Can Captured Carbon be Put to Use?

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An introduction to CCUS proposals and their viability

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Carbon Capture Use and Storage (CCUS) is a proposal to “store” captured carbon dioxide (CO_2) in manufactured goods, such as carbon-based fuels, sparkling water, or chemicals, and is treated as a potential tool to combat global warming by various governmental, international and industrial funding initiatives. In the following we will present an introduction to CCUS technology, several case studies of CCUS pathways including a critical assessment of the extent to which these CCUS approaches can make a meaningful contribution to climate mitigation, and an overview of public funding programs for CCUS and industry investment programs for the development of CCUS projects.

Overall, it can be said that the potential for CO_2 as a feedstock for industrial processes is minuscule relative to global CO_2 emissions. The same applies to the CO_2 storage potential, because CCU(S) products re-release most carbon after a short period of time. The high energy requirements of CCU(S) approaches and the accompanying carbon footprint deserve to be closely reviewed.

Introduction into CCUS technology: the CO_2 capture process

CCUS always starts with CO_2 removal processes and is based on technologies able to capture CO_2 from industrial emissions or from ambient air. All CO_2 removal approaches depend on chemical reactions to scrub CO_2 from the atmosphere or from exhaust gases. The two most developed processes are liquid solvents and solid sorbents: CO_2 dissolves in liquid solvent material or sticks to the surface of a solid sorbent. However, the CO_2 filtering process is only the first step: to allow their repetitive use, the filters must be able to release the captured CO_2. This regeneration process typically requires high temperature (80°C to 800°C), which in turn requires high energy inputs:

- Direct Air Capture (DAC) processes require 5 to 11 GJ of electrical and/or thermal energy to capture one tonne of CO_2. A comparison to illustrate the very high energy consumption of the capture process: In 2018, the annual average consumption of electricity in households in the EU-28 was 5.68 GJ per capita.
- Capturing CO_2 emitted by fossil-fuel combustion, for example at coal-fired power stations, increases the consumption of fossil fuels by up to 30 percent. This means, even more fossil fuels would need to be extracted and burned to produce the same amount of energy with CO_2 capture technology.

After the energy-intensive capturing process, further quantities of energy are required to compress, purify and transport the CO_2 for the following manufacturing pathway. This additional energy consumption is not yet considered in the aforementioned energy consumption calculations.

Introduction into CCUS technology: different CCUS pathways

According to the International Energy Agency (IEA), the yearly global demand for CO_2 is about 230 million tonnes, the fertiliser industry being the largest consumer (~130 Mt), followed by CO_2-based Enhanced Oil Recovery (70 to 80 Mt). CO_2 is also already used to enhance plant growth in greenhouses or to produce food and feed. Further possible CCU(S) pathways, which are currently being developed, include CO_2-based chemicals and fuels, CO_2 as a feedstock for plastics, or for use in construction materials. However, CO_2 is a thermodynamically highly stable molecule, that's why reactions with CO_2 usually involve further energy-intensive processing steps.

Case study: CO_2 fertilization in greenhouses

The Swiss **Climeworks AG**, a spin-off of the ETH Zürich, developed technology to capture CO_2 from ambient air. The DAC capture process requires 8.6 to 11.2 GJ of thermal and electrical energy to capture one tonne of CO_2. This amount of energy suffices to supply 1.5 to 2 European citizens with electrical energy for a full year.

Climeworks first DAC plant was commissioned in Hinwil, Switzerland, in 2017, and supplies captured CO_2 to a nearby greenhouse. Although the ventilation rate in modern greenhouses is low, air exchange with outdoor air cannot be entirely ruled out. In other words, there is no guarantee that the captured CO_2 is completely absorbed by plants. Greenhouse temperature and humidity, further important growth factors, are often controlled by ventilation measures, which may result in further CO_2 losses. However, even if the larger proportion of the captured CO_2 is absorbed by plants, as soon the harvested greenhouse crops are digested or composted, most of the absorbed carbon will be re-released to the atmosphere. Although CO_2 fertilisation can be used to enhance plant growth for a wide variety of greenhouse crops, this CO_2 pathway is not suitable to permanently store CO_2. Many ongoing and planned projects ignore the aforementioned facts, among them the **ATHOS** project, which intends to capture 7.5 million tonnes of CO_2 annually, for example in the Amsterdam port area, and utilization in horticultural greenhouses is among the CO_2 "storage" options envisaged. ATHOS is a planned CO_2 storage hub, organised by a consortium of Gasunie, Energie Beheer Nederland B.V. (EBN), Port of Amsterdam and Tata Steel. In February 2020, the project proposal has been confirmed as a "Project of Common Interest" by the European Parliament[2]. The power requirements and emissions produced to capture, compress and transport CO_2 for fertilizing greenhouse crops with CO_2 should be comprehensively analysed and evaluated, also with regard to proposed cross-border transport of CO_2.

