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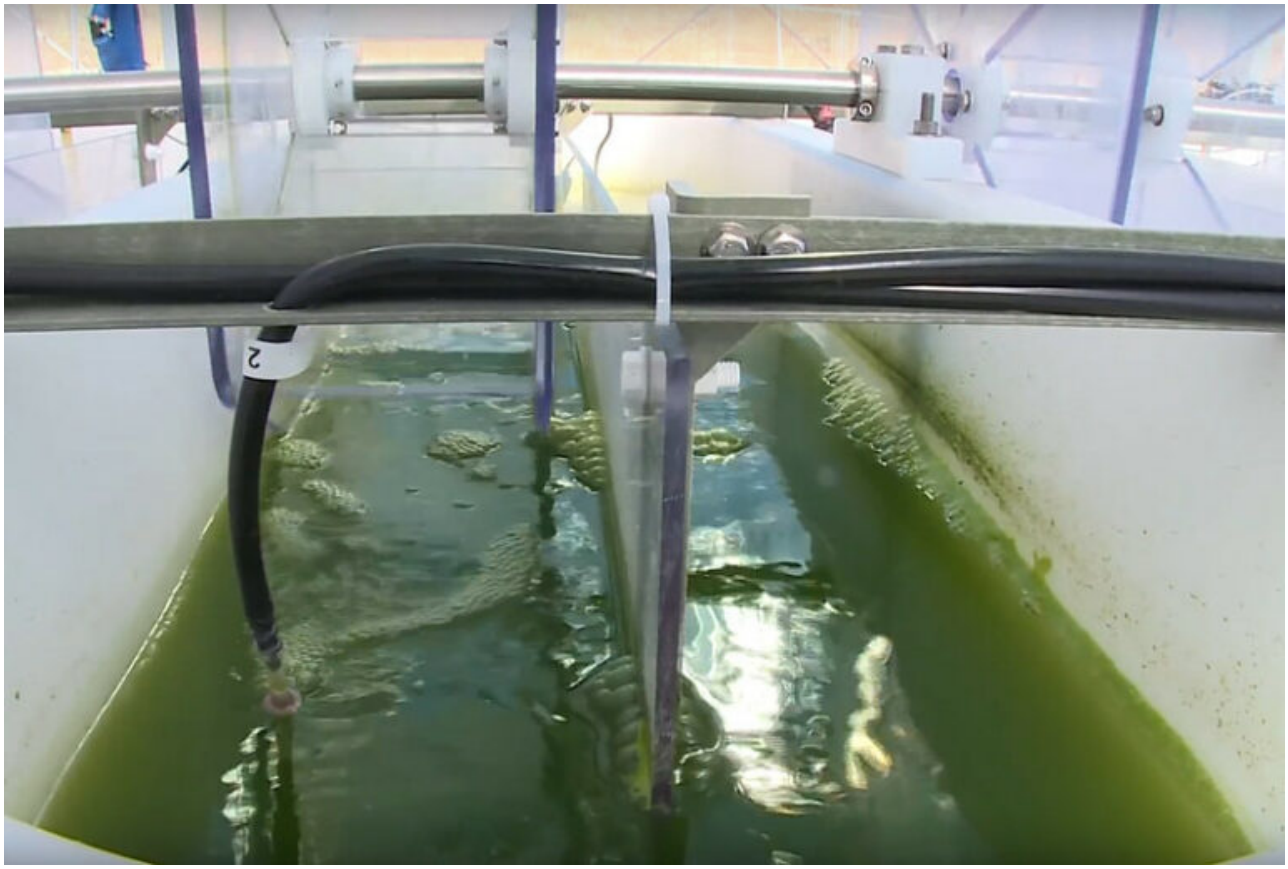

by Anja Chalmin

LARGE-SCALE WEATHER MODIFICATION PROGRAMS IN CHINA AND TRIALLING NEW TECHNOLOGIES IN THE UAE

Weather modification programs could cover 60 % of China's landmass by 2025

The Chinese government continues to implement its large-scale weather modification activities, which were announced in December 2020. By 2025, the program aims to cover more than six million square kilometres. This is more than 60 % of China's land area and almost twice the size of India. In addition to large-area cloud seeding, the program involves an extensive monitoring network, including monitoring vapour presence and movements in different atmospheric layers. This network will be further expanded and local press has reported that the Chinese Meteorological Administration plans to establish new weather centres. In the eastern Chinese province of Anhui, a centre will be built from which large unmanned aerial vehicles will operate. The centre will also conduct various experiments, including research on precipitation enhancement and cloud observation.[i]

