CO_2–THE RAW MATERIAL THAT COMES FROM AIR

The Zurich-based company Climeworks has developed technology that sucks carbon dioxide (CO_2) from the air and uses it as a raw material for various applications. In spring 2017, a pilot and demonstration facility will be set up in Hinwil (ZH). It separates CO_2 from the atmosphere and then uses it as a fertilizer in a greenhouse. Climeworks is hoping to use the innovative technology to contribute to the mitigation of CO_2-induced global warming.

Six modules for CO_2 capture are housed in a 40-foot shipcontainer. They are located at Climeworks company headquarters in Zurich-Oerlikon, ready to be installed at the pilot and demonstration facility in Hinwil in the Zurich Oberland region. The facility for CO_2 capture shall go in operation in spring 2017. Photo: Climeworks

Technical report about the findings of a pilot and demonstration project in the area of CO_2 capture from the air and related to synthetic fuels, financed by the SFOE. The report has been published, among other places, in the magazine Erneuerbare Energien (issue April 2017).

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Federal Office of Energy SFOE

Once the spirit gets out, one can barely get it back into the bottle. Very similar to the fairy tale of the "spirit in the bottle," carbon dioxide spewed out by the combustion of heating oil, petrol and other fossil fuels contributes to climate warming and its massive consequences. Once the CO_2 is in the air, there is no turning back. Or is there? The Zurich company Climeworks has set itself the goal to pack the spirit back into the bottle—in other words to recapture CO_2 released into the atmosphere. With this technology, the company aims to help counter climate change. The CO_2 obtained can be reused as a raw material, thus avoiding the release of further carbon containing molecules into the atmosphere.

Capturing CO_2 from cars

The ETH Zurich spin-off has been working on this goal for seven years. Several smaller systems have proven that CO_2 capture from the air technically works. In the spring of 2017, Climeworks will set up the first plant in Hinwil, Zurich that removes CO_2 from the atmosphere to a significant degree: 900 tonnes (t) of CO_2 per year. This is equivalent to the per year greenhouse gas emissions of 330 medium-class cars (diesel / 6.8 l / 15,000 km). The pilot and demonstration plant in Hinwil consists of 18 modules, each equipped with a special filter that separates CO_2 from the atmosphere (see text box p. 3). The separation process requires heat and electricity. The plant in Hinwil obtains the required heat from the adjacent refuse recycling plant of the Zweckverband Kehrichtverwertung Zürcher Oberland (KEZO).

But what are the 900 t of CO_2 used for? In the current project, the carbon dioxide is pumped into greenhouses located only a few hundred meters away in which the company Gebrüder Meier Primanatura AG cultivate lettuce, cherry tomatoes and other vegetable varieties. Greenhouse crops are supplied with additional carbon dioxide (beyond the CO_2 contained in the air) because this strengthens the plants and promotes yield. Some of the CO_2 respired by plants is reabsorbed by photosynthesis, the rest escapes into the atmosphere. Currently, the greenhouse operators purchase additional CO_2 from the chemical industry, where ‹technical CO_2› is generated as a waste product. In the future, the CO_2 will be supplied by Climeworks. "We have used technical CO_2 for tomatoes, aubergines and cucumbers during the growing season from February to October, and in the future we may also use it in winter, when the lettuce grows," says company chief Fritz Meier.

The plant in Hinwil was built to show that "CO_2 capture from the atmosphere on a larger scale is possible," says Climeworks co-founder and managing director Dr. Jan Wurzbacher. If successful, the CO_2 from the air can be used for various purposes, the production of carbonated beverages, for example. In addition to the positive impact on the climate, the process also has economic advantages. "Carbon capture from the air makes it possible to supply CO_2 locally in places where the raw material has so far been very difficult to obtain such as in certain regions of the Middle East, Africa or South America, and where we can already offer CO_2 at market prices," says Wurzbacher. "With the continuous further development of our product, we are expanding the application areas and regions in which we can competitively offer CO_2 from the air."

Greenhouse of the Gebrüder Meier Primanatura AG in Hinwil (ZH): The CO_2 is fed to the plants through the perforated black tube (the hose has been removed from the holder for the photo, normally it is located below the plants and not visible). Photo: Gebr. Meier

Synthetic fuels from CO_2

The Swiss Federal Office of Energy supports the plant in Hinwil as part of its pilot and demonstration program. The four-year project aims, among other things, to clarify under real conditions, at what cost and with how much energy CO_2 capture from the atmosphere is possible. Cost and energy needs - these are the key factors that should ultimately determine the business model of Climeworks. If successful, another vision of Climeworks could become a reality: the use of CO_2 from the air for the production of synthetic, climate-neutral fuel. For this project, Climeworks cooperates with the car maker Audi and the Dresden fuel producer Sunfire. In the next two to three years, according to Wurzbacher, an initial production plant for synthetic fuel, produced from atmospheric CO_2, will be put into operation.

