pipelines** at USD 3.5-32.4/tCO2. Transport via **offshore pipelines** up to 1 500 km entails costs of up to USD 58.4/tCO2. **Shipping ranges** from USD 12.5-22.4/tCO2 for distances between 180 km to 1 500 km.

10.3.3 Geological storage of CO2

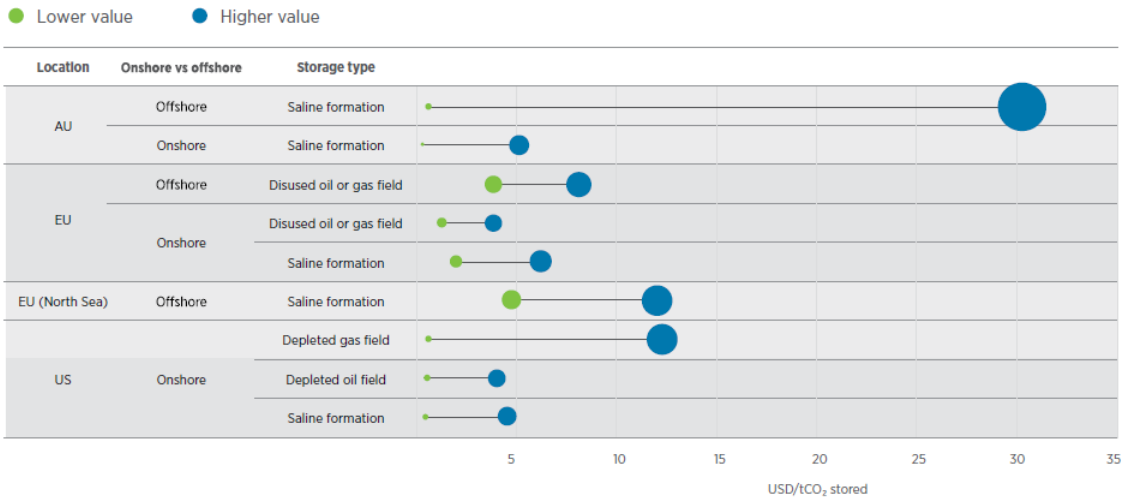
Permanent geological storage options include saline formations and depleted oil and gas fields. Other storage options relate to enhanced hydrocarbons – **particularly enhanced oil recovery (EOR)**. Geological storage in saline formations and in EOR has been carried out at Mtpa scale in past decades, but there is not yet experience in storing CO2 at Gtpa scale, as the CO2 captured has not yet reached Gtpa scale.

The largest experience in storing CO2 is in EOR, which has a very low risk of CO2 leakage. For CO2 pumped underground into geological formations, researchers expect less than 0.0008% of stored CO2 to be leaked over 10 000 years. While the risks of leakage are small, public perceptions towards this approach may still become an issue. Monitoring and verification processes will be important, and must be a mandated and –ideally – a regulated part of any storage project.

There is more than **12 000 Gt of potential**, albeit mostly unverified, of CO2 storage resources in saline formations globally, out of which 400 Gt of storage is currently well documented; but there are only a small number of large-scale commercial projects. There are currently six projects storing almost 0.009 Gtpa of CO2 in the United States, Canada, Algeria and Norway.

Depending on the continent, **onshore saline formation cost** estimates range from USD 0.2–6.2/tCO2, with the cheapest storage in Australia and the most expensive in the EU. **Off-**

Figure 10.4: Cost estimates for onshore and offshore storage



Source: IRENA (2021)

shore saline formation costs range from USD 0.5-30.2 /tCO2, with a lower range in Europe (figure 10.4). Costs estimates for depleted oil onshore fields in the US range from USD 0.5-4.0/tCO2, and gas onshore fields in the United States range from USD 0.5-12.2/tCO2. Cost estimates for **depleted onshore oil and gas fields** in the EU range from USD 1.2-3.8/tCO2, with offshore at USD 3.8–8.1/tCO2. These cost ranges come with many caveats; in particular, lower ranges look optimistic and it is unclear how much they include the costs of monitoring, verification or pressurisation.

