Geoengineering Map Update: Carbon markets are a major driver for geoengineering

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The Geoengineering Map Update summarises the latest developments on the Geoengineering Monitor Map highlighting new trends for civil society and climate justice movements to follow in their efforts to oppose geoengineering.

By Anja Chalmin

Critical Updates

- There is currently a new wave of government programmes, especially in the US, to investigate the effectiveness and environmental impact of geoengineering technologies. At the same time, there is a growing number of start-ups claiming that these technologies are safe and marketing them as a safe climate solution.
- The number of companies whose core business is selling carbon credits based on geoengineering technologies is also growing. Many of these companies are new to the market and have quickly made lucrative deals selling carbon credits to suppliers in carbon markets. Carbon markets such as Frontier and Carbon[x] are therefore likely to be a major driver of geoengineering. Environmental risks are neglected in these deals.
- Solar radiation management has been tested in several locations without scientific and/or public involvement and control.
- New technical geoengineering approaches are presented, including lunar dust to scatter sunlight and cool the Earth's climate, ionisation technology to influence the amount of precipitation, ocean fertilisation with slow-release fertiliser, and a machine intended to accelerate the growth of sea ice.

Recent updates in solar radiation management

Solar radiation management (SRM) attempts to reflect the sun's light and warmth back into space, but has no answer to the buildup of greenhouse gases in the Earth's atmosphere and would also not stop ocean acidification. Scientists at the Intergovernmental Panel on Climate Change (IPCC) have warned that "*solar radiation modification approaches, if they were to be implemented, introduce a widespread range of new risks to people and ecosystems, which are not well understood*". The SRM developments presented here include stratospheric aerosol injections (SAI) and marine cloud brightening (MCB). SAI aims to spray large quantities of particles into an upper layer of the atmosphere to act as a reflective barrier to incoming sunlight. MCB aims to create whiter clouds in order to reflect more sunlight back to space. Various actors have conducted or planned SRM experiments – in several cases without scientific and public participation and scrutiny, and economic interests are also a driving force.

Make Sunsets – USA

Make Sunsets recently started selling 'cooling credits' based on SAI. For this purpose, the US start-up company of Luke Iseman and Andrew Song fills weather balloons with helium and sulphur dioxide (SO_2). The balloons are supposed to rise into the stratosphere, burst there, release the SO_2 particles and "*create reflective clouds in the stratosphere*". The company launched the first balloons in Mexico. However, these flights were not authorized, and when they became public, the Mexican government banned further balloon launches in Mexico. As a result, Make Sunsets moved further experiments to the US. In February 2023, the company released three balloons at Rancho San Rafael Regional Park in Reno, Nevada, during an annual balloon festival. In a blog post, Luke Iseman claimed to have received "*OKs to launch from both the Federal Aviation Administration and Reno International Airport*" – according to The Verge, these claims could not be confirmed. On 21 April 2023, Make Sunsets planned to launch an unknown number of balloons filled with helium and SO_2 from Mission Dolores Park in San Francisco, California. The start-up failed to obtain a permit for this location and the launches ended up taking place in a car park on the Berkeley waterfront in San Francisco Bay. The company is looking for sites for further balloon launches and continues to market 'cooling credits'.

DEGREES initiative – SRM research around the globe

In early 2023, the UK-based DEGREES (**DE**veloping country **G**overnance, **RE**search and **E**valuation for **S**RM) initiative has again received donations from Open Philanthropy, established by Facebook co-founder Dustin Moskovitz.. Since 2018, the DEGREES has funded scientists in the Global South to model SRM approaches and analyse the potential impacts of SRM on their regions. In early 2023, the number of research teams increased to 26 teams. There are 24 ongoing projects in Argentina, Bangladesh, Benin (two teams), Brazil, Cameroon, Chile, Ghana, India, Indonesia / Indonesia (two teams), Iran, Jamaica, Kenya, Malaysia, Mali, Nigeria, Pakistan, Philippines, South Africa (three teams), Thailand and Uganda. Two projects completed were based in Bangladesh and Côte d'Ivoire. It is not known according to which criteria the DEGREES initiative selects the projects. All research teams model the deployment of SRM and focus on the impact of SRM on precipitation, temperature, spread of diseases, agriculture and/or marine biogeochemistry. No funding was given to researchers critical of geoengineering or to experts from other disciplines, such as political or social sciences. Where known, the SRM focus is on SAI, in Thailand SAI and MCB. Modelling is based on climate models developed in the Global North: GeoMIP (Geoengineering Model Intercomparison Project) and GLENS (Geoengineering Large Ensemble Project) – so the standards used in DECIMALS continue to be set by the dominant research community of the North. To date, the research teams have published 13 articles in peer-reviewed journals, with more than 25% of the participating authors coming from the USA or Europe.