Case study: CO_2 as a feedstock for fertilizer production

At present, India is the country with the largest number of CCU(S) projects for fertilizer production, with four fertilizer plants based in Andhra Pradesh and Uttar Pradesh. All sites capture between 0.05 to 0.15 million tonnes of CO_2 from flue gas during ammonia manufacturing per year and use the captured CO_2 as a feedstock for urea production.

The making of urea is an energy-intensive process, because it requires high temperature and high pressure. The average energy demand per tonne of urea is above 5 GJ, with coal being the primary energy source in urea production. Per tonne of urea, the consumption of CO_2 is estimated at ~740 kg. Shi, et al. (2020) calculated the amount of greenhouse gases generated for every tonne of urea produced at more than 2,180 kg of CO_2-equivalent.

The production of urea is incapable of storing CO_2 for several reasons. The manufacturing process generates large amounts of greenhouse gases. Adding an energy-intensive CO_2 capture process to the production line would further increase the energy expenditure per tonne of urea produced. Additionally, after being applied as a fertilizer on agricultural lands, a substantial proportion of the "stored" CO_2 re-enters into the atmosphere within a short period of time.

Case study: CO_2 as a feedstock for food and feed

The US-based **Air Company** bottles a vodka based on air-captured CO_2. Further CCU(S) producers use captured CO_2 as a feedstock for products such as proteins for food and feed, protein-based meat, carbonated beverages or dry ice. For the production of protein-based food or feed, the captured CO_2 is often fed to algae and/or microorganisms and the harvested biomass is used as a source material to extract proteins. The Finnish producer **SolarFoods** developed a differing approach: the company captures CO_2 from ambient air and converts the captured CO_2 into proteins, by using electricity and air.

This CCU(S) pathway is also characterized by short product lifecycles. For this reason, none of the manufactured foods and feeds is able to offer a permanent storage option. Once a product is consumed, most of the CO_2 will be re-released to the atmosphere within a short period of time. The energy-intensive CO_2 capture process will have an impact on the life cycle assessment of the manufactured food and feed products, but transparent evaluations are not yet available.

Case study: CO_2 as a feedstock for fuels

CO_2 can be used as a feedstock to produce fuels, for example by Fischer-Tropsch synthesis. This pathway usually combines captured CO_2 with hydrogen. The processing operation requires considerable amounts of energy, because CO_2 is an inert (reaction-sluggish) molecule. Despite the high energy consumption – the number of public and private projects supporting the development of CO_2-derived fuels is steadily increasing and funds flow abundantly. In June 2020, two new cooperations became known:

- **Norsk e-Fuel AS** announced the commissioning of its first Power-to-Liquid technology plant in Herøya, Norway, for 2023, aiming to produce fuels based on captured CO_2, water and electricity. The plant will be established with Climeworks CO_2 capture technology and the German **Sunfire GmbH** provides technology to produce syngas with the help of high temperatures and high pressure. Both production steps are very energy-intensive.
- **Lufthansa Group, Climeworks and Synhelion** signed a joint Letter of Intent, aiming to produce aviation synfuels. Climeworks would again contribute its Direct Air Capture technology and **Synhelion**, another spin-off of the ETH Zürich, its solar thermal technology to convert CO_2 and H_2O into syngas, a process requiring temperatures at 1,500°C. The syngas is subsequently processed into fuels using Fischer-Tropsch synthesis.

The German company **CAPHENIA Fuels** developed a slightly different approach and is producing syngas from biogas (methane), CO_2, H_2O, and electricity. The energy-intensive production process involves the following steps: (1) methane breaks down into carbon and hydrogen at 2,000°C, (2) heated carbon and preheated CO_2 are mixed and converted into carbon monoxide at 1,000°C, (3) water is added and reacts to form carbon monoxide and hydrogen, (4) synthesis of fuels based on hydrogen and carbon monoxide. CAPHENIA Fuels aims to develop synfuels for aviation, shipping and car traffic. Lufthansa AG, Swiss and the Austria Aviation Association supported the R&D activities with more than nine million Euro.