10.3.4 Total end-to-end process costs

Cost estimates of avoided CO2 for carbon capture, transport and storage range from USD 22-225/tCO2 depending on the sector, capture technologies, distance from storage and storage location.

The lowest range is for the production of **ammonia and methanol** (USD 22–62/tCO2), followed by **natural gas processing plants** (USD 31–49/tCO2) and production of **hydrogen** (USD 73–88/tCO2). The highest range is in the **iron and steel industry**, with costs of USD 75–131/tCO2, followed by the **cement industry** (USD 62–102/tCO2), with the most expensive price put on the production of **ethylene** (USD 212–225/tCO2).

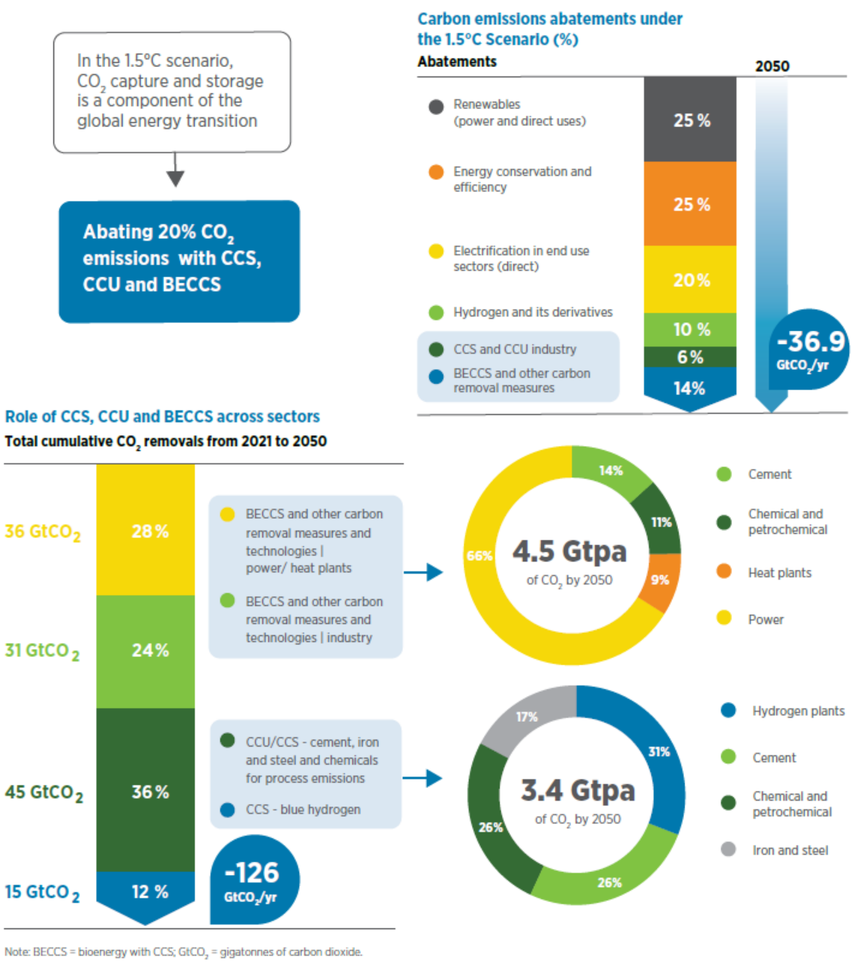
Cost estimates for **bioenergy** with carbon capture, transport and storage also vary significantly depending upon the sector of application (USD 69–105/tCO2).

10.4 The future role of CCS, CCU and CDR

Low-cost renewables make carbon capture combined with fossil fuel use unnecessary in many sectors and contexts, but it will be needed in some applications (figure 10.5).

Renewables and CCS (applied to fossil fuel use and/or process emissions) are often perceived as competitors in the energy transition but in some applications they can be partners and, in a few cases, CCS is the only option.