The production of synthetic gas from coal or biomass (also Synthetic Natural Gas / SNG) used for the propulsion of gas powered vehicles, has already been tested. If one wants to produce synthetic gas in a renewable way, it can be achieved by the methanation of CO_2 with hydrogen. The hydrogen required for this can be produced from water by electrolysis. If renewable energy (eg from solar cells or wind power plants) is used for all process steps (CO_2 capture, electrolysis, methanation), the resulting fuel does not contain fossil fuels (directly) and can be burned like gasoline, diesel or kerosene in an internal combustion engine. A car powered by this fuel ejects only as much CO_2 as has been separated from the air for the production of the fuel; So its engine is CO_2 neutral. For Urs Elber from the Competence Center for Energy and Mobility at the Paul Scherrer Institute (Villigen / AG), this is an interesting approach: "Renewable electricity, by converting it into synthetic gas, is less efficient than when used directly in electromobiles. However, synthetic gas does have the advantage that it can be produced when more current flows into the grid than is being consumed (for example, on very sunny and windy days). Moreover, it can be stored well and also seasonally. If the future production costs remain similar to those of fossil sources, such fuels certainly have a chance at profitability."

Research on Synthetic Liquid Fuels

Audi has been operating a plant in Werlte, Lower Saxony since 2013 that produces synthetic gas from hydrogen and CO_2. However, the CO_2 does not originate from the air, but from biogas. From the annual production of the plant, 1,500 gas-driven cars can travel 15,000 kilometers a year. A further step is the production of liquid fuels such as synthetic gasoline (petrol) / diesel / kerosene (in short, 'Power-to-L', where L stands for 'liquid'). CO_2 (or CO) and hydrogen are also the basic chemical elements for this. With a pilot plant, the company Sunfire from Dresden has demonstrated how tailor-made synthetic liquid fuels with the desired properties can be produced. At the moment, the company is working on the large-scale implementation of this technology. Such liquid synthetic fuels, along with biokerosene, could also open the opportunity for the air traffic industry to switch to renewable energies.

HOW TO WIN CO_2 FROM AIR

The air consists of nitrogen and oxygen but also contains carbon dioxide (CO_2) in low concentrations of 400 ppm (corresponds to 0.04%). Contrary to what one might think, an air pack with the dimensions of 100 m x 100 m x 100 m weighs around 1 200 tonnes (t), including about 700 kg of CO_2.

For Climeworks, the CO_2 contained in the air is a resource. Their method ('Direct Air Capture') separates CO_2 from the atmosphere in high purity (> 99.9%). To accomplish this, air is sucked in with a fan and passed through a filter made of a special cellulose fiber. The cellulose, because of its large surface, functions like a sponge. Supported by ammonia derivatives (amines) that are present in the Climeworks module in solid form (rather than the liquid form found in flue gas systems), the CO_2 is chemically bound in the filter. After two to three hours, the filter becomes saturated with CO_2. At this time, the fan is switched off, the filter chamber is closed, the contents are heated to about 95 °C and at the same time, the pressure is reduced to 200 mbar. The CO_2 molecules are released from the filter and can be vacumed off. Afterwards the process starts over, the fan takes in air and the filter absorbs CO_2 once again.

A Climeworks capture module performs around five cycles per day and captures 135 kg of CO_2 during this period. To heat the filter it needs heat in the range of 1500 - 2000 kWh per t of CO_2. In the case of the pilot and demonstration plant in Hinwil, the heat comes from the KEZO refuse incineration plant. The power requirement for the fan and control is 200 - 300 kWh per t CO_2. The filter is cooled by air or water. One module has a life expectancy of about four years. BV

↗ The demonstration facility for CO_2 capture in Hinwil can be visited as part of a guided tour starting in mid-June 2017. Registrations are be accepted at: tours@climeworks.com.

The question of what role synthetic fuels will play in the future is still open. At present, and in the foreseeable future, there is not enough surplus electricity from renewable sources of energy available in Switzerland in order to be able to realistically produce synthetic fuels. An important question is also how renewable electricity is to be used in mobility: as a liquid fuel? As synthetic gas in gas-powered vehicles? As hydrogen in fuel cell vehicles? Or directly as a current in electromobiles? "Numerous technical, environmental and economic questions are still open, which we must examine in research and pilot projects. In particular, it must be shown that synthetic fuels have a positive overall enviornmental balance," says Philippe Müller, head of the SFOE section Cleantech. Synthetic fuels should not to lead to an erosion of efficiency targets in car traffic, emphasizes Müller: "We need efficient cars *and* clean fuel."

