ETH zürich

Background information

Under embargo until 12:00 CET on 6 December 2023

DemoUpCARMA – Capturing and storing CO_2

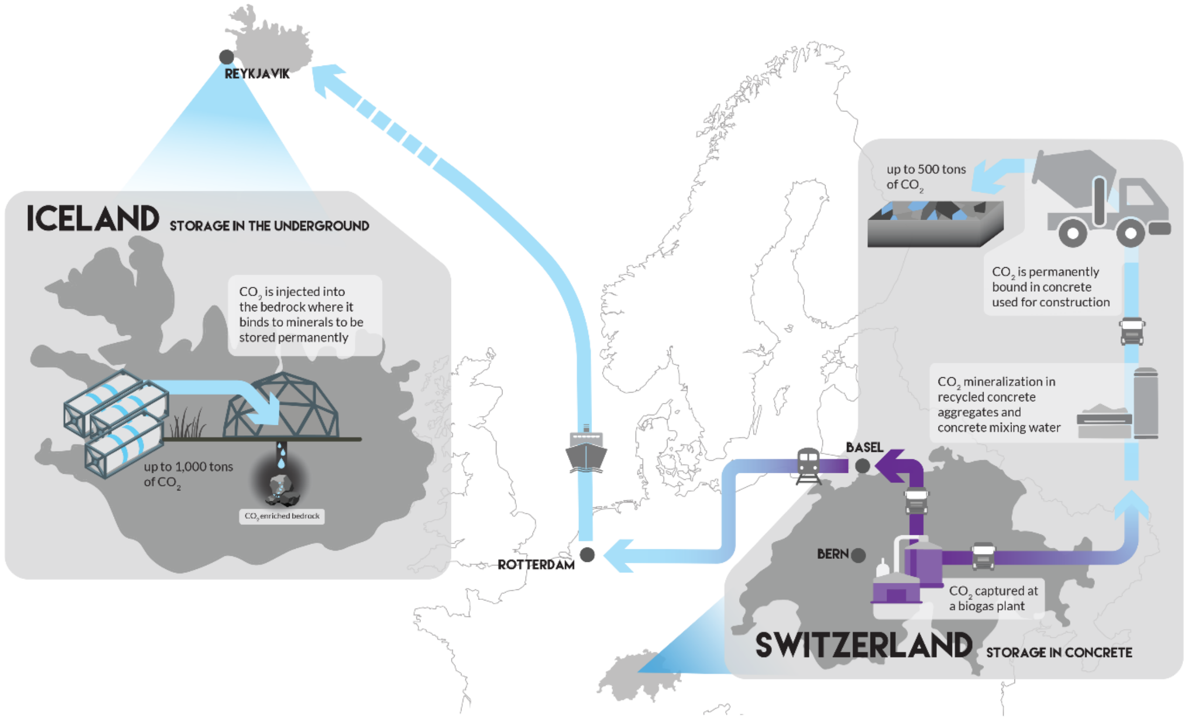

Figure: The DemoUpCARMA project's two CO_2 pathways (image source: DemoUpCARMA, ETH Zurich)

DemoUpCARMA (Demonstration and Upscaling of CARbon dioxide MAnagement solutions for a net-zero Switzerland) is a pilot project led by ETH Zurich. Its aim was to implement two pathways that lead to the permanent removal of CO_2 from the atmosphere or to the avoidance of CO_2 emissions:

- CO_2 utilisation and permanent storage in demolition concrete in Switzerland using a novel technology. This pathway is referred to as Carbon dioxide Capture, Utilisation and Storage (CCUS).
- CO_2 transport and permanent storage in a geological reservoir abroad. This pathway is referred to as Carbon dioxide Capture, Transport and Storage (CCTS).

DemoUpCARMA investigated the optimum design of these pathways and how to scale them in the medium to long term, taking into account technological, economic, regulatory, political and societal factors. Negative emissions are integral to reducing Switzerland's greenhouse gas emissions to net zero by 2050 and achieving the country's climate goals. The Energy Perspectives 2050+ assume that 12 million tonnes of hard to abate CO_2 are emitted each year, e.g. from waste incineration plants or agriculture. Of this, 7 million tonnes of CO_2 will probably have to be offset with negative emissions.

DemoUpCARMA was funded and supported by the Swiss Federal Office of Energy (SFOE) and the Federal Office for the Environment (FOEN). The project involved 24 partners from science and industry, some of whom provided additional funding and contributions in kind. See also www.demoupcarma.ethz.ch.

Further information: Prof. Marco Mazzotti (marco.mazzotti@ipe.mavt.ethz.ch), Dr Viola Becattini (viola.becattini@ipe.mavt.ethz.ch), Project Management, Institute of Energy and Process Engineering at ETH Zurich

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CO_2 storage in demolition concrete in Switzerland

As part of DemoUpCARMA, the ETH spin-off Neustark, founded in 2019, has refined its process for the permanent storage of CO_2 in recycled concrete aggregate and concrete mixing water and tested it on an industrial scale.