New funding and program extension for the UAE cloud seeding program

Cloud seeding tests with unmanned aerial vehicles are also being carried out in the United Arab Emirates. The UAE is one of the driest countries in the world, with less than 100 millimetres of precipitation per year. The government's Program for Rain Enhancement Science was launched in 2015 with five million US dollars in funding. The program aims to explore new cloud seeding methods and technologies in order to increase precipitation by 20 %. To achieve this goal, the government also funds research projects outside the country and promotes exchange with research institutions worldwide. The cloud seeding activities and the research program are led by the National Centre of Meteorology (NCM). The research activities include modeling, experimental design and technical developments.

The UAE has been conducting weather modification activities since the 1980s. Today, NCM coordinates more than 60 networked weather stations, a radar network and five specialized aircrafts for cloud seeding operations. Their research program focuses on various cloud seeding agents, such as silver iodide, dry ice, potassium chloride and sodium chloride. In 2018, NCM established

the Emirates Weather Enhancement Factory, a facility to produce and trial seeding agents, including nano-coated materials. In 2019, airborne cloud seeding was conducted using salt crystals coated with a layer of titanium dioxide nanoparticles. The flights were performed over the northern and eastern parts of the country. The NCM has tested the use of drones for cloud seeding activities since 2017. The drones were used, for example, to study the possibility of inducing rain through electric charges. At the beginning of this year, the research programme was extended for another three years and new funding totalling 1.5 million US dollars was made available.

Israel ends 50 years of rain enhancement research due to lack of impact & high cost

Israel has decided to discontinue its rain enhancement project after more than 50 years of research. The reasons given for the move were that cloud seeding is not sufficiently effective, has not been proven by long-standing statistical evaluations and comes with high costs.

CURRENT RESEARCH TRENDS AND FUNDING IN ALGAE- AND PLANT-BASED PROJECTS

New funding for algae-based biofuel research in the USA

In the United States, the Department of Energy (US-DOE) announced up to twenty million US dollars in federal funding for algae-based research and development projects. The funding announcement is part of the US-DOE's Carbon Utilization Programme and is currently being tendered. The aim of the call for proposals is to increase the productivity of algae per cultivation area as a feedstock for processing biofuels and further products. The US-DOE has a history of research in producing biofuel from algae and conducted an algae-based biofuel research programme called the Aquatic Species Program from 1978 to 1996. The program collected and screened more than 3.000 strains of microalgae and trialed algae production in California and Hawaii. CO_2, captured at coal-fired power plants, was fed to the ponds. The project was abandoned on account of difficulties, including the high energy costs during algae production.

Scaling up algae biomass cultivation in Malaysia

The Singapore-based Chitose Bio Evolution Ltd. and the oil and gas company Eneos Holdings announced joint plans to scale algae biomass cultivation in Malaysia. The project partners aim to build a 200,000 m² algae production plant. The algae are to be harvested and dried and then processed into products such as algae fuel, chemicals and animal feed. The project partners are currently looking for donors in order to be able to implement the project from a financial point of view.

Researchers in California aim to grow algae based on heterotrophic growth

Researchers at the University of California, Riverside, aim to produce biofuels from algae. Unlike many other biofuel projects, they are not relying on autotrophic processes based on photosynthesis, but on heterotrophic algae growth which uses sugars or starches, for example, as an energy source for algae. The researchers state that the heterotrophic processes are much more effective compared to autotrophic processes. In this project algae growth will take place in the dark, but solar energy will be used to promote heterotrophic growth. Further details on the process will be revealed at the end of the project, later in the year, in the form of scientific publications.

