Taking Back Emissions

Using the market to capture carbon dioxide from the atmosphere

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The policy paper summarised in 10 points

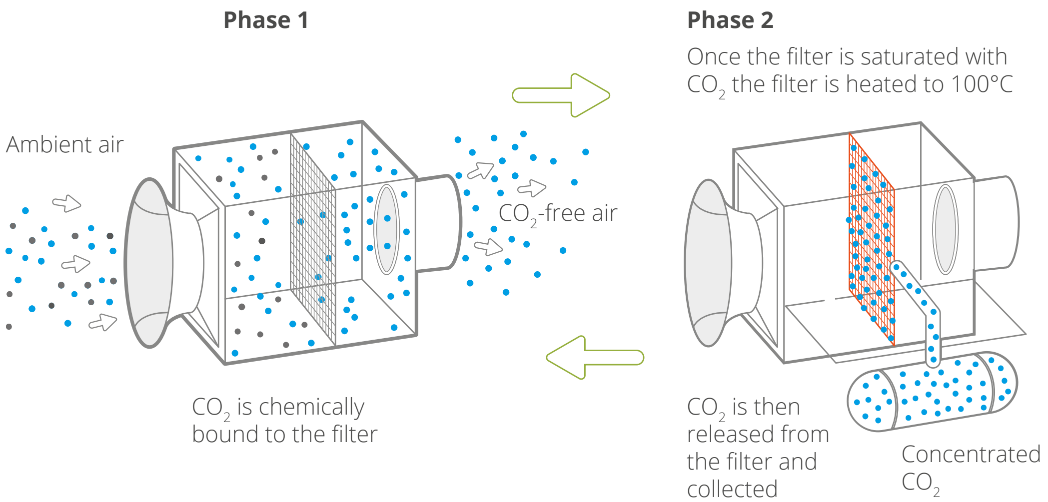
1. Direct air capture (DAC) is a technology that enables carbon dioxide emissions to be removed from the atmosphere. As of May 2019, there were 11 DAC plants installed around the world.
2. After the carbon dioxide has been captured, it can be stored underground in geological formations or used, for example, for fuel or in greenhouses to increase growth production.
3. When direct air capture is used together with carbon storage, the flow of carbon is from the atmosphere to the ground, resulting in a decrease in the concentration of carbon dioxide in the atmosphere.
4. It is very likely that carbon dioxide removal will be needed to reach the Paris agreement goals.
5. When direct air capture is combined with carbon utilisation, the flow of carbon is from the atmosphere to a product and then back to the atmosphere, depending on the sequestration time in the product. The result is that the concentration of carbon dioxide in the atmosphere neither increases nor decreases.
6. One disadvantage of DAC is that it is energy-consuming. Its development should, therefore, go hand in hand with the development of low-carbon energy production.
7. DAC with carbon storage is one of the two carbon-dioxide removal technologies illustrated in the scenarios of the European Commission's in-depth analysis of its long-term strategic vision for a climate-neutral economy by 2050. However, there has been less EU action on carbon dioxide removal.
8. A Liberal environmental policy should be technology-neutral. Instead of supporting certain chosen technologies, policymakers should create conditions for a market with negative emissions. Companies can then compete on providing the most effective method of reducing carbon dioxide.
9. One solution could be to include carbon dioxide removal technologies in the EU's emissions-trading system. The extent to which climate goals are achieved through emissions reductions or carbon dioxide removal technologies would be up to the market to decide, as long as emissions are still decreasing.
10. Tax incentives, such as tax credits for companies that remove carbon dioxide, as in the US, is another option to stimulate interest around carbon dioxide removal in Europe.

What is direct air capture (DAC)?

Direct air capture (DAC) is a technology that uses chemicals to capture carbon dioxide from the atmosphere. The process consists of two steps. The first is air is sent into a facility and meets a material that chemically binds carbon dioxide. The carbon dioxide binding material can be in solid or liquid form. The next step is that energy, for example in the form of heat, is used to separate the carbon dioxide from the chemicals that bind it. The concentrated carbon dioxide can then be stored or used as a resource.