The production of CO_2-derived fuels is again based on energy-intensive CO_2 capture processes, followed by energy-intensive further processing, and the produced fuel will be consumed in short or medium term. Therefore, this pathway can also not be considered as a CO_2 storage option.

Case study: CO_2 as a feedstock for the building sector

Captured CO_2 can be used as a feedstock to produce various building materials, for example building blocks or roof tiles. This requires a mineral carbonation process: CO_2 reacts with a metal oxide to form magnesium or calcium carbonates. The carbonation process itself is energy-intensive, in addition it requires the mining and transport of minerals.

Further approaches seek to substitute cement or concrete: **Terra CO_2Technologies Ltd.** develops a process to convert captured CO_2 and mine waste into cementitious materials and **Carbicrete** concrete made from steel slag and captured CO_2.

In comparison to CCU(S) products such as food, synfuels or beverages, these processes, in theory, could be capable of storing CO_2 for longer periods. However, the approaches consume high amounts of energy and although we tend to think of buildings as being permanent structures, buildings also have a limited lifetime. In China, the largest cement producer in the world, ordinary houses are designed to last 50 years. However, according to a recent study conducted by Bai, et al (2019), the average lifetime of Chinese brick-concrete and steel-concrete buildings is 30 to 40 years, due to materials and construction technology used. A study conducted for the European Parliament in 2016, reports a replacement rate for buildings of about one percent a year, which can be translated into an average service life of buildings of about 100 years in Europe. By 2020, the European Commission aims to re-use 70 percent of the construction waste, including concrete, which can be recycled or used as backfilling material. To enable re-use, concrete rubble needs to undergo reprocessing, for example thermal-mechanical treatments with heating to around 650°C for one hour. The effects of such treatments on captured CO_2 are not yet known.

International support programmes for CCUS

The **ACT programme** – **A**ccelerating **C**CS[1] **T**echnologies as a new low-carbon energy vector – consists of 13 partner countries from Europe and North America. The consortium has so far mainly invested in CCS-related R&D, but announced around €30 million for developing CCUS technologies in a call launched in June 2020.

The **MIC3 Carbon Capture and Storage Challenge** was initiated by Mission Innovation, a governmental initiative with participants from four continents. MIC3 was launched in 2017, is led by the UK Department for Business, Energy and Industrial Strategy, and is funded with about €90 million. The MIC3 action plan aims to significantly reduce CO_2 emissions from power plants and carbon intensive industries by implementing and commercializing CCS as well as CCUS technologies.

The **Oil and Gas Climate Initiative** (OGCI) was founded and is financed by companies from the oil and fuel industries, for example BP, Chevron, ExxonMobil, Occidental, Petrobas, Saudi Aramco, Shell and Total. In 2016, the member companies announced to fund the OGCI with one billion USD over ten years, aiming to enhance CCS and CCUS innovations with the potential to reduce greenhouse gas emissions. The initiative plans to support five emerging CCUS hubs and to identify new CCUS hubs in about 25 countries.

Governmental subsidy programmes for CCUS

Most governmental CCUS programmes are operated in the USA, Europe and the UK.

The United States launched a **Federal support programme for CCS/CCUS** in 2019. The programme aims to lower CO_2 emissions at fossil-based energy sources and plans to support CCUS deployment at four project sites with up to US$20 million in federal funding. The **National Carbon Capture Centre** (NCCC) in Wilsonville, Alabama, is a public-private partnership and financed by public institutions as well as by oil and fossil fuel-based industries, for example ExxonMobil, American Electric Power and Total. In May 2020, the NCCC announced plans to expand its testing programme to the development of cost-competitive CCUS option. The **Wyoming Integrated Test Centre** (ITC) is another public-private partnership and conducts CCUS- and CCS-related R&D activities at six demonstration sites with coal-based flue gas in Wyoming. In addition to federal or state-based programs, public funding flows into commercial research projects, for example via the American Recovery and Investment Act, a program financed by the US Department of Energy (US-DOE). Within this programme, **Alcoa Inc.** was granted with US$13.5 million for capturing CO_2 and converting it into mineral carbonates; the **Touchstone Research Laboratory Ltd.** was supported with US$6.7 million for capturing and converting CO_2 into algal lipids.