Figure 10.5: The role of CCS, CCU and BECCS across sectors



Source: IRENA (2021)

The respective roles of renewables versus CCS vary by country, sector and the specific contexts of each deployment. **Factors of importance include:** relative costs; practicality of deployment; availability of supporting transport and storage infrastructure; actual emission abatement potential; deployment time scales; skills and knowledge; social impacts; and societal attitudes.

In most contexts in the **power sector, renewables outcompete CCS** on cost per tonne of CO2 and sustainability grounds.

10.4.1 Carbon capture in industry

Carbon capture for fossil fuel and process **emissions in industry** must be aggressively scaled to reach c. 3.4 Gtpa by 2050 (figure 10.5).

In IRENA's 1.5°C Scenario, the use of CCS and CCU for fossil fuel or process emissions is limited to the most essential applications – in particular to capturing process emissions in hydrogen, cement, iron and steel and chemical production with a limited deployment for industry/waste incinerators, etc. CCS is not deployed for fossil-fuel based power production.

In the 1.5°C Scenario, CCS and CCU for fossil fuel or process emissions from power, fuel production and industrial process rises from 0.04 Gtpa today to 2.8 Gtpa of CO2 in 2040 and

3.4 Gtpa of CO_2 in 2050, cumulatively capturing 58 Gt globally over that period.

These figures include 2.4 Gtpa in 2050 from CCS applied in the **cement, chemical and steel sectors**, and 1.1 Gtpa in 2050 captured in the production of **blue hydrogen from natural gas with CCS**, which accounts for 30% of total hydrogen supply.

10.4.2 Bioenergy with CCS (BECCS)

Bioenergy with CCS (BECCS) is essential for the net-zero goal but needs to reach **4.5 Gtpa by 2050** and faces multiple challenges (figure 10.5).

CDR processes, combined with long-term storage, can in principle remove CO_2 from the atmosphere, resulting in negative emissions. CDR technologies are therefore a critical component of net-zero pathways.

CDR measures and technologies can include nature-based processes such as reforestation, as well as technology or engineered approaches such as BECCS, DACCS and some other experimental approaches.

The most developed example of CDR technology is BECCS. Biomass absorbs CO_2 from the atmosphere as it grows, and the use of CCS prevents most of that CO_2 from going back to the atmosphere during biomass final use. The overall result is that CO_2 is effectively removed from the atmosphere through biomass growth and storage elsewhere.

Net-zero pathways rely on BECCS but it is currently unproven in most contexts and there are complexities to be addressed. The extensive use of BECCS requires both a scaling up of CCS deployment and strategies to ensure sufficient suitable and sustainable biomass feedstock supplies.

There are a range of potential applications of BECCS, including: power and heat generation with biomass providing some or all of the fuel (e.g. wood pellets, sugarcane or municipal solid waste); cement kilns with biomass providing the fuel; blast furnaces for iron production, where charcoal can be used as a fuel and reducing agent; chemical plants where the chemical feedstock is biomass (e.g. bio-methanol or in bioethanol production); and biogas upgrading where the CO_2 fraction of biogas is separated for the production of biomethane.

Depending on the plant design, biomass can be the only fuel, or it can be co-fired with coal or natural gas. In the past decade, a small number of coal power plants have been converted into 100% biomass power plants or are in the process of doing so. However, the number of such conversions to date is small and only one fully converted power plant has a clear publicly announced plan to add CCS; as yet, no co-firing coal or natural gas power plants have announced plans to add CCS.

In IRENA's 1.5°C Scenario, BECCS use results in 2.7 Gtpa of CO_2 captured and stored in 2040, and 4.5 Gtpa of CO_2 in 2050 (figure 10.5). This includes the carbon balance in the chemical and petrochemical industry through carbon stocks in chemical products, recycling and carbon capture in waste incineration. As a result, towards 2050 the power and industry sectors become net negative; i.e. the CO_2 captured more than compensates for remaining CO_2 emissions in those sectors. To capture 4.5 Gtpa of CO_2 by 2050 would require investments of more than USD 1.1 trillion between 2021 and 2050.