SAI balloon flight in Aylesbury, UK

In March 2023, it was revealed that researchers in the UK had conducted two open-air experiments to test SRM devices and to release SO_2 into the Earth's stratosphere. In October 2021 and in September 2022, Andrew Lockley, an independent researcher, formerly of University College London, and European Astrotech Ltd, a provider of high-altitude balloon services, launched a high-altitude weather balloon filled with lifting gas (helium or hydrogen) and SO_2 into the stratosphere. The researchers named the project SATAN (Stratospheric Aerosol Transport and Nucleation). The launch site was at European Astrotech Ltd in Aylesbury, Buckinghamshire, in south-east England. The project was financed by anonymous private donations and by European Astrotech Ltd.

Yale University: SAI in the polar regions

In late 2022, a study was published by Wake Smith, Yale University, which examined the financial and logistical implications of SAI in the polar regions at or near 60 degrees north and south latitude. The study estimates the cost of SAI at US$ 11 billion per year and states that 175,000 flights per year would be required to inject enough SO_2 particles into the stratosphere to cause a 2°C temperature drop in the polar regions. During these flights, the aircraft would release their own emissions, which would contribute to global warming. The researchers state in their paper: "*an SAI program with global benefits that would entail deployment directly overhead of far less than 1% of the world's population and nearly none of its agriculture may prove an easier sell to a skeptical world than a full-on global deployment. Given its apparent feasibility and low cost, this scenario deserves further attention*". Yale University has been researching and commercializing geoengineering for more than a decade and has also looked at boreal deforestation, MCB, enhanced weathering and CO_2 capture.

NOAA's Earth's Radiation Budget program (USA)

For the current year, the US National Oceanic and Atmospheric Administration (NOAA) has been awarded $9.5 million for its Earth's Radiation Budget program. The program was launched by the US government in 2019 and aims to study processes in the stratosphere, including SAI and MCB. Since 2022, NOAA has been conducting research flights to study the stratosphere (Project SABRE).

SilverLining / Marine Cloud Brightening Project (USA)

The non-profit organisation SilverLining provides financial and advocacy support to the Marine Cloud Brightening Project (MCBP) and to MCB and SRM in general. In late 2022, as part of its Safe Climate Research Initiative, SilverLining awarded US$ 7 million to projects aimed at increasing the albedo of the Earth's atmosphere. In February 2023, SilverLining published a roadmap to advance SRM, including indoor and outdoor testing of MCB within the next five years. SilverLining's executive director, Kelly Wanser, was the executive director of the MCBP until about three years ago, and has made several attempts to implement an experimental MCB research plan outdoors since about 2010.

Centre of Climate Repair at Cambridge University (CCRC): New partners for MCB research (UK, the Netherlands)

In February 2023, the CCRC signed a multi-year agreement with the UK-based Refreeze the Arctic Foundation to fund research into MCB methods and started a six-year research project with the Climate Institute of Delft University of Technology in the Netherlands to research MCB. In March 2023, the CCRC was looking for research staff to develop, compare and model different water droplet generation systems. Back in 2021, the CCRC had announced plans to support the design and construction (and testing?) of a prototype for a MCB approach outlined by Stephen Salters of the University of Edinburgh.

Great Barrier Reef (GBR): MCB, fogging and shading (Australia)

The GBR Foundation's latest annual report reports "*proof of concept established for fogging and marine cloud brightening technique*". Researchers at the University of Sydney have been conducting MCB trials in the open ocean since March 2020. Since 2021, the exact time, duration, location, and size of the trial area have not yet been made public. Parts of the research results became known through a recent newspaper article: „*the wrong type of droplet could be a disaster: "different sized droplets affect the cloud in different ways – so if you make the wrong sized droplets you can actually make the cloud dimmer instead of brighter.*" The GBR Foundation reports, that the possibilities of misting or fogging over areas of the GBR are also investigated. "*As with cloud brightening, the aim is to reduce the amount of sunlight and heat that reaches the sea surface and the coral reefs beneath*."

Other recent studies on SAI and MCB (Russia, USA)

In Russia, the St. Petersburg Federal Research Center of the Russian Academy of Sciences is modelling the effect of SAI on solar radiation influx and temperature regime, and plans to undertake further modelling of the effect of SAI on water system productivity and rapid biological invasions.

Researchers at Indiana University in Bloomington, Indiana, are modelling whether MCB should be used in the Gulf of Mexico to reduce local temperatures.

Researchers at Princeton University, New Jersey, modelled MCB in the subtropics, focusing on the right size of the sea salt aerosol, and found that the right size for MCB likely depends on local conditions. The researchers also noted that MCB in the tropics can lead to significant changes outside the tropics, for example in the Arctic and Southern Ocean.

Updates on space-based SRM proposals

Space-based SRM aims to control the amount of incoming solar radiation. Most space-based proposals seek to reduce incoming solar radiation by placing a structure between the Sun and the Earth at the so-called Lagrange point L1. Lagrange point L1 is a point in space between the Earth and the Sun, about

1.5 million kilometres from the Earth, where the gravitational forces of the planet and the Sun virtually neutralise each other.