Genetically modifying crop plants to absorb more CO_2 in the UK and USA

Researchers at the University of Edinburgh, UK, would like to enhance the CO_2-assimilation and growth of crop plants by genetically modifying the plant enzyme rubisco, an enzyme responsible for the transport of CO_2 in plants. In some algae there is a cell structure that can concentrate and supply the rubisco enzyme with more CO_2, thus, the supply of CO_2 for photosynthesis is improved. The cell structure is named pyrenoid. The researchers' goal is to use genetic manipulation to establish a pyrenoid-like structure in cells of crop plants in order to accelerate their CO_2 uptake and photosynthesis processes. The research is financed by the British Research and Innovation Biotechnology and Biological Sciences Research Council and the Leverhulme Trust.

DowDuPont is funding a similar approach in the United States. ZeaKal, a company based in San Diego, California, also aims to increase CO_2 absorption and photosynthesis rates in crop plants. The company is trying to change the plants by genetic manipulation so that they can absorb more CO_2. The rubisco enzyme also plays an important role here. With the financial support of DowDuPont, ZeaKal is trying to modify several crop plants, including soybean, maize, hemp, sugarcane, rice and forages and aims to commercialise the modified plants under the brand name PhotoSeed™.

NEW AND BIGGER PLANS FOR BECCS PROJECTS IN THE UNITED STATES

In February, the Summit Agricultural Group announced Summit Carbon Solutions – the *"world's largest"* Bioenergy project with Carbon Capture and Storage (BECCS). The project aims to build a pipeline for CO_2 transport, and plans to capture about ten million tons of CO_2 annually from 18 ethanol plants in Iowa, Minnesota and Dakota. The captured CO_2 will be pumped into central North Dakota to be stored underground. Each of the ethanol plants will install a CO_2 capture device, liquefy the CO_2, and receive a pipeline connection that will lead to the main pipeline. The Summit Agricultural Group hopes the BECCS project will be operational in 2024 and plans to extend the CO_2-pipeline to other CO_2-generating industries. The project costs are estimated at two billion US dollars. The exact location for the announced CO_2 injections in North Dakota has not yet been revealed, but some speculate that it will be located in the salt caves near Bismarck, North Dakota.

A month later, Schlumberger New Energy, Chevron Corp., Microsoft and Clean Energy Systems announced a front-end engineering and design study for yet another BECCS project in the US. The investment decision is scheduled to be made in 2022 and if the project goes ahead the BECCS plant will be located in the Mendota area, California. The goal is to convert agricultural residues from almond trees to electricity, while capturing CO_2. The captured CO_2 will be stored underground in a nearby geologic formation. For Schlumberger and Clean Energy Systems, this is the second attempt to implement a carbon capture and storage project in California. The last project, the Kimberlina (WestCarb) project, was cancelled in 2016 for financial reasons.

Energy intensive BECCS testing activities expand in Japan

In Japan, Toshiba Energy Systems & Solutions Corporation (Toshiba ESS) has embarked on a CO_2 capture project at an ethanol plant. The Sekisu Chemical Ethanol Plant is to be built in Kuji City, Iwate Prefecture. The CO_2 capture project is planned as a test site and is funded by the Japanese government through the Carbon Cycle Society Model Demonstration Project. Toshiba ESS plans to use the captured CO_2 to produce syngas. The post-combustion CO_2 capture technology that is being used was developed by Toshiba ESS at its own research and development center in Kawasaki City, Kanagawa Prefecture. The capture technology works with an amine-based CO_2 solvent. The solvent absorbs CO_2 at low temperature and releases it again at high temperature, thus the process involves a high energy input. Since 2009, Toshiba's capture technology is being tested at the Mikawa thermal power plant in Omuta City, Fukuoka Prefecture, at a biomass-fired unit fuelled with palm kernel shells. The Mikawa BECCS demonstration plant was recently upgraded to capture 0.18 million tons of CO_2 per year and is also government funded. The fate of the captured CO_2 at Mikawa has not yet been disclosed. Another Toshiba EES test site, in Saga City, captures CO_2 at the municipal waste incineration plant. The captured CO_2 is pumped to a nearby algae farm, the algae harvest is used for cosmetic products. Neither syngas nor cosmetic products are permanent carbon stores, because they are short-lived consumer products. As the CO_2 capture process is energy-intensive, it can be assumed that the whole process generates additional climate-relevant CO_2 instead of reducing it.