BECCS can, in principle, be utilised in a range of processes but the optimum application

Figure 10.6: Potential for biogenic carbon capture in 2050 in IRENA's 1.5°C Scenario

Process group	Biogenic carbon capture potential in 2050
	$GtCO_2$
Power	4.43
Heat	1.29
Cement	0.37
Iron and steel	0.03
Chemicals	1.18
Pulp and paper	0.35
Food sector	0.30
Biorefinery	2.15
Total	**10.12**

Source: IRENA (2021)

of BECCS requires more detailed investigation of costs, logistics and sustainable biomass supply chains, and will be highly country and context specific. IRENA's 1.5°C Scenario includes biomass-based processes from which 10.12 Gtpa could be captured and stored by 2050 (see figure 10.6). Of that potential, the scenario assumes 44% (4.5Gtpa) is actually captured and stored but is not specific about where BECCS would be applied. The most significant opportunities are in power, heat, chemicals and biorefineries but BECCS could also be significant in cement, pulp and paper, and food production. The potential in iron and steel production is low in the 1.5°C Scenario by 2050, since the scenario assumes a nearly complete transition away from blast furnaces by then, but the BECCS potential could be larger there during the transition or if more blast furnaces utilising biomass and CCS are retained.

To illustrate the scale of BECCS required, the Drax power plant in the UK has converted four coal-fired units (each rated at c. 660 MW) to biomass and is planning to retrofit CCS to at least two units. Each individual unit would capture circa 4 Mtpa. Capturing 4.5 Gtpa would require over 1 100 such units around the world, or an equivalent, and most BECCS applications will be much smaller than this.

10.4.3 Other CDR technologies

Other CDR technologies include DACCS and some other approaches that are mostly at an early experimental stage, which makes their future potential hard to quantify. According to this early experience, projects face high energy and land requirements, but offer flexibility in terms of their location.

DACCS is another CDR technology that is in the early stages of development and a long way from reaching the gigatonne-scales needed to be impactful. There are two commercial plants currently operating and capturing a negligible amount of CO2 (0.0009 Mtpa, 0.9 ktpa), and one other plant is under development and would add an additional 0.021 Mtpa (21 ktpa) of CO2 capture. In addition, there are 15 pilot and demonstration plants – three completed, seven in operation and five at various stages of development.

These technologies do not currently play a major role in the IRENA 1.5°C Scenario. However, countries and investors are beginning to make financial commitments to large-scale DACCS projects, which – if successful in driving scale – would allow DACCS to offset some of the need for BECCS or could allow for more emissions elsewhere.

10.5 Carbon Capture in Norway

This chapter is based on the links:

Longship white paper

Langskip - fangst og lagring av CO2

10.5.1 Overview

This section is based on the links:

CCS Norway

Long ship

Government Norway (Carbon capture and storage - CCS)

Government Norway (Long ship project)

CSS Norway (Public and private cooperation)

Norway has the knowledge and many years of experience with CCS, not only in CCS technology such as CO^2 monitoring and storage but in essential related sectors such as geology, offshore engineering and industrial processes.

With a large, natural geological CO2 storage capacity area under the North Sea and more than 20 years of experience with CO2 storage, Norway is in a strong position to demonstrate CCS at scale.

The Government proposes September 21, 2021 to launch a carbon capture and storage (CCS) project in Norway. The project has been named 'Longship', in Norwegian 'Langskip'.

Longship seeks to fulfill the objectives of both Government and industry by reducing investment barriers for business and developing sustainable value creation opportunities.

Reducing barriers. Since the world has agreed on ambitious climate targets and there is a growing consensus among international bodies that CCS is needed to achieve them, why has CCS not already taken off?

To date there has been a lack of investment in CCS projects. The very same IEA, UN and EU reports which extol the virtues of CCS have also been quick to point this out.

This lack of commercialization has primarily been driven by several CCS specific market failures. So there is an obvious need for cooperation between the private and the public sectors to overcome market hurdles to increase investment in CCS.

How then, do we unlock this investment? The key lies in demonstrating CCS to prove that it is viable, building open-access CO2 infrastructure and developing public-private cooperation.