The EuropeanCommissions **Innovation Fund** aims to demonstrate innovative low-carbon technologies and scheduled its first project call for 2020. The fund plans to invest up to €10 billion within the next ten years, CCUS is among the supported innovations. The European Union’s Horizon2020 programme supports several ongoing CCUS research projects, among them STRATEGY CCUS, eCOCO2, **ECO-BASE**, **ALIGN-**CCUS and **LEILAC**. **STRATEGY CCUS** – Strategic Planning of Regions and Territories in Europe for Low-Carbon Energy and Industry through CCUS – aims to study and develop CCUS as a low-carbon energy and industry option in Southern and Eastern Europe. The **eCOCO2** programme – Direct electrocatalytic COnversion of CO_2 into chemical energy carriers in a co-ionic membrane reactor – aims to develop and demonstrate a scaleable CO_2 conversion process for the production of "carbon-neutral" synthetic jet fuels. The **ALIGN-CCUS** (Accelerating Low carbon Industrial Growth through CCUS) project, funded with €23 million, describes CCUS as a potential carbon abatement option and aims to transform six European industrialized regions into low-carbon centers. The Baltic Sea Region network for CCS (**BASRECCS**), a network supported by the Baltic States and the Global CCS Institute, announced support for CCUS projects in 2018. The network aims to enable at least one full-scale CC(U)S-project in the Baltic Sea region by 2030, followed by a network of CC(U)S projects by 2040.

The UK Ministry for Energy and Clean Growth launched the **CCUS – UK Action Plan** in 2018. The plan, a public-private initiative funded with £20 million, aims to support the development and construction of CCUS technologies at industrial sites across the UK. In 2019, the formation of a CCUS advisory group was announced, to help deliver the action plan. The fossil fuel-based industry is well-represented in the advisory group, for example, by Shell, BP, Tata Steel and Drax. Governmental funding for the **South Wales Industrial Cluster** (SWIC) was announced in April 2020. SWIC aims to reduce emissions at CO_2-intensive industrial sites in southern Wales, for example from power stations, refineries or building industry. CCS and CCUS are among the funded options. **HyNet** and the **Net Zero Teesside**, are further public-private schemes. Both projects aim to capture CO_2 produced by burning fossil fuels and transport it to nearby industrial sites for CCUS as well as for offshore injections in the Irish or Northern Sea.

The **UK-China Guangdong CCUS Centre** (GDCCUSC) was launched in 2013 and is financed with governmental support from the UK, China, USA and by industrial partners, for example Alstom, Shell Cansolv and the Global CCS Institute. The centre aims to facilitate the development of CCS and CCUS in Guangdong Province, China, for example by studying the use of CCS/CCUS technology at Huizhou Refinery.

In Japan, the Research Institute of Innovative Technology for the Earth granted funding for a CCUS demonstration project in Osaka: **Mitsui Chemicals** of Japan constructed a demonstration plant to produce methanol from industrial CO_2 effluent. The **Tomakomai CCS Demonstration Project** is financed by the Japanese government, captures CO_2 from a fossil fuel-based power plant and was initially founded to develop CCS technology. Since April 2020, the pilot plant is also used to develop and demonstrate CCUS technology, such as methanol synthesis, using the captured CO_2 as a feedstock.

Outlook

According to the IEA, the annual global demand for CO_2 as a feedstock for industrial processes is around 230 million tonnes – this corresponds to less than one percent of the global annual CO_2 emissions. The IEA estimates the annual demand to rise by an average of 1.7 percent (~2,5 million tonnes per year).

The interest in CCUS technologies has increased during the past years, this is reflected in a growing number of projects and increased funding. The largest share of CCUS projects does not provide information on funding sources and amounts, thus, the global investments in CCUS are hard to quantify. The available investments amount to 715 million Euro, 54.6 percent financed by industry, 44 percent by public sources, and 1.4 percent by foundations. The US Department of Energy, the UK Department of Transport and the European Union are the largest public funding bodies. The list of industrial sponsors reads like a company directory of the oil and fossil fuel-based industries: Audi, BP, British Airways, Chevron, China Steel Corporation, ENI, Equinor, ExxonMobil, Lufthansa Group, Occidental, Petrobas, REPSOL, Saudi Aramco, Shell, Swiss, TOTAL, Virgin Atlantic, …

Recycling CO_2 instead of emitting CO_2 creates a green image – at least at first glance. But the climate cannot be saved by CCU(S), because the possible applications and the required quantities of CO_2 for chemical processes and materials are limited. In addition, the carbon footprint for CCU(S) products should by assessed by independent studies, because all reactions with CO_2 are dependent on large amounts of energy input. Above all, the suggested solutions will re-release most of the "stored" carbon after (too) short a period of time. Given the considerable energy expenditures of CCUS approaches, the use of CO_2 does not necessarily reduce (and possibly even increase) emissions and therefore, investments in avoiding CO_2 emissions should have priority.