University of Luxembourg: new materials for space-based geoengineering

Researchers at the University of Luxembourg have investigated lighter and therefore cheaper materials for space-based geoengineering. The researchers propose membranes made of ultra-thin polymeric films and of silicon dioxide nanotubes.

University of Utah: space-based geoengineering with lunar dust

Researchers from the Department of Physics and Astronomy at the University of Utah propose using lunar dust to cool the Earth's climate by scattering sunlight. According to the researchers, about ten million tonnes of lunar dust would be needed to achieve a significant climate effect. The dust would be collected on the Moon and then shot into space and towards Earth using an electromagnetic cannon. The researchers point out that the large amount of dust is problematic, especially as it would probably need to be replaced every few days to maintain the effect. The idea of shading the Earth from space with dust is not new – researchers at the University of Glasgow have been exploring various concepts of space-based geoengineering for two decades, including placing a cloud of dust captured from near Earth asteroids.

Recent updates in weather modification

Weather modification (WM) refers to ground- and cloud-based technologies that seek to alter weather and precipitation, but not overall climate patterns. WM technologies, such as cloud seeding, attempts to increase or suppress precipitation, using aircraft, ground generators, and rockets. Because WM is thought to have only regional impacts, it is not often considered a form of geoengineering. However, WM technologies are important precursors of today's geoengineering technologies, e.g., there are overlaps with SRM technologies, which also aim to release particles into the atmosphere. WM technologies have been in use since the 1940s and have remained unchanged for a long time – particles such as silver iodide (AgI) and salt particles, which tend to attract water, are thought to accelerate the process of condensing water droplets in the sky. Meanwhile, other approaches are also attracting attention, especially cloud seeding based on charged ions or water particles.

Different attitudes to cloud seeding in the USA

After more than seventy years of cloud seeding, the **California** Energy Commission announced in March 2023 a research project to improve the efficiency of cloud seeding and to enhance the validation of the efficiency of cloud seeding.

In March 2023, it was decided that the U.S. Bureau of Reclamation would provide US$ 2.4 million for airborne and ground-based cloud seeding activities in the **Colorado** River basin. The seeding agent, AgI, is promoted as "*a naturally occurring compound that is safe and barely detectable when dispersed through cloud seeding*". According to the European Chemical Agency (ECHA), AgI is very toxic to aquatic life with long lasting effects and ECHA recommends avoiding spills or the release of AgI into the environment.

In March 2023, the **Illinois** General Assembly decreed that, effective immediately, no form of weather modification will be allowed in the state, including the seeding of clouds by aircraft or ground.

In March 2023, discussions concerning the **North Dakota** Cloud Modification Project (NDCMP) became known. The NDCMP has been conducted every year since 1960. Discussions are currently underway on whether to continue using state funds for the programme. In addition, there will be no future seeding over counties that no longer wish to participate in the seeding programme, e.g., Ward County and Burke County have left the programme.

The US Department of Agriculture's Aerial Application Technology Research Center in College Station, **Texas**, is conducting test flights over Texas to study cloud seeding. The research aims to make water droplets in clouds coalesce, making them large and heavy enough to rain down. This is to be achieved by introducing electrically charged water particles into the clouds. These particles have the opposite electrical charge as the water in the

clouds and are thus supposed to act as cloud condensation nuclei. The droplets in the clouds are attracted to the charged particles, coalesce, and form larger droplets. The water particles are charged by electrostatic nozzles, sprayed by aircraft below clouds, and carried into the clouds by updrafts.

United Arab Emirates Research Program for Rain Enhancement Science (UAEREP)

The UAEREP was announced in 2015 and entered its fifth funding round in 2023. The research program is led by the National Centre of Meteorology (NCM) and includes modelling, experimental design, technical developments, and cloud seeding activities.

Cloud seeding in China

China's Sky River project was proposed in 2015, developed since 2016 and planned for implementation in 2018. The programme aimed to channel up to ten billion cubic metres of additional rainfall into China's arid northern regions by implementing a large-scale cloud-seeding programme across the Tibetan Plateau, covering an area of ~ 1.6 million square kilometres with a massive WM network. By 2022, six weather satellites were to support the operation of tens of thousands of iodide burners. By 2018, more than 500 iodide burning chambers had been installed on alpine slopes in Tibet, Xinjiang and other areas. There has been no news on the implementation of the Sky River programme since 2019, but China continues to plan large-scale weather modification activities, aiming to cover an area of more than six million square kilometres by 2025. Scientists question and criticize large-scale weather modification activities because of the unknown local and transboundary impacts. In March 2023, the meteorological services of China and the UAE signed a Memorandum of Cooperation to promote cooperation in the field of weather modification and meteorological science.

WeatherTec AG: cloud seeding activities in Asia, Australia and Europe

WeatherTec AG aims to increase precipitation with its cloud ionisation technology. The company is headquartered in Switzerland and has offices in Germany and Jordan. WeatherTec's technology is based on charging aerosols in the atmosphere using a solar-powered emitter station on the ground. The emitted aerosols are supposed to transfer negative charges to the clouds. The charge differences are supposed to cause condensation processes in the clouds, leading to the growth of water droplets that then rain down. The technology has been deployed in Switzerland, Jordan, the United Arab Emirates and Australia.