The Norwegian Contribution in the development of CCS. CCS has been proven to be technically viable in several existing projects around the world. Globally, there are large-scale CCUS projects already in operation, such as Equinor's Sleipner project, SaskPower's Boundary Dam project and Shell's Quest project.

All of these projects are incredibly useful and Longship will be building on the lessons that have been learned and shared as CCS technology has developed over the years. In addition, the Longship aims to address more of the market failures which have so far held up investment in CCS as a broad climate mitigation tool. Longship aims to do this by:

- Demonstrating the full CCS chain
- Establishing an open access transport and storage infrastructure
- Capturing CO2 from a cement factory and potentially from a Waste to Energy (WtE) plant
- Testing CCS under the condition of relevant EU regulation

Longship is also driven by public-private cooperation with a shared responsibility for investment. Each industrial partner is responsible for designing their own project, while the state coordinates and creates a framework for each partner's role.

10.5.2 Longship project

This section is based on the link:

Government Norway (Longship)

In a Government White Paper to the Norwegian parliament submitted 21/09/2020, the Government proposes to launch a carbon capture and storage (CCS) project in Norway. The project has been named 'Longship', in Norwegian 'Langskip'.

Longship is a milestone in the Government's industry and climate efforts. The project will lead to emission cuts, and facilitate development of new technology and thus new jobs.

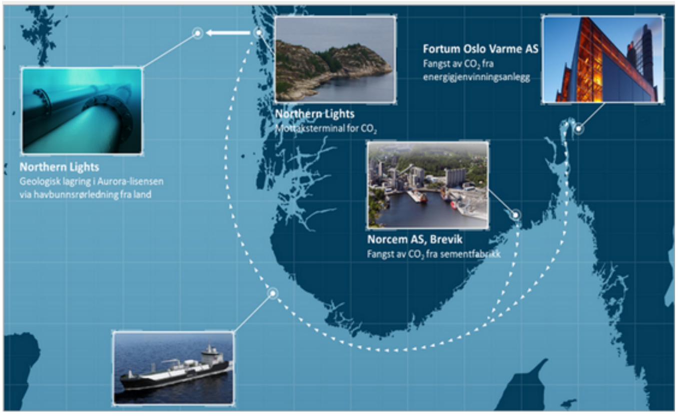
Others must follow.

The Government proposes to first implement carbon capture at Norcem's cement factory in Brevik. In addition, the Government also intends to fund Fortum Oslo Varme's waste incineration facility in Oslo, providing that the project secures sufficient own funding as well as funding from the EU or other sources.

For Longship to be a successful climate project for the future, other countries also have to start using this technology.

Longship also comprises funding for the transport and storage project Northern Lights, a joint project between Equinor, Shell and Total. Northern Lights will transport liquid CO^2 from capture facilities to a terminal at Øygarden in Vestland County. From there, CO2 will be pumped through pipelines to a reservoir beneath the sea bottom.

Figure 10.7: CSS projects in Norway



Source: Gassnova

Bit by bit.

For many years, various Norwegian governments have supported technology development, test and pilot projects, and underscored the importance of carbon capture and storage as an important climate tool internationally. The present Government has followed up this work and made targeted efforts on CCS since 2013.

According to the UN Intergovernmental Panel on Climate Change, CCS will be necessary to reduce global greenhouse gas emissions in line with the climate targets at the lowest possible cost. There are currently few facilities in operation on a global basis. We therefore need more projects that bring learning and technological development. In turn, they will help reduce costs. If CCS is to become an efficient climate policy instrument, new facilities must be established in Europe and globally.

A necessary climate measure.

Norway has committed itself to cutting domestic emissions by 50-55 precent by 2030.

For the world to achieve the goals that we have committed ourselves to in the Paris Agreement, we need large-scale carbon capture and storage. Not all emissions can be cut by applying renewable energy. In several industrial processes, such as production of cement, CCS is the only technology that can cut emissions. With Longship, Norway will support development of climate solutions for the future.