The Haru Oni Fuels project in Chile

The energy company AME, German Siemens Energy, German carmaker Porsche AG, petroleum company ENAP from Chile and energy company Enel from Italy announced the joint development and implementation of the Hari Oni Project to produce '*Highly Innovative Fuels*'. The companies plan to produce a synthetic fuel from captured CO_2 and water. The CO_2 is to be captured from direct air with wind energy, which is why the windy Magallanes province in Chile was selected as the project site though the exact location has not yet been disclosed. In addition to the direct air capture process, the splitting of water into oxygen and hydrogen is also very energy-intensive. In the next step, the captured CO_2 and hydrogen are processed into synthetic methanol, the feedstock for further processing into fuels. In 2022, the Hari Oni project plans to produce 0.75 million litres of methanol, part of which is to be processed into fuel. By 2026, the fuel production is to be expanded to 550 million litres. Porsche has been named as the primary customer for the fuel and has announced investments of 20 million euros for the project. The German Federal Ministry of Economics and Energy has pledged funding of eight million euros. The total costs during the pilot phase have been estimated at 38 million US dollars. According to a press report the direct air capture technology will be provided by Global Thermostat, but there is no official confirmation on this from the project partners so far. The project combines Direct Air Capture (DAC) and Carbon Capture Use and Storage (CCUS). Since fuel is a short-lived consumer good, the carbon is only trapped for a short time, i.e., it is wrong to speak of carbon storage.

In March, it was made public that the Chilean government was in talks with the Port of Rotterdam on a similar project. The two parties have signed a Memorandum of Understanding on the supply of hydrogen from Chile to the Netherlands.

The list of discontinued CCS projects in the United States grows longer

In September 2020, the US-DOE published a list of nine selected projects for cost-shared research and development under the

funding opportunity announcement (FOA) DE-FOA-0002187, *"Carbon Capture Research and Development (R&D): Engineering Scale Testing from Coal- and Natural Gas-Based Flue Gas and Initial Engineering Design for Industrial Sources"*. The National Energy Technology Laboratory (NETL) is responsible for managing the selected projects. Funding recipients are companies and public research institutions. The aim of the projects is to find and trial more effective and cheaper ways of capturing CO_2 from industrial flue gases. The tests are carried out in laboratories, at the National Carbon Capture Center in Wilsonville, Alabama, or under real-life conditions. In addition to liquid sorbents, membranes are also tested, along with other materials. The duration of the projects is up to five years. The total budget of the funding programme is fifty million US dollars, with up to thirteen million US dollars for individual projects.

A CCS project funded with 190 million US dollars of taxpayers' money was halted in May 2020 after only three and a half years. In January, the Petra Nova Carbon Capture project was abandoned indefinitely for financial reasons. The project was located at the W.A. Parish power plant, near Houston, Texas. The plant is operated by a 50/50 partnership between Petra Nova, a subsidiary of NRG Energy, and JX Nippon Oil & Gas Exploration Corp. The Petra Nova project has cost a total of one billion US dollars. Despite the high costs, the project captured less than 10 % of the power station's total emissions. One of ten production units, the coal-fired Unit 8, was retrofitted with a post-combustion CO_2 capture facility. The captured CO_2 was transported 82 kilometers via pipeline to the West Ranch oil field near Houston for enhanced oil recovery (EOR).

With this, the list of CCS projects that were ultimately discontinued has become once again somewhat longer. The list already includes, for example, the FutureGen project in Meredosia, Illinois. The list also includes the Texas Clean Energy Project, which received more than 800 million US dollars in public funding. All further projects can be found in the interactive world map on geoengineering, a tool of the Heinrich Böll Foundation and the ETC Group.

