Ch10. Carbon Capture

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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 CO_2 emissions reductions.

- **Renewable sources**, including renewable power generation sources and the direct use of renewable heat and biomass, would contribute to 25% of CO_2 emissions reductions.
- An additional 25% of CO_2 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 CO_2 emissions reductions.
- The use of **hydrogen and synthetic fuels and feedstocks** would enable 10% of CO_2 emissions reductions.

The role of Carbon Capture

However, some fossil fuel use will remain in 2050 and some industrial processes will produce CO2 emissions irrespective of the energy source.

There are different types of carbon capture technologies:

- **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.
- **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.

The role of Carbon Capture

- **Carbon Dioxide Removal (CDR)** refers to processes that actually "remove" CO_2 from the atmosphere rather than simply reduce what is added. If combined with long-term storage, these can result in negative emissions.

CDR Technologies Remove CO_2 from the atmosphere.

- **BECCS (bioenergy with carbon capture and storage)** When growing, biomass captures CO_2 from the atmosphere. In power or industrial processes, the biomass (or fuels derived from the biomass) is combusted, releasing CO_2. In BECCS the majority of that CO_2 is captured and then stored.
- **DACCS (direct air carbon capture and storage)** Instead of capturing CO_2 from point sources such as relatively high concentration flue gas streams, the CO_2 is separated from ambient air.

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.

There are currently three operational commercial facilities that use **bioenergy with CCS (BECCS)** and seven commercial plants are in development.

There are currently **two facilities that use DACCS**, with one in development, plus 15 pilot and demonstration plants in operation or development.

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

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.

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

Transportation costs

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.

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

Based on current estimated costs for capacities of 2.5 to 20 Mtpa CO_2 for distances between 180 km and 500 km. **Onshore pipeline** has the lowest costs at USD 1.7–6.1/tCO_2, followed by **offshore pipelines** at USD 3.5-32.4/tCO_2.

Transport via **offshore pipelines** up to 1 500 km entails costs of up to USD 58.4/tCO_2.

Shipping ranges from USD 12.5-22.4/tCO_2 for distances between 180 km to 1 500 km.

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

Geological storage of CO_2

There is more than **12 000 Gt of potential**, albeit mostly unverified, of CO_2 storage resources in saline formations globally, out of which 400 Gt of storage is currently well documented.

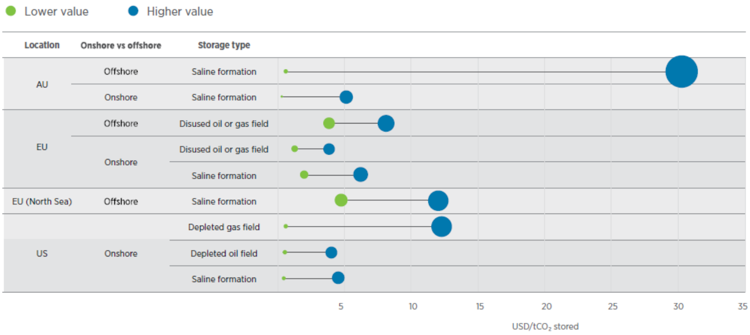
Depending on the continent, **onshore saline formation cost** estimates range from USD 0.2–6.2/tCO_2, with the cheapest storage in Australia and the most expensive in the EU.

Offshore saline formation costs range from USD 0.5-30.2 /tCO_2, with a lower range in Europe (figure 1). Costs estimates for depleted oil onshore fields in the US range from USD 0.5-4.0/tCO_2, and gas onshore fields in the United States range from USD 0.5-12.2/tCO_2.

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

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.

Figure: Cost estimates for onshore and offshore storage



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

Total end-to-end process costs

Cost estimates of avoided CO_2 for carbon capture, transport and storage range from USD 22-225/tCO_2 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/tCO_2), followed by **natural gas processing plants** (USD 31–49/tCO_2) and production of **hydrogen** (USD 73–88/tCO_2).

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

The highest range is in the **iron and steel industry**, with costs of USD 75–131/tCO_2, followed by the **cement industry** (USD 62–102/tCO_2), with the most expensive price put on the production of **ethylene** (USD 212–225/tCO_2).

Cost estimates for **bioenergy** with carbon capture, transport and storage also vary significantly depending upon the sector of application (USD 69–105/tCO_2).

The future role of CCS, CCU and CDR

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.

The future role of CCS, CCU and CDR

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.

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.

The future role of CCS, CCU and CDR

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.

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).
- Biogas upgrading where the CO2 fraction of biogas is separated for the production of biomethane.

The future role of CCS, CCU and CDR

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.

The future role of CCS, CCU and CDR

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.

Case Study

CSS in Norway. In the webpage of the course