Marine geoengineering – recent updates

Most attempts to deploy marine geoengineering technologies are shaped and driven by commercial interests. Currently, companies are trying to commercialise ocean fertilisation, ocean alkalinity enhancement (OAE) and artificial upwelling. While start-ups are trying to commercialise marine geoengineering approaches as a safe climate solution, government programmes are simultaneously launching to study the effectiveness and environmental impact of the same technologies. A selection of the most recent developments is presented here.

Climate Arks, UK, aims to commercialise ocean fertilisation

Climate Arks Ltd, based in London, plans to commercialise ocean fertilisation using floating structures. The structures will slowly release nutrients for ocean fertilisation, which will be released into the ocean by wind and wave energy over a period of up to 20 years. Among the founders of Climate Arks is Franz Oeste, the developer and co-patent-holder of the iron salt aerosol (ISA) method.

Seafields Solutions Ltd announces trial in UK waters

The British company Seafields aims to cultivate sargassum seaweed in the open sea and use artificial upwelling to provide the seaweed with nutrients. The harvested seaweed would be pressed into bales and sunk into the deep sea. In March 2023, Seafields announced an additional artificial upwelling trial to take place in the UK in 2023. The trial was announced after Seafields received a £ 0.25 million funding award from Innovate UK, the

UK's national innovation agency. It "*will take place this year in the UK from possible sites in Northumberland or Devon*". The company also announced that its "*ultimate vision is to build a farm that is 0.02% of the planet's surface, the size of Portugal, in the south Atlantic sub-tropical gyre, by 2032*". To finance such projects, Seafields plans to sell carbon credits for the sunken bales and sargassum-derived materials.

Sargassum trials off Gran Canaria planned by MACROCARBON SL

MACROCARBON SL, a spin-off of the Alfred Wegener Institute for Polar and Marine Research (AWI), was founded in March 2023 with Dr Mar Fernández Méndez as managing director. The company plans to harvest sargassum and process it into raw materials for the chemical industry or as biofuel. MACROCARBON is expected to capture 100 million tonnes of carbon by 2040 and one gigatonne by 2050. Las Palmas, Gran Canaria, was chosen as the company's headquarters partly because of the sargassum that thrives in nearby waters and the high sea conditions. Seafields and CarbonWave plan to invest in MACROCARBON SL.

New ocean fertilisation experiments off the Indian coast

India's National Institute of Oceanography (NIO) in Goa has announced further open ocean fertilisation experiments for spring 2023. In 2022, NIO, under the guidance of the Centre of Climate Repair at Cambridge, conducted ocean fertilisation experiments with buoyant flakes in the Indian Ocean. The open ocean trial was conducted in mesocosms in the Arabian Sea, 220 nautical miles outside India's Exclusive Economic Zone.

Ebb Carbon, California: delays in commissioning

The company Ebb Carbon seeks to commercialise an electrochemical process for removing acid from seawater, with the goal of fixing more CO_2 in the form of bicarbonate in the oceans and reducing ocean acidification. The first Ebb Carbon system was due to come online in 2022 – this target has been postponed indefinitely for reasons that are not public.

Canadian Planetary Technology plans to dump $Mg(OH)_2$ in St Ives Bay, Cornwall, UK

Halifax-based Planetary Technology Inc. is developing and commercialising a technology described as ocean alkalinity enhancement (OAE), which aims to mimic natural weathering and increase the alkalinity of the ocean. In September 2022, Planetary conducted an initial OAE trial in St Ives Bay, Cornwall, as part of the UK Department for Business, Energy & Industrial Strategy's (BEIS) Direct Air Capture and Greenhouse Gas Removal programme. Planetary has been selected for this programme in 2021. This initial trial will be followed by a demonstration project in spring 2023, which aims to see up to 300 tonnes of magnesium hydroxide ($Mg(OH)_2$) dumped into the bay. The $Mg(OH)_2$ is to be mixed with wastewater at a treatment plant and discharged into the bay via sewers. According to press reports, the Environment Agency has given its approval. However, the press also reports growing concerns about the plans in Cornwall, such as possible unintended negative side effects. In the meantime, there have been several protests against the project. Planetary claims that OAE is safe and that the CO_2 will be removed in the long term. However, the company has commercial interests, including selling CO_2 credits to Shopify.

Planetary Technologies was founded with the goal "*to take one gigaton of carbon out of the atmosphere every year starting from 2035.*" In early 2023, the target was postponed to 2045 without giving any reasons.

In February 2023, researchers from the University of Hamburg commented on OAE as follows "*The real-world application of OAE, however, remains unclear as most basic assumptions are untested. […] One of the concerns is the stability of alkalinity when added to seawater.*"

Results of the pan-European research project OceanNETs (Ocean-based Negative Emission Technologies)

OceanNETs objective is to investigate the feasibility and impact of ocean-based approaches to remove CO_2 from the atmosphere. Approaches being investigated include marine enhanced weathering and biomass sinking. These two studies share the results of the OceanNETs research project.