Norway is in a good position to contribute to the development of CCS. The country has a strong technological community in the field of carbon capture, transport and storage. For decades, the development and operation of the CO2 storage projects on the Sleipner and Snøhvit fields have demonstrated safe carbon storage on the Norwegian continental shelf.

Effective climate policies must be positive industrial policies. Through Longship, the Government will strengthen Norwegian industry by enabling enterprises to meet the climate requirements of the future. The project is an important contribution to green growth and will secure and create new jobs in the industry.

Longship facilitates the further development of CCS both in Norway and Europe. The project has been matured to a level required for an investment decision, and the decision basis shows that all parts of the project are feasible.

The project also involves risks. For Longship to have the desired effect, an ambitious development of climate policies in Europe is needed. The risks are primarily connected to the economy of the project, such as the technical integration of the different parts of the project, the scope of following projects and necessary support schemes for such projects from the EU and individual countries. What is not at risk is the safety and integrity of the storage solution for CO^2.

25 billion NOK.

The total investments in Longship are estimated at NOK 17.1 billion. This includes both Norcem, Fortum Oslo Varme as well as Northern Lights. The operating costs for ten years of operation are estimated at NOK 8 billion. The total cost estimate is thus NOK 25.1 billion. Longship will receive state aid in accordance with negotiated agreements. The state's part of these costs are estimated at NOK 16.8 billion.

10.5.3 CO^2 transport and storage: Northern Lights project

This section is based on the links:

CCS Norway (Northern Lights)

Northern Lights

Equinor (Northern Lights)

Equinor is the operator of the Northern Lights project, which also includes **Shell** and **Total** (figure: 10.8). They will build an open access CO2 transport and storage infrastructure that provides capacity above and beyond that required for the **Norcem** and **Fortum** capture sites.

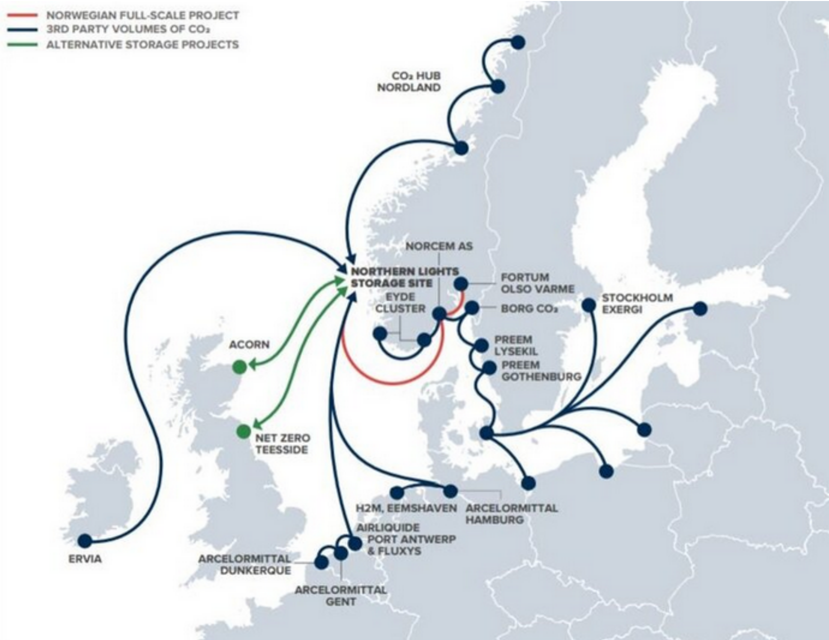
As a part of the Longship CCS project, we share the experience from previous and ongoing CCS projects like Northern Lights. By increasing the knowledge of CCS technologies, we aim to speed up the development and demonstrate that carbon capture and storage can be executed at large scale.

The Northern Lights project is developing a CCS technology where the CO^2 will be stored in pressurized tanks before being pumped offshore through a pipeline to one or more injection wells that are located on the seafloor. No offshore platform is required for these wells and they will be controlled using existing oil and gas infrastructure on the Norwegian continental shelf. Much of the design and operations of these facilities is similar to the ones used for liquid petroleum gas (LPG), with the exception of the fire hazard, which is absent for CO^2.