Another funding round for Direct Air Capture (DAC) in the United States

In March 2021, the US administration announced a new funding opportunity for DAC research. The funding opportunity announcement (FOA) DE-FOA-0002481 *"Materials and Chemical Sciences Research For Direct Air Capture Of Carbon Dioxide"* is open for proposals from research institutions, industry, and non-profit organizations. The research goals are comparable to the previous year's programme – DAC is to become cheaper and faster while consuming less energy. However, this time "Direct Ocean Capture" (DOC) proposals will also be considered, meaning projects that remove CO_2 from the ocean or other surface waters. At 24 million US dollars, the funding volume is slightly higher than in the previous year.

In 2020, the US administration has already provided more than twenty million US dollars in funding for DAC. Last September, the US-DOE published a list of eighteen selected project proposals for cost-shared research and development under the funding opportunity announcement (FOA) DE-FOA-0002188, *"Novel Research and Development for the Direct Capture of Carbon Dioxide from the Atmosphere"*. Managed by NETL, the projects have started their work over the last few months and will run for up to three years. All selected proposals aim to develop new or improve existing filters or sorbents to capture and release atmospheric CO_2. The grant recipients include Global Thermostat. The company intends to find a DAC system that works without interruption. Currently, Global Thermostat's chemical CO_2 sorbent has to be heated up to about 90°C every fifteen minutes so that the captured CO_2 can be released and the sorbent can be reused. The company InnoSepra LLC is also developing DAC technology and is looking to find CO_2 filters that consume less energy in the DAC process. Several projects attempt to make the DAC process more effective and at the same time less (energy) expensive by testing selective membranes or metal-organic frameworks as CO_2 filters.[ii]

Two DOC projects are currently already funded by the US-DOE's ARPA. In March, the California Institute of Technology began developing a device to remove CO_2 from ocean water. At the end of the two-year project, a DOC prototype is expected to be available. The project conducted by the Massachusetts Institute of Technology plans to develop a DOC approach based on nanoengineered surfaces and an electrode system. In addition to technical details, the two-year project will also assess the cost of the technology.

THE ROLE OF GEOENGINEERING IN FUTURE US POLICY

In addition to various funding programs for the further development of different geoengineering technologies, e.g., DAC, CCUS and CCS, geoengineering is also increasingly being promoted as a climate technology innovation.

In February, the White House formed a working group to set up ARPA-C, the Advanced Research Projects Agency – Climate. The new agency is to promote low-carbon energy technologies with a budget of one hundred million US dollars. Among other things, ARPA-C also aims to accelerate progress in CO_2 capture and storage.

The American Jobs Plan published this March lists funding opportunities for CCS, CCUS and DAC, e.g., carbon capture

demonstrations projects for large steel, cement, and chemical production plants as well as expanding the 45Q tax credit in order to *"accelerate responsible carbon capture deployment and ensure permanent storage"*. The Carbon Capture, Utilization, and Storage Tax Credit Amendments Act introduced in the Senate suggests the allocation of additional funds for DAC and CCUS projects. The bill proposes to provide a US$ 120 tax credit per ton of captured CO_2 to DAC projects if the captured CO_2 is injected into saline formations for storage. When the captured CO_2 is used for EOR, US$ 75 per ton in tax relief would be granted.

This new tax arrangement for DAC projects would financially benefit the world's largest DAC plant announced by Carbon Engineering and Oxy Low Carbon Ventures LLC, a subsidiary of the international gas and oil company Occidental Petroleum. The new DAC plant will be located on an Occidental oil field in the Permian Basin in Texas. Occidental is the largest oil producer in the Basin and has employed CO_2 – EOR since 2010. Until now, the CO_2 had to be transported via pipelines for EOR, this is no longer necessary with the new DAC plant, which is expected to capture one million tons of CO_2 per year. The captured CO_2 will be used for EOR. The new DAC plant and the announced tax relief for DAC have the following energetic and climatic consequences:

- corresponds to the equivalent of 681 million kg of oil and is sufficient to supply more than 100,000 US residents with electricity for a year.
- estimates that about 30 % of the CO_2 injected for EOR escapes directly back into the atmosphere.
- occur for various reasons, including earthquakes or other underground movements.

While the tax incentives are certainly profitable for Occidental, the benefits for the taxpayer and the climate are not apparent. It is therefore questionable, whether the extensive subsidies and tax reliefs are appropriate and unfortunate that investments in better solutions are being crowded out as a result.