The technology for capturing carbon dioxide from the air is not new. It has been used on spaceflights and submarines since the 1950s. But it is only since the turn of this century that the technology has begun to be recognised as a tool to combat climate change. There are, according to a report released in May 2019, 11 DAC plants installed around the world.[1]

Example of DAC-technology



Source: Climeworks

After the carbon dioxide has been captured, it can be stored underground in geological formations or used in several ways. The consequences from a climate point of view will differ depending if the carbon dioxide is stored or used.

Capturing carbon dioxide from the atmosphere and then storing it is a tool for reducing the concentration of carbon dioxide in the atmosphere. If the captured carbon dioxide is converted into valuable products, such as fuels, construction materials or plastics, then DAC could help replace fossil fuels.

DAC is one of several technologies for carbon dioxide removal, other examples are forestation and bio energy with carbon capture and storage (BECCS). Carbon dioxide removal technologies are also known as negative emission technologies.

In this paper, the term DAC refers to the process where carbon is captured from the atmosphere regardless of whether the carbon dioxide is later stored or used. The terms DAC with carbon storage (DACCS) and DAC with carbon utilisation is used for these specific technologies.

Climeworks direct air capture plant in Switzerland. Source: Climeworks

DAC with carbon storage

The purpose of geological storage is to store the captured carbon dioxide permanently.[2]

Storing carbon dioxide underground in geological formations is not a new technology. In 1996, Statoil started the world's first commercial carbon dioxide storage under the Norwegian North Sea. Between then and June 2015, around 15.5 million tonnes of carbon dioxide has been stored there.[3] Globally, there are 19 large-scale commercial carbon capture and storage (CCS) facilities in operation and 32 in construction or early development.[4]

When direct air capture is combined with carbon storage, the flow of carbon dioxide goes from the atmosphere to the ground. The carbon dioxide flow is then the opposite to that of extracting fossil fuels (oil, coal or natural gas), burning them and releasing the emissions into the atmosphere. DAC, together with carbon storage is, therefore, a way of reducing the concentration of carbon dioxide in the atmosphere.

It is very likely that carbon dioxide removal will be needed to reach the goal of the Paris Agreement of "pursuing efforts to limit the temperature to 1.5°C above pre-industrial levels".

The world must achieve net zero emissions by 2050 if global warming is to be limited to 1.5°C, according to the UN's climate panel, the IPCC. Net zero emissions are achieved when *"anthropogenic* CO_2 *emissions are balanced globally by anthropogenic* CO_2 *removals over a specified period."*[5] The IPCC writes further in its special report for policymakers *Global warming of 1.5 °C* that *"All pathways that limit global warming to 1.5°C with limited or no overshoot project the use of carbon dioxide removal on the order of 100–1,000* $GtCO_2$ *over the 21st century."*[6] As a comparison, the global carbon dioxide emissions from fossil fuels and industry were 36,2±2 gigatonnes by 2017.[7]

The Royal Society, a British scientific academy, has assessed how much carbon dioxide the different technologies could remove until the year 2100 and concludes that DAC has the potential to remove up to 500 gigatonnes of carbon dioxide until the year 2100. That makes DAC the carbon dioxide removal technology that has the single biggest potential.[8]

The existence of carbon-dioxide removal and DAC are, however, not a reason not to act on greenhouse-gas emissions. In the IPCC's four *"illustrative model pathways"* that limit global warming to 1.5°C, carbon dioxide emissions decrease by 91-97% between 2010 and 2050.[9]

DAC with carbon utilisation

Instead of being stored, carbon dioxide can used in several ways. It can, without chemical transformation, be used in enhanced oil recovery, that means that it is used to increase the amount of crude oil that can be extracted from an oil field, and as an additive in food and beverage products.

Another possibility is to convert the carbon dioxide into a valuable product by chemical transformation. If the carbon dioxide reacts with specific minerals (calcium or magnesium silicates), stable carbonate minerals are formed that can be used to produce construction materials such as concrete.