Space to grow – CO^2 transportation from across Europe.

Given the ambition to transport CO^2 from across the European Continent, the receiving terminal has been designed with future expansion in mind. The number of pressure tanks can be increased and there is even an option for building a second jetty to be able to receive two tankers at a time. The pipeline from the receiving terminal can transport the volumes of CO^2 required and additional wells can be connected to the end of the pipeline.

Figure 10.8: Northern Lights project



Source: Equinor

Regulation.

Equinor was awarded a permit to develop the CO^2 storage site on behalf of the Northern Lights consortium in January 2019. The acreage lies to the south of the giant Troll hydrocarbon field, west of Bergen, and represents a prime location for the geological storage of CO^2 deep below the seafloor.

Northern Lights drilled a well to confirm the properties of the storage reservoir in Q1 2020 and this will also serve as the injector well once CO^2 starts flowing from the capture plants when the project begins.

However, before injection of CO^2 can commence, the Northern Lights consortium will also need to obtain a CO^2 Storage permit from the Environmental Protection Agency, which has a mandate to protect the natural environment on the seafloor and in the sea itself.

In order to adhere to the regulations that come with these permits, Equinor and their partners will put in place a robust monitoring system, similar to the ones they have used for many years at the Sleipner and Snøhvit storage fields.

10.5.4 Carbon capture: Fortum Oslo Varme

This section is based on the links:

Fortum web page

CCS Norway (Fortum Oslo Varme)

Fortum Oslo Varme's **Waste-to-energy plant** at Klemetsrud on the outskirts of Oslo, Norway's capital could be the world's first of its kind with full-scale carbon capture. The plant will be able to capture 400,000 tonnes of CO^2 a year, and provide transfer opportunities to other industrial plants in the Nordic region and Europe. Fortum Oslo Varme's CCS project shows how cities across Europe best possibly can handle waste that should not or cannot be recycled. The excess heat from the end treatment of residual waste is used to produce electricity, district heating and soon cooling to the city of Oslo.

The flue gas from the end treatment of waste is currently cleaned of dioxins, NOX and CO. Now Fortum wants to capture the CO^2. A 5500 hour pilot in 2019 demonstrated the possibility to capturing **more than** 90% **of all** CO^2 **in the flue gas**. Estimately 50% of the waste incinerated at the plant is of biological origin such as non-recyclable food scraps, paper and wood, making the plant carbon-negative. When capturing CO^2 from biological origin, it means that CO^2 is taken out of the atmosphere. This is also known as bio-CCS, or BECCS, something that both the European Commission, the UN and the International Energy Agency all emphasize is of the utmost importance for achieving the world's climate goals.

The City of Oslo has ambitious climate targets and needs CO^2 capture at the waste-to-energy plant to reach its goal. The carbon capture project is also strongly rooted in Fortum's strategy to build a cleaner world.

City solutions by responsible waste handling:

- Goal to capture about 400 000 tonnes CO2 per year, 90% cleaning of CO2.
- CCS at Waste-to-Energy plants will capture both fossil and biological CO2 (50% BECCS).
- CO2 transport to port via emission free trucks: WtE-plant not at port.
- Successful pilot testing on real flue gas: 5500 test hours, up to 95% capture.
- Technology supplier with full-scale experience (Shell's amine), EPC contractor TechnipFMC.
- Feasibility, Concept and FEED studies completed 2015-2019.
- Fortum Oslo Varme's carbon capture project is one of 70 projects that in the March of 2021 was qualified for a final and more comprehensive application round for support from the EU Innovation Fund.
- The application for the second stage was submitted June 23rd 2021.
- The European Commission's allocation of funds is made in the Q4 of 2021.

10.5.5 Carbon capture: Norcem

This section is based on the links:

CSS Norway (Norcem)

Norcem web page

A good video about "Green cement" is in the next link:
CNBC Green cement

Norcem AS is the sole **producer of cement** in Norway, and is an experienced international supplier of cement. Norcem has an ambitious plan to capture the carbon emissions derived from the production of cement, and it participate actively in the **Northern Lights project**.

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