The results show that the infrastructure required for CO_2 storage can be installed in an existing concrete recycling plant and operated on an industrial scale. For storage purposes, concrete aggregate produced during demolition (e.g. of buildings) is mixed with biogenic CO_2 provided by ARA Bern, a wastewater treatment and biomass recycling company. The CO_2 mineralises to form calcium carbonate, thus remaining permanently stored; only temperatures of over 600°C or very strong acids are able to release the CO_2 bound in this way. Mineralisation ensures that the CO_2 remains stored in the concrete aggregate even after it has been reused in road construction or added to fresh recycled concrete, used and then demolished again. Each tonne of recycled concrete aggregate can bind around 13kg of CO_2. Empa laboratory tests also show that concrete containing carbonated recycled concrete aggregate has higher compressive strength than primary concrete. This opens the door to reducing the cement content and the associated CO_2 emissions.

Concrete mixing water is a by-product that is produced when concrete mixing vehicles and concrete mixing plants are cleaned. It consists of water with a solids content (mainly cement and sand) of less than 10 percent. The concrete mixing water is collected in a basin and added to the ready-mixed concrete as a water substitute. It can absorb around 25kg of CO_2 per cubic metre. In the laboratory, the addition of carbonated concrete mixing water to primary concrete showed improved workability and also increased compressive strength compared to primary concrete to which non-carbonated concrete mixing water had been added.

Storing CO_2 in both recycled concrete aggregate and concrete mixing water has a positive effect on the climate. More emissions are avoided and, when using biogenic CO_2 as in DemoUpCARMA, more emissions are eliminated than generated. The efficiency levels (ratio of useful energy to supplied energy) were over 90 percent. When it comes to costs, there are economies of scale to be had: with an integrated storage system, costs can be reduced in the long term starting from a quantity of 500 tonnes of stored CO_2 per year.

Further information on this pathway can be found in the blog post “How we can lower the carbon footprint of concrete today”.

Further information: Dr Johannes Tiefenthaler, Founder and Co-CEO, Sophie Dres (sophie.dres@neustark.com), Head of Communications, Neustark AG

CO_2 storage in a geological reservoir in Iceland

The DemoUpCARMA project was the first to demonstrate a CO_2 supply chain from capture and transport to geological storage in Icelandic basalt. Biogenic CO_2 is captured and liquefied at ARA Bern. From there, it is transported by lorry in special containers to Weil am Rhein, Germany, where it is then transported by rail to the port of Rotterdam in the Netherlands, and onwards by sea freight to Iceland. In Iceland, the container is transported from the port to the geological reservoir by lorry.

So far, 80 tonnes of CO_2 have been transported to Iceland. A life-cycle assessment has shown that the entire supply chain causes significantly fewer greenhouse gas emissions than are avoided through geological storage. This means that although additional emissions are generated during transport, the CO_2 balance is still positive in the end. If the CO_2 is biogenic, as in our pilot project, it can even lead to negative emissions. Each stored tonne of CO_2 generates around 200 to 250kg of CO_2 emissions, so it is possible to store 750 to 800kg net CO_2. Transport using fossil fuels causes the most emissions; in the future, this could be optimised by using renewables in rail transport or establishing a CO_2 pipeline network.

In Iceland, the Swiss CO_2 is mixed with seawater and injected into the basaltic subsoil through a specially constructed borehole at a depth of 300 to 400 metres. Previously, the partner company Carbfix had been dissolving the CO_2 in freshwater in order to mineralise it underground. Now an extensive monitoring network is being employed to investigate whether the procedure and the mineralisation processes also work with seawater and how exactly the mineralisation occurs. Due to delivery difficulties caused by the pandemic and the war in Ukraine, transport and material procurement were delayed. In addition, technical problems meant drilling progressed more slowly than originally hoped. In consequence, injections could not commence until the beginning of November 2023, meaning that only a few results are available so far. The DemoUpStorage partner project will support and monitor the injection and CO_2 mineralisation in the reservoir until the end of 2024.

The costs calculated in the project amount to several hundred Swiss francs per tonne of stored CO_2. However, it must be noted that this cost calculation was done for a pilot project, where the associated challenges are likely to have increased costs. Costs could be brought down in the future by economies of scale, an established regulatory framework and more experience in transport management.

Further information on this pathway can be found in the blog post “Testing a new procedure: First injection of CO_2 dissolved in seawater into basalts in Iceland”.

Further information: Prof. Stefan Wiemer (stefan.wiemer@sed.ethz.ch), Director, Swiss Seismological Service (SED) at ETH Zurich

Transport and financing

Transport from the emission source to the storage location is a central element of CCT(U)S. As part of the project, the establishment of a real supply chain from the capture unit to the concrete recycling plant functioned smoothly. In contrast, the cross-border supply chain to Iceland brought with it a number of challenges that would hardly have become apparent through modelling alone. One such difficulty, for example, related to declaring the CO_2 for export and the associated regulations.