J. Wu, et al. on the risks of **ocean biomass sinking** in Earth System Dynamics, February 2023: "*Our results suggest that open-ocean mariculture and sinking (MOS) has, theoretically, considerable CDR potential as an ocean-based CDR method. However, our simulations also suggest that such large-scale deployment of MOS would have substantial side effects on marine ecosystems and biogeochemistry, up to a reorganization of food webs over large parts of the ocean.*"

S. Foteinis, et al. on energy consumption and potential pollutant input from **coastal enhanced weathering (CEW)** in Environ. Sci. Technol., April 2023: "*When CEW's full environmental profile was considered, it was identified that fossil fuel-dependent electricity for olivine comminution is the main environmental hotspot, followed by nickel releases, which may have a large impact on marine ecotoxicity. Results were also sensitive to transportation means and distance. Renewable energy and low-nickel olivine can minimize CEW's carbon and environmental profile.*"

US-DOE announced US$ 45 million to validate marine CO_2 removal

In February 2023, the US Department of Energy (US-DOE) announced the Sensing Exports of Anthropogenic Carbon Through Ocean Observation (SEA CO2) program. The program is funded with US$ 45 million, will be implemented by the Advanced Research Projects Agency-Energy (ARPA-E) and aims to promote sensor technology and modelling for ocean carbon transport and storage on a regional scale.

National Oceanic and Atmospheric Administration (NOAA) funding programme on marine CO_2 removal

February 2023 was the application deadline for a marine CO_2 removal research programme announced by NOAA in November 2022 as part of its Ocean Acidification Programme. 'Marine Carbon Dioxide Removal (mCDR): Research and Development for Assessing Large Scale Carbon Removal and Local Scale Ocean Acidification Mitigation' aims to gain a better understanding of mCDR, particularly the extent and permanence of CO_2 removal, potential co-benefits, and potential risks. The total estimated budget for the programme is US$ 30 million.

Additional Ventures & Ocean Visions: Ocean Alkalinity Enhancement (OAE) research award

In 2022, the organisation Additional Ventures launched its OAE research award and invited applications for the R&D programme. The programme aims to "*assess whether OAE can safely, permanently, and cost-effectively sequester atmospheric CO_2 at scale*". Applications are currently being assessed and funding decisions are expected in 2023. Additional Ventures is supported by the organisation Ocean Visions in the selection of OAE grant applications.

Solid Carbon: Cascadia Basin open-ocean demonstration seeks funding

The project 'Solid Carbon: A Climate Mitigation Partnership Advancing Stable Negative Emissions' is a four-year research partnership led by Ocean Networks Canada (ONC), an ocean observing facility hosted by the University of Victoria. The research partnership plans to develop, design, and test a floating platform capable of capturing CO_2 from ambient air and injecting it below the seafloor for carbon mineralisation.

In 2023, it was announced that Solid Carbon is currently seeking partners to fund an open ocean demonstration in the Cascadia Basin off the coast of Vancouver Island, British Colombia, and that the demonstration area will be located at a water depth of approximately 2,700 meters.

New trend: alkalinity enhancement in rivers (Canada, Denmark, UK, USA)

Researchers at Dalhousie University, Halifax, Canada, and CarbonRun Carbon Dioxide Removal Ltd, Halifax, are proposing to implement alkalinity enhancement in rivers. The research project has modelled OAE and conducted demonstration tests in rivers in Nova Scotia, Canada.

Researchers at the University of Denmark and Heriot-Watt University, Edinburgh, UK, tested the addition of alkaline minerals to rivers in a laboratory environment.

Researchers at the University of Rhode Island, Narragansett, USA, have hypothesised the removal of CO_2 by adding alkalinity to the Amazon watershed.

Welsh Real Ice Development Company Ltd aims to test a re-icing device in a polar region

The startup has designed a machine, powered by hydrogen and/or renewable energy, that draws water from below the ice surface to create a pond of water on the ice surface that refreezes. With this approach, Real Ice aims to accelerate the growth of sea ice during the cold months. The company aims to test its device in the field in 2023 and 2024, with prototype testing planned for 2025. "*Within the next four years, Real Ice is aiming to generate enough sea ice to cover one entire bay in the Arctic. After this, it hopes to collaborate and partner with governments, large industrial partners and local communities to expand the use of the technology and improve on the deployment approach while scaling*."

Geoengineering with algae: new projects and funding opportunities

There are new subsidies for companies planning to produce biofuels or other algae-based products to 'capture' CO_2. It should be noted that algae cultivation in closed systems is energy intensive, e.g., light and fertiliser are needed. The conversion process, e.g., into biofuels, is also energy intensive. When products such as biofuels are consumed, the CO_2 they contain is released back into the atmosphere. Additional CO_2 may also be generated during the production process. Some of the current developments in the field of macro- and microalgae production for CO_2 capture are described here. There are many other projects with similar plans.