Cleaning the atmosphere of CO_2

Climeworks founders, Jan Wurzbacher and Christoph Gebald, developed the fundamentals of the novel CO_2 filter and associated processes to capture CO_2 ten years ago during their training at ETH Zurich, in collaboration with the Swiss Material Research Laboratory (Empa). A first generation demonstration device had a capture capacity of approx. 2 t of CO_2 / year. Climeworks' standard module, which is available today, captures 50 t of CO_2 / year. Climeworks believes that large-scale plants could separate large amounts of CO_2 from the air in the long term. If the gas is subsequently deposited in deep rock layers (instead of being used as a fuel), this removes net CO_2 from the atmosphere and thus counteracts climate change. "In order to reach the global climate goals, the directives of the Intergovernmental Panel on Climate Change are, that it is not enough to become CO_2-neutral by 2050. In addition, 10 billion tonnes of carbon dioxide must be removed from the atmosphere every year, equivalent to one third of today's global emissions from oil, gas and coal," says Jan Wurzbacher. In order to achieve these volumes, approximately 11 million Hinwil systems would be required, supplemented by the corresponding CO_2 storage facilities.

This would be a Herculean task; The magnitude, however, does not deter Jan Wurzbacher: "To filter out 1% of global CO_2 emissions from the air every year, we need about 750,000 ship containers filled with our modules. This is the number of containers that are dispatched to the Port of Shanghai within two weeks. The Climeworks Managing Director is convinced that the capture and deep storage of CO_2 within the framework of global economic performance is a viable option that will contribute to solving the climate problem.

CO_2 storage is technically feasible

How such an effort could be achieved politically and financially remains unclear. From a purely technical point of view, however, there are no insurmountable obstacles. "The capture and storage of CO_2 is technically feasible and safe," says Gunter Siddiqi, Director of the SFOE research program geoenergy. "Scenarios modeled by the federally owned Paul Scherrer Institute point out that the capture and storage of CO_2 can serve to achieve climate goals at the lowest possible investment costs. "From a global perspective, the promotion

WOOD AND PLANT COAL

In addition to Carbon Engineering (Squamish / Canada) and Global Thermostat (New York / USA), Climeworks is one of three companies in the world that holds the CO_2 capture from air and its recycling as a business model. The innovative approach has its critics. They point out that CO_2 is only present in low concentrations in the air and it would be more sensible to separate CO_2 where it occurs in a more concentrated form; for example, at the outlet of municipal waste incineration plants and other incineration plants where the CO_2 content is typically between 5 and 13%.

Critics also doubt that the energy required for CO_2 capture is used sensibly. On the one hand, there is the issue of the energy balance of the process, on the other hand that of the CO_2 balance, because without the long-term storage of the CO_2, the Climeworks process has only a neutral effect. "It is not decarbonization, but in the best case, climate neutral CO_2 is produced, but only if the energy used comes from renewable sources," wrote the Ökozentrum Langenbruck in a 2016 position paper. The institute promotes active carbon (also known as ‹plant coal›/ biochar or ‹woodcoal›) as further decarbonization strategy. This results from the conversion of wood and green waste as well as municipal solid waste by pyrolysis. The resulting activated carbon is used as a fertilizer and thus the carbon is bound in the soil over the long term. At the same time, the pyrolysis releases energy from which about 500 kWh of electricity and 2000 kWh of useful heat per ton of avoided CO_2 emissions can be obtained. BV

In combustion processes or, for example, the cement industry (Fig.), CO2 is produced in relatively high concentrations. Photo: Laurent Burst / LafargeHolcim

of renewable energies is not enough to achieve the targets, Siddiqi says. Still unclear at the moment, is where CO_2 can be stored in Switzerland over the long term. Saltwater-bearing rock formations of the Swiss Midlands in depths of around 1,000 - 2,500 meters are one possibility. For applications abroad, the primary considerations are to separate the CO_2 where it occurs in large quantities such as in waste incineration plants, cement plants and in the chemical industry.

↗ www.climeworks.com

↗ **Information** on the project is available from Dr. Yasmine Calisesi (yasmine.calisesi [at] bfe.admin.ch), Head of SFOE pilot and demonstration projects.

↗ For further **reports** on research, pilot, demonstration and flagship projects in the CCS area, please visit: www.bfe.admin.ch/cleantech/05761/05763/05782/index.html?lang=de&dossier_id=05135.

SFOE SUPPORTS PILOT, DEMONSTRATION AND FLAGSHIP PROJEKTS

Climeworks' CO_2 capture facility in Hinwil (ZH) is one of the pilot, demonstration and flagship projects through which the Swiss Federal Office of Energy (SFOE) is promoting the development of economical and rational energy technologies and is driving forward the use of renewable energies. The SFOE supports pilot, demonstration and flagship projects with 40% of allowable costs. Applications can be submitted at any time.

↗ **Informations**:
www.bfe.admin.ch/pilotdemonstration
www.bfe.admin.ch/leuchtturmprogramm

Author: Dr. Benedikt Vogel, commissioned by the Swiss Federal Office of Energy (SFOE)
Version: May 2017