The challenges differ depending on the supply chain, as illustrated by the two case studies that DemoUpCARMA examined: different solutions for capture processes and systems were tested for the Hagenholz waste-to-energy plant in Zurich and the Jura cement plant in Wildegg. The studies showed that the choice of capture technology depends on which energy resources (e.g. heat or electricity) are already available at the site or can be put to effective use.

In terms of costs, the currently established multimodal transport chain (with lorry, rail and ship) is relatively expensive for CCTS and is expected to offer few economies of scale. A significant reduction in costs and emissions could probably only be achieved in the long term through the construction of a pipeline network. However, the construction of such CO_2 pipelines would first require the creation of a legal basis at cantonal or federal level, with the latter requiring a constitutional amendment. The high financing and interest costs of such a major project would be lowest if the public sector were able to bear them. However, the legal basis for this would first have to be created, requiring a political majority. Alternatively, warranties or guarantees from the federal government would also be worth considering. The investment costs could possibly be reduced if a model were established under which various CO_2 emitters join together to form a network and exploit synergy effects in transport and storage.

The most expedient business model for managing and operating such a network appears to be a regulated business model with a central operating company. This would offer low financing costs, incentives for efficient operations and the flexibility to evolve with changes in the regulatory environment over time. There are currently no viable business models for CCT(U)S in Switzerland. Insufficient or unclear regulatory guidelines are currently hampering market development. This means climate finance mechanisms need to be developed for specific use cases. For operators of installations with high greenhouse gas emissions that participate in the Swiss emissions trading system, for example, the crediting of CCT(U)S measures would be an important factor in generating additional investment. This is provided for in the current revision of the CO_2 Act.

With CCT(U)S, a positive climate footprint can already be achieved today, as the life-cycle assessments carried out show. Regardless of the methods chosen for transport and capture, the emissions produced are lower than the amount of CO_2 stored.

Further information: Dr Viola Becattini (viola.becattini@ipe.mavt.ethz.ch), Project Management, Institute of Energy and Process Engineering at ETH Zurich

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Background information

Acceptance

Future CCT(U)S projects must not only be financed and regulated, but also supported by politics and society. A representative survey conducted as part of DemoUpCARMA shows that the Swiss public currently knows little about CCT(U)S. This points to a great need for information, particularly with regard to the specifics of implementation. The perceived benefits and risks differ for the two CO_2 storage pathways examined, meaning they are highly context specific. People's level of acceptance is influenced by personal factors such as their general attitudes towards climate change or their political orientation. Initiatives that are driven by trustworthy actors attract greater support, with science in first place, followed by authorities and NGOs.

The results of a representative online experiment also indicate that people are more willing to bear the costs of CCT(U)S if long-term storage is guaranteed. Respondents consider it important for storage abroad to meet high safety standards and be accepted by the local population. In view of the upcoming challenges for the implementation of CCT(U)S initiatives, early involvement of various interest groups and a transparent information policy are important elements in establishing acceptance.

A stakeholder survey has further shown that critical voices might arise once CCT(U)S initiatives are actually implemented or when they are scaled up. This makes it important to involve various interest groups as early as possible. At the same time, the stakeholders directly involved have a high level of awareness of the problem and the need for action; this awareness was further heightened in the course of DemoUpCARMA.

Further information: Dr Michèle Marti (michele.marti@sed.ethz.ch), Head of Communication and the Risk Communication Research Group, Swiss Seismological Service (SED) at ETH Zurich

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Conclusions

DemoUpCARMA has shown that two pathways to permanent CO_2 storage are technically feasible and have a positive climate footprint. Compared to modelling alone, the pilot character of the project had the advantage of highlighting unexpected challenges as well as practicable solutions. In addition, DemoUpCARMA helped to create and communicate new knowledge about CCT(U)S and bring together relevant stakeholders, who are now jointly initiating follow-up projects. By focusing on scaling CCT(U)S initiatives, DemoUpCARMA was also able to identify a number of challenges:

- A framework has yet to be established for the sustainable and financially viable implementation of large-scale CCT(U)S initiatives.
- There is currently no reliable business model for CCT(U)S for Swiss CO_2 emitters.
- It is unclear whether and under what conditions the Swiss general public supports or rejects specific CCT(U)S initiatives.

Based on the project findings, the project team sees a particular need for action in the following areas:

- Improving planning certainty, particularly with regard to the regulatory framework.
- Creating financial incentive systems or funding measures to establish CCT(U)S initiatives.
- Appointing an entity to develop a pipeline system to pursue this option for transporting large quantities of CO_2.
- Conducting pilot studies with mobile capture units for the practical testing of various processes.
- Planning and building large-scale CO_2 capture units for major emission sources.

Background information

- Ongoing research and regular updating of life-cycle assessments and techno-economic analyses.
- Actively involving various interest groups and the general public in the assessment, planning and implementation of CCT(U)S initiatives.

Further information: Prof. Marco Mazzotti (marco.mazzotti@ipe.mavt.ethz.ch), Project Management, Institute of Energy and Process Engineering at ETH Zurich

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