New federal funding in the US

In March 2023, the US Department of Energy (US-DOE) announced federal funding of up to US$ 10 million for algae-based research and development. The funding 'Reducing Agricultural Carbon Intensity and Protecting Algal Crops (RACIPAC, DE-FOA-0002910)' aims to support the cultivation and protection of algae crops as "*an abundant and renewable biofuel source vulnerable to loss from predation, organic competition, and pest infestation*". The topic area supports "*DOE's "Sustainable Aviation Fuel Grand Challenge" goal of increasing the current production of 35 billion gallons annually to reach 100% of U.S. aviation fuel demand by 2050*."

Neste algae-to-fuel plant (Finland, Spain)

In February 2023, Finnish company Neste announced plans to set up an algae pilot plant in Spain to demonstrate the cultivation and processing of algae into biofuels. The project is currently in the planning phase and no final investment decision has been made.

Algiecel raised funds to further develop its technology (Denmark)

In January 2023, Denmark's Algieciel AppS raised € 1.3 million in a financing round to further develop a technology that aims to store CO_2 emissions in microalgal biomass. The startup has developed a photobioreactor that fits into a shipping container and seeks to make the container available to industrial emitters. A first pilot photobioreactor was completed at the Danish Technological Institute (DTI) in late 2022.

Amazon funded algae project: North Sea Farm 1 (the Netherlands)

North Sea Farm 1 was announced in February 2023 and is expected to be operational by the end of this year. The project will be part of a wind farm off the coast of the Netherlands and aims to test and improve seaweed farming methods, while exploring the potential for CO_2 capture. The project will be led by North Sea Farmers in

collaboration with scientists from Plymouth Marine Laboratory. The project is funded with € 1.5 million through Amazon's Right Now Climate Fund.

ExxonMobil stopped funding Viridos, but Bill Gates keeps it going

The company Viridos is researching and developing algae-based biofuels since 2009, and ExxonMobil became Viridos' main funder and research partner. In December 2022, ExxonMobil stopped funding this research focus, in part because the algae strains did not produce enough lipids for biofuel production. In March 2023, Viridos raised US$ 25 million in a financing round led by the Bill Gates Breakthrough Energy Fund with Chevron and United Airlines, and can continue to operate on this basis.

Running Tide: sale of carbon credits to Microsoft and plans for deployment in the Arctic Ocean and the Canadian Pacific

US-based Running Tide Technologies Inc. plans to grow seaweed such as kelp in large quantities in the open ocean and then sink it to a depth of 1,000 metres on the ocean floor – aiming to capture and store carbon. The approach involves ropes wrapped with kelp seeds being released into the water, where they grow for several months. The kelp is attached to biodegradable buoys made from forestry waste and coated with calcium carbonate, aiming to increase the alkalinity of the ocean. After ~ three months, the kelp plants are supposed to become too heavy and sink. In March 2023, Running Tide has sold 12,000 tonnes of CO_2 removal to Microsoft and has two years to fulfil the agreement. The contract with Microsoft is likely to be fulfilled off the coast of Iceland, where Running Tide plans to sink large quantities of seaweed over the next four years along with buoys, which are theoretically compostable. It was recently announced that the project will be carried out in Iceland's Hvalfjörður Fjord.

In early 2023, Running Tide announced plans to conduct sinking seaweed experiments with researchers from the Alfred Wegener Institute Helmholtz Center for Polar and Marine Research (AWI) and in partnership with Ocean Networks Canada (ONC). The collaboration with AWI will take place in the Fram Strait area of the Arctic Ocean and aims to observe if and how different species of algae (kelp, sargassum and ulva) and the buoys used to float the seaweed decompose at a depth of 4,000 metres. The partnership with ONC plans to conduct a sinking seaweed and buoys substrate experiment in the Cascadia Basin in the Canadian Pacific. The project aims to deploy 500 tonnes to 5,000 tonnes of buoys in offshore waters every two to five weeks throughout the year. Scientists have raised concerns about the potential impact on marine ecosystems.

Carbon markets are a major driver for enhanced weathering on farmland

There is a growing number of companies that apply finely ground rock to agricultural land for enhanced weathering, but whose core business is selling carbon credits. Some of these companies are featured here – they are all new to the market and have quickly made lucrative deals selling carbon credits to vendors on the carbon markets. It can be assumed that the carbon markets, like Frontier and Carbon^{x}, are a major driver for geoengineering. These practices come with risks to the environment and soil quality, such as the accumulation of heavy metals, but potential harms are left out of the deals.

Lithos Carbon is one of the largest suppliers of carbon credits to Frontier

San Francisco-based Lithos Carbon was founded in March 2022 and claims to have spread over 11,000 tonnes of finely crushed basalt rock over 1,000 acres of U.S. farmland for enhanced weathering by October 2022. Lithos Carbon's core business is selling carbon credits and the company has secured over US$ 6 million in a funding round. Lithos is one of the largest suppliers of carbon credits to Frontier, a carbon market led by Stripe, Shopify and others. In 2022, Frontier purchased 640 tonnes of "CO_2 removal" from Lithos. By October 2023, Lithos plans "*to have over 5,000 new acres live*".