Further information

ETC Group and Heinrich Böll Foundation (2020) *Geoengineering Map,* https://map.geoengineeringmonitor.org/

Heinrich Böll Foundation and ETC Group (2020) *Geoengineering – Technical Briefing: Carbon Capture and Storage (CCS)*, July 2020

Heinrich Böll Foundation and ETC Group (2020) *Geoengineering – Technical Briefing: Carbon Capture Use and Storage (CCUS)*, July 2020

Heinrich Böll Foundation and ETC Group (2020) *Geoengineering – Technical Briefing: Direct Air Capture (DAC)*, July 2020

Sources:

Artola, et al. (2016) *Boosting Building Renovation: What potential and value for Europe?*, European Parliament, Policy Department A: Economic and Scientific Policy, October 2016, https://www.europarl.europa.eu/RegData/etudes/STUD/2016/587326/IPOL_STU(2016)587326_EN.pdf

Bai, et al. (2019) *Spatial and Temporal Variations of Embodied Carbon Emissions in China's Infrastructure*, in Sustainability, Vol. 11, https://doi.org/10.3390/su11030749

Batool and Wezels (2019) *Decarbonisation options for the Dutch fertilizer industry*, PBL Netherlands Environmental Assessment Agency, The Hague, publication number 3657, https://www.pbl.nl/sites/default/files/downloads/pbl-2019-decarbonisation-options-for-the-dutch-fertiliser-industry_3657.pdf

Bhushan, et al. (2019) *How green is the urea sector?*, in: DownToEarth, published: June 05, 2019, https://www.downtoearth.org.in/news/agriculture/how-green-is-the-urea-sector–64836

ETC Group and Heinrich Böll Foundation (2020) *Geoengineering Map,* https://map.geoengineeringmonitor.org/

European Commission (2019) *Waste: Construction and Demolition Waste*, December 2019, https://ec.europa.eu/environment/waste/construction_demolition.htm

Heinrich Böll Foundation and ETC Group (2020) *Geoengineering – Technical Briefing: Carbon Capture and Storage (CCS)*, July 2020, LINK

Heinrich Böll Foundation and ETC Group (2020) *Geoengineering – Technical Briefing: Carbon Capture Use and Storage (CCUS)*, July 2020, LINK

Heinrich Böll Foundation and ETC Group (2020) *Geoengineering – Technical Briefing: Direct Air Capture (DAC)*, July 2020, LINK

EUROSTAT (2019) *Electricity and heat statistics*, accessed: June 2020, https://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_and_heat_statistics

International Energy Agency (2019) *Putting CO2 to Use. Creating value from emissions*, published: September 2019, https://maritimecyprus.files.wordpress.com/2019/11/putting_co2_to_use.pdf

Kalinowska-Wichrowska, et al. (2020) *Waste-free technology for recycling concrete rubble*, in: Construction and Building Materials, Vol. 234, https://doi.org/10.1016/j.conbuildmat.2019.117407

Shi, et al. (2020) Evaluation of Industrial Urea Energy Consumption (EC) Based on Life Cycle Assessment (LCA), in: Sustainability, Vol 12, https://doi.org/10.3390/su12093793

Stanghellini, et al. (2008) *Carbon dioxide fertilization in Mediterranean greenhouses: when and how is it economical?*, in Acta horticulturae, Vol. 807, January 2008, https://doi.org/10.17660/ActaHortic.2009.807.16

Wang, et al. (2014) *CO_2 Fertilization System Integrated with a Low-cost Direct Air Capture Technology*, in: Energy

Procedia, Vol. 63: 6842-6851, https://doi.org/10.1016/j.egypro.2014.11.718

1 Carbon Capture and Storage

2 Appearing on the list means the project can apply for priority funding, but it’s not a guarantee that it receives funding.