Carbon dioxide can also react with other molecules to form chemicals or fuels. In addition, it can be used in photosynthesis to enable plants and bacteria to produce chemicals.[10]

One interesting possibility is to use the carbon dioxide in the photosynthetic processes of algae microorganisms, such as cyanobacteria and microalgae, since algae production can create up to a 50-fold productivity improvement in plant-based oil production and protein production compared with common agricultural crops. Algae can, for example, be used as biofuels, proteins and chemicals.[11]

One study estimates that industrial production of microbial proteins can replace between 10-19% of conventional crop-based animal-feed protein demand, and as a result, decrease the global cropland area, global nitrogen losses from croplands and agricultural greenhouse-gas emissions by 6%, 8% and 7% respectively, by 2050.[12]

When carbon dioxide is used, it will in most cases return to the atmosphere. If the carbon dioxide is, for example, converted to fuel, then it will return to the atmosphere when the fuel is used. If the carbon dioxide is converted to a polymer in a plastic product, then the sequestration time depends if, and after how long, the plastic product is burned.[13] Compared to DACCS, carbon utilisation will not contribute to reducing the concentration of carbon dioxide in the atmosphere if the carbon is not locked in a product for a long time. But compared to products that include carbon from the ground, like fossil fuels, carbon capture and utilisation will not emit new carbon dioxide into the atmosphere. When products based on carbon capture utilisation replace products based on fossil fuels, emissions of new carbon dioxide to the atmosphere are avoided. Carbon dioxide utilisation can, therefore, be used as a tool for reducing emissions.

When carbon is transformed into mineral carbonates, it can be used to make concrete and cement that can last for many decades. This can be seen as a way of combining carbon storage with carbon utilisation.

Using the carbon dioxide is a way of improving the economics of DAC. There is great potential in carbon capture and utilisation. Globally, the value of the products that can be produced with carbon dioxide is estimated at $5 trillion. However, DAC facilities have competition in terms of supplying carbon dioxide to the market, since carbon dioxide can also come from natural sources or point-source emitters of CO2, like fossil fuel plants. A disadvantage for DAC is that the price of CO2 from point sources is lower than the current cost of DAC. But DAC technology might have two advantages. It is scalable and can, therefore, provide the exact amount of CO2 required by a customer and can be built near the customer, therefore avoiding lengthy transportation of CO2.[14]

To summarise

- When fossil fuels are used, carbon is released from the ground to the atmosphere. The result is then that the concentration of carbon dioxide in the atmosphere increases.
- When direct air capture is used together with carbon utilisation, the flow of carbon moves from the atmosphere to a product and then back to the atmosphere, depending on the sequestration time of the product. The result is then that the concentration of carbon dioxide in the atmosphere doesn't change.
- When direct air capture is used together with carbon storage, the flow of carbon is from the atmosphere to the ground. The concentration of carbon dioxide in the atmosphere then decreases.

This is somewhat simplified, however. It takes energy, for example, to capture the carbon dioxide, and as this energy could come from fossil fuels or low-carbon energy sources. This is further discussed in the section "Potential problems with DAC."

Commercial status and costs

Climeworks, Carbon Engineering, and Global Thermostat are three companies that have at least a pilot or demonstration carbon dioxide removal plant.[15] A description of Climeworks and Carbon Engineering's technology and business model is outlined below.

Climeworks targets capturing 1% of the global greenhouse gas emissions by 2025, and in 2017 it took the first step towards that goal when, in Switzerland, it started what it calls the *"world's first commercial-scale direct air capture plant"*. The plant collects 900 tonnes of carbon dioxide per year.[16] The carbon dioxide is then sold to the food and beverage industry, to use in the production of vegetables and to the energy, fuel and materials markets.[17]

Climeworks also has a test plant in Iceland where waste heat from a geothermal plant is used to release the carbon dioxide that the DAC-facility captures. The carbon dioxide is then bound to water and pumped 700 meters underground, where the carbon dioxide reacts with basalt rock, a rock that can react with and bind carbon dioxide, so that stable carbonate minerals are formed. The carbon dioxide is then, in the end, stored as a part of the rock in the subsurface.[18]