Carbon^{x} purchased over € 1 million for “permanent carbon removal” (France)

Carbon^{x} is a recently formed “*permanent carbon removal*” seller based in Paris, France. In March 2023, Carbon^{x} announced purchases over € 1 million from five projects, including CarbonCapture (direct air capture), Sonnenerde (biochar), Vesta (coastal enhanced weathering), UNDO (enhanced weathering), and InPlanet (enhanced weathering). Among the Carbon^{x} criteria: “*The carbon must be removed and stored for at least multiple centuries, with low reversal risk.*” This is not guaranteed for any of these projects recently purchased by Carbon^{x}.

UNDO sells carbon credits to Carbon^{x} and Microsoft (UK, USA)

UNDO Carbon Ltd., founded in 2022 and based in Scotland, UK, spreads finely crushed basalt rock on agricultural land for enhanced weathering and works with sites in the UK and USA. In March 2023, UNDO sold carbon credits to Carbon^{x}. In April 2023, UNDO announced a contract with Microsoft to spread 25,000 tonnes of crushed basalt rock on agricultural land in the UK.

Germany’s InPlanet GmbH spreads rock dust in Brazil and sells carbon credits to Carbon^{x} and Frontier

InPlanet spreads finely crushed silicate rock from mines for enhanced weathering on agricultural land in south-east Brazil. By March 2023, InPlanet says it has applied more than 1,500 tonnes of crushed rock to eleven farms. The company’s core business is the sale of carbon credits. In March 2023, InPlanet sold carbon credits to Carbon^{x} and in December 2022, the company signed an agreement with Frontier for carbon removal in Brazil. In January 2023, InPlanet raised € 1.2 million in a funding round. According to InPlanet the “*carbon will be locked away for 1000+ years*” and there are “*no negative side effects to the environment*”. However, mining products can contain substances with harmful effects, such as heavy metals. Heavy metals such as copper and nickel can accumulate in agricultural soils through increased weathering. InPlanet recommends enhanced weathering for tropical regions with soils poor in nutrients. This is in contradiction to findings, which suggest that weathering is highly sensitive to temperature with optimum results at temperatures between 10°C and 15°C, since both low and high temperatures limit weathering.

Recent developments in direct air capture (DAC)

US-DOE funding: American Made DAC Prizes

In December 2022, the US-DOE launched the American-Made DAC prizes. The awards are designed to advance carbon removal technologies. Up to US$ 3.7 million in prizes will be awarded to regional teams that submit plans to accelerate DAC.

US-DOE funding: development of regional DAC hubs

In December 2022, the US-DOE announced funding of more than US$ 3.5 billion for the development of four domestic regional DAC hubs, each of which will demonstrate commercial-scale DAC technology that has the potential to capture at least one million tonnes of CO_2 from the atmosphere annually and permanently store that CO_2 in a geological formation or by conversion into products (CCUS). In March 2023, it was announced that Swiss DAC company Climeworks, Californian DAC company Heirloom and Battelle had teamed up to bid for US$ 500 million in funding.

Heirloom: first pilot site in the U.S.

In February 2023, start-up company Heirloom announced its first pilot site for its DAC technology, built near San Francisco. Some of the CO_2 captured there will be supplied to CarbonCure Technologies Inc, a company that injects captured CO_2 into concrete.

Occidental Petroleum: DAC facility in western Texas, USA

In January 2023, a subsidiary of Occidental Petroleum, an international oil and gas production corporation, announced plans to build the world's largest facility to capture CO_2 from the air in the oil and gas fields of west Texas. The DAC plant is scheduled to come on stream in 2024 and capture up to 0.5 million tonnes of CO_2 per year, later expanding to one million tonnes of CO_2 per year.

CO_2 mineralisation project in UAE

In January 2023, the Omani start-up company 44.01 announced plans to expand into the UAE with a mineralisation pilot project in Fujairah, in the north-east of the UAE. The project will be carried out in partnership with Abu Dhabi National Oil Company (ADNOC), Fujairah Natural Resources Corporation (FNRC), and renewable energy company Abu Dhabi Future Energy Company (Masdar).

Removr secures government grant (Norway)

In February 2023, Norwegian DAC technology company Removr announced that it has received NOK 36.3 million (USD 3.51 million) in government funding to develop an industrial pilot project at the Mongstadt Technology Centre in Norway. The pilot project is expected to capture 300 tonnes of CO_2 from the air annually starting in 2024.

Recent developments in carbon capture and storage (CCS) and Bioenergy with CCS (BECCS)

Europe's Net-Zero Industry Act

In March 2023, the EU Commission announced its intention to create capacity for the underground storage of 50 million tonnes of CO_2 annually by 2030.