Although the project consumes large amounts of energy and generates CO_2, Shopify has reserved *"10,000 tonnes of permanent carbon removal capacity"* and intends to market the amount of CO_2 as a carbon sequestration service. Shopify, an online commerce platform headquartered in Canada, aims to drive demand for carbon removal and to help the carbon removal industry grow.

FURTHER UPDATES

SCoPEx, the Stratospheric Controlled Perturbation Experiment, hosted at Harvard University through Harvard´s Solar Geoengineering Research Program, planned to field test Stratospheric Aerosol Injection (SAI) equipment in Sweden. The first field test flight intended to test the hardware. Later flights planned to release particles into the stratosphere. SCoPEx has in the past sought out various test sites in the United States for field trials, including high-altitude balloon providers in New Mexico and Arizona. In 2020, the test was moved to the **Swedish Space Corporation** near Kiruna in Sweden and was scheduled to be conducted in the summer of 2021. In March 2021 the test was cancelled due to widespread opposition from Saami Council, Swedish Civil Society and researchers. In an interview, a member of the SCoPEx team announced that the flight may now be moved back to the US or operated elsewhere.

The US-based DAC-developing company Global Thermostat and ExxonMobil extended the joint research and development agreement. The partners study the potential scalability of Global Thermostat's DAC technology. Press reported that "*ExxonMobil has provided the company with millions of dollars and a team of 10 ExxonMobil employees*".

C-Capture Ltd., a spin-off from the University of Leeds, UK, developed a CO_2 capture approach based on a solvent technology. C-Capture's 2021 funding round has raised £8 million in funding, provided by BP Ventures, Drax, IP Group and the British Business Bank's Future Fund.

The Australian Rainbow Bee Eater Pty Ltd developed a pyrolysis plant that produces synthetic gas and biochar. The plant is named ECHO2 and the only plant in operation is based at the Holla Fresh Bioenergy & Biochar Project in Tantanoola, South Australia. The feedstock for biochar production comes from agriculture and forest residues. The company claims to store carbon by producing biochar from organic residues. In 2021, Rainbow Bee Eater sold carbon credits to Microsoft (400 Mt) and Shopify.

The Artic Ice Project suggests covering Arctic ice with a layer of floating reflective material to slow down the melting of the ice and/or to restore Arctic ice. The proposed cover material is a reflective silica glass and consists mostly of silicon dioxide. The silica glass has the form of tiny glass spheres. Since ~2010, the project has carried out trials at various test sites. The project's largest test site is the Arctic North Meadow Lake near Utqiagvik (Barrow), in Alaska. Testing of various reflective materials on the shallow lake started during winter 2015/2016. New tests are currently being carried out on the lake, but the scope of the tests in terms of area size and materials tested is not known. This winter, tests are also being conducted on a small lake in

Minnesota. The exact location of Lake Elmo, a small man-made pond, is unknown. The Artic Ice Project's next goal is to perform tests on sea ice. The tests will be conducted at the University of Manitoba's Sea-ice Environmental Research Facility (SERF) in Winnipeg, Canada and in Svalbard, Norway. The exact period and scope of the tests is not known.

End notes:

[i] To date, the Sky River (Tianhe) Project has been the largest cloud seeding program in China: https://map.geoengineeringmonitor.org/wm/sky-river-(tianhe)-project

[ii] InnoSense LLC: https://map.geoengineeringmonitor.org/other/u-s-federal-funding-for-dac-innosense-llc, Rensselaer Polytechnic Institute https://map.geoengineeringmonitor.org/other/u-s-federal-funding-for-dac-rensselaer-polytechnic-institute, Palo Alto Research Center: https://map.geoengineeringmonitor.org/other/u-s-federal-funding-for-dac-palo-alto-research-center

FURTHER INFORMATION

Geoengineering Monitor: "What is geoengineering", https://www.geoengineeringmonitor.org/what-is-geoengineering/

ETC Group and Heinrich Böll Foundation, "Geoengineering Map", https://map.geoengineeringmonitor.org/

Geoengineering Monitor: Technical briefings provide background information on the above-mentioned geoengineering technologies, https://www.geoengineeringmonitor.org/technologies/