Carbon Engineering has run a pilot plant in British Columbia in Canada since 2015, and the plant captures around 1 tonne of carbon dioxide a day from the atmosphere. The carbon dioxide is, for example, used as one of the ingredients in the production of synthetic transportation fuel and for enhanced oil recovery.[19] Both Bill Gates and the oil sands magnate Norman Murray Edwards have invested in Carbon Engineering.[20]

There is also an increasing interest in Silicon Valley for starts-ups that combine carbon capture with carbon utilisation.[21] In September 2019, Carbon Engineering announced that it will double the carbon dioxide removal capacity in its new plant.[22]

The first *"state-of-the-art megaton scale DAC plant"* is estimated to have a levelised cost of between $124 to $325 per tonne of CO2 according to an analysis from Rhodium Group, a research provider. However, this analysis is made from an American context. Economies of scale and mass production can create *"substantial cost reductions"* when more and larger DAC plants are built.[23]

Another way is to look at the cost of using direct air capture as a form of carbon offsetting. Carbon offsetting is when, for example, companies or individuals that undertake an activity that creates emissions, for instance air travel, compensate by financing an activity that will decrease emissions.[24] Climeworks offers individuals the removal of 600 kilos of carbon dioxide, and converts it into stone at its plant in Iceland, at the cost of €588.[25] That gives a price per tonne of €980. By way of comparison, the *"gold standard"*, that was established by WWF and other NGOs,[26] offers climate offsets, by investing in wind energy projects, from $10 per tonne.[27]

However, it should also be said that carbon offsetting by projects like investing in wind energy has been criticised. A report on the Clean Development Mechanism, a mechanism of the Kyoto Protocol that *"allows emission-reduction projects in developing countries to earn certified emission reduction (CER) credits,"* to be used *"by industrialized countries to a meet a part of their emission reduction targets under the Kyoto Protocol"*,[28] prepared for the European Commission came to the conclusion that "85% of the projects covered in this analysis and 73% of the potential 2013-2020 Certified Emissions Reduction (CER) supply have a low likelihood that emission reductions are additional and are not over-estimated". The report concludes that "Most energy-related project types (wind, hydro, waste heat recovery, fossil fuel switch and efficient lighting) are unlikely to be additional." Emission reductions are additional when they "should not have occurred in the absence of the mechanism"[29] As a result, carbon offsetting using direct air capture and carbon mineralisation can be seen as a way of supporting new climate technology with high potential.

There are also examples of when subsidies are used. The Swedish government decided in June 2019 to give 100 million kronor (around €9 million) in investment support to technologies that create negative emissions.[30]

EU, carbon dioxide removal and DAC

The European Commission presented in November 2018 a long-term strategic vision for a climate-neutral economy by 2050, called A Clean Planet for all - *A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy.*[31]

The European Commission writes in its in-depth analysis of the vision that *"Reaching the global objectives of the Paris Agreement without measures aiming at removing CO2 from the atmosphere is extremely challenging. It could even become quickly impossible if no immediate and very ambitious global action is undertaken. Therefore, removing the CO2 from the atmosphere has to be considered as an option for a long term GHG reduction strategy".* DAC with carbon storage is, together with the capture of carbon from the combustion of biomass or fossil fuel, the only carbon capture technologies that are used in the European Commission's scenarios.[32] The European Parliament said in a resolution adopted in March 2019 about the strategy from the Commission that the EU should prioritise emission reductions and natural carbon sinks and reservoirs over carbon dioxide removal technologies.[33] All EU member countries, except Poland, agreed in December 2019 to make the Union climate neutral by 2050.[34]

The interest in the EU for carbon-dioxide-removal technologies (CDR) has not been big, so far. *"But among EU climate policymakers so far there is little talk on CDR, let alone action"*, according to a study published in Climate Policy in October 2018.[35] DAC is not mentioned in the European Commission's communication on *The European Green Deal*. Carbon capture, storage and utilisation is, however, mentioned as a priority area when it comes to breakthrough technologies.[36]

Potential problems with DAC

Direct Air Capture is, however, not without potential problems.

It takes energy to bring in the flow of air through the facility and, after the carbon dioxide has been captured, to release it so that it can then be stored or used.[37]

To release the carbon dioxide from a liquid material a temperature of 900°C degrees is needed, to release the carbon dioxide from a solid material requires a temperature of 100°C. The use of a liquid material that captures carbon dioxide, therefore, requires more energy. The heat can come from burning natural gas or hydrogen.[38] Another option could be to use waste heat from industrial processes.[39]

According to one study published in *Nature*, for DAC plants to capture around 30 gigatonne per year by the year 2100 would require around 50 EJ/year of electricity, which is more than half of today's total electricity production and about 10-15% of the global generation projected in 2100.[40]

When it comes to energy demand, DAC can be an opportunity to use excess energy from intermediate energy sources like solar and wind. With the development in renewable energy, there are sometimes large, if not unlimited, amounts of cheap electricity available. When the production of inflexible renewable energy is high, such as when it is windy, but the demand is low, such as during public holidays, it can even result in negative prices for electricity. For example, Germany had negative electricity prices for around 146 hours in 2017.[41]

However, for excess electricity from the sun and wind to be able to supply DAC on a large scale, much larger amounts of renewable electricity are needed. According to one study, there is a potential to bring down 500 million tonnes (Mt) of carbon dioxide per year in Europe by only using excess electricity from renewable sources. However, in order for such large amounts of surplus electricity to be available, it is necessary that renewable energy accounts for approximately 80% of electricity production.[42]

To put 500 million tonnes of carbon dioxide per year in context, the total greenhouse gas emissions in the EU in 2017 were equivalent to 4 483 Mt carbon dioxide.[43]

How the electricity and heat that is used to power DAC are produced affects the total climate effect from the DAC-system. If fossil energy is used, carbon dioxide will be emitted, thereby counteracting the total climate gain with DACCS.

If, for example, the electricity comes from solar power and the heat comes from hydrogen produced by electrolysis, which is the process of using electricity to split water into hydrogen and oxygen, using near zero carbon sources, in a DAC-facility, then just 0.01-0.03 million tonne CO2 per year will be emitted for every million tonne that the facility will capture. It will, in this case, result in a big net removal of carbon dioxide. But if the electricity is generated by fossil fuels, then *"significant CO2 emissions will result, thereby reducing the effect of a direct air capture plant in terms of CO2 removal from the air."* The emitted carbon is lower when a low-carbon energy such as solar, wind or nuclear is used to run a DAC facility.[44] This data comes from the American National Academy of Science, Engineering and Medicine, and it cannot be ruled out that figures produced in a European context would have been somewhat different.

DAC is more efficient from a land use point of view in comparison to capturing carbon dioxide by using afforestation/reforestation and BECCS. Growing trees absorbs carbon dioxide. However, the land area that is needed for a DAC-system powered with natural gas to capture one unit of CO2 is 40 times smaller compared to the land area that it takes for a tropical forest to capture the same unit of carbon dioxide. The indirect land-use of DAC can increase if a DAC-facility decreases the local carbon dioxide concentration in the atmosphere and creates lower crop efficiency. However, this risk is *"not yet well understood"*.[45]

The process of Direct Air Capture requires water. Most of the water used in the process is contained in a closed-loop system and continuously recycled, but water loss could occur. But the conclusion in a report from the American National Academies of Sciences, Engineering and Medicine about a system with a liquid carbon capture material is that *"the process does not produce a significant amount of wastewater, and onsite wastewater treatment is not anticipated."* When it comes to a system that uses solid carbon capture material, the estimation is that about 1.6 million tonnes of water would be lost for every million tonnes carbon dioxide that is captured. However, this number can vary significantly, and during some conditions, fresh water can actually be produced from the air.[46]

Acknowledge and address potential problems

The potential problems with DAC must be addressed. DAC is energy consuming, and to maximise the climate gain, it is important that as much as possible of the energy comes from low-carbon energy sources. The development of DAC has to happen together with the development of low-carbon energy. A high price for carbon dioxide, that