U.S. Department of Energy (US-DOE) funding announcement

In January 2023, the US-DOE announced US$ 131 million in funding for CO_2 capture from power plants and industrial facilities, direct air capture, and the assessment of potential CO_2 storage sites. The call will support 33 research and development projects, including the following:

- R&D project to advance the wide-scale deployment of CO_2 capture and storage technologies at the University of Wyoming (US$ 10.5 million);
- Three R&D projects to explore potential geological storage sites for captured CO_2, CO_2 transport, injection and monitoring of the geological sites; two carbon capture, use and storage projects in the building sector (US$ 2.7 million);
- Up to US$ 820 million for up to 10 projects for large-scale testing of CO_2 capture technologies;
- Up to US$ 1.7 billion for about six projects to demonstrate commercial-scale CO_2 capture technologies in combination with infrastructure for transport and geological storage of CO_2. The programme will focus on funding demonstration projects that can be easily replicated, e.g., in power plants and other large industrial sources of CO_2 emissions such as cement, pulp and paper, iron and steel.

New funding for Svante Inc (Canada)

In December 2015, the company Svante, a developer of CO_2 capture technology, raised US$ 318 million, which will be used to accelerate the manufacturing of Svante's technology. The fundraising round was led by oil and natural gas corporation Chevron U.S.A. Inc. with other participants including global investment company Temasek, OGCI Climate Investments, oil company Delek US and real estate company Hesta AG, and new investors, 3M Ventures (the venture capital arm of 3M Company), Full Circle Capital, GE Vernova, Japan Energy Fund, Liberty Media, M&G Catalyst, Samsung Ventures, TechEnergy Ventures and United Airlines Ventures.

Heartland Greenway: BECCS project faces resistance, USA

The company Navigator CO_2 Ventures seeks to provide CCS solutions. Its Heartland Greenway project aims to combine biomass with CCS. The project involves the construction of a 1,300 miles pipeline network to pump captured and liquefied CO_2 from more than 30 ethanol or other industrial plants to central Illinois for underground injection. In July 2022, Navigator applied to the Illinois Commerce Commission (ICC) for a permit to build a carbon pipeline through 13 counties. In January 2023, Navigator withdrew the application. In February 2023, Navigator submitted an updated application to the ICC that added 42 miles to the proposed pipeline. According to Reuters, the project is struggling to secure a site to store the captured CO_2, as local residents fear that the underground storage could leak. There are also concerns along the proposed pipeline route about possible pipeline leaks and damage to agricultural land from pipeline construction. As Navigator's first proposed geological storage site could not be secured, a second site in a neighbouring county is being considered.

According to a local radio station in central Illinois, the new pipeline "*would start south of Springfield and run 42 miles south to a "termination and delivery point in Montgomery County for sequestration areas being developed" by the company*".

Heidelberg Cement, Heidelberg Materials (Belgium, USA)

In January 2023, Heidelberg Materials announced plans to build a CO_2 capture facility at its Antoing cement plant in Belgium. The plant is expected to capture 0.8 million tonnes of CO_2 per year when in full operation.

In Mitchell, Indiana, the US-DOE is funding a FEED study for a two million tonne per year CO_2 capture facility at Heidelberg Cement's US subsidiary Lehigh Hanson.

CO_2 storage licences in the North Sea

The Norwegian Ministry of Petroleum and Energy offered exploration licences for CO_2 storage in two areas Norwegian continental shelf in the North Sea to four companies in March 2023. The companies are Aker BP, OMV Norway, Wintershall Dea Norway and Stella Maris CCS.

Plans for a CCS project in Kenya

In northern Kenya, a CCS pilot project is to begin injecting CO_2 more than 400 metres underground into volcanic rock, where the CO_2 is expected to mineralise. The project is being planned by Cella Mineral Storage, a start-up working with a Kenyan geothermal company.

Plans for a CCS project in Libya

In January 2023, Italy's energy company Eni and the National Oil Corporation of Libya agreed to develop a large natural gas project with CCS. The final investment decision is expected in 2023.

Project Greensand (Denmark)

In March 2023, project Greensand was inaugurated under the management of the British chemical company Ineos and the German gas and oil producer Wintershall Dea. By 2030, the project plans to inject up to eight million tonnes of CO_2 1,800 metres beneath the North Sea every year.

UK funding commitment

In March 2023, the UK government pledged up to £ 20 billion (US$ 24 billion) over the next two decades for local carbon capture and storage projects that pump captured CO_2 underground.

Blue hydrogen with CCS in Japan

The Japanese exploration company Inpex Corporation will use a CO_2 capture technology developed by German chemical corporation BASF to produce blue hydrogen and ammonia from locally produced natural gas as part of

the “Kashiwazaki Clean Hydrogen/Ammonia” project. The captured CO_2 will be injected into regional gas fields. The project is financed by the Japanese government organisation New Energy and Industrial Technology Development Organization.

Explore the Geoengineering Monitor Map for more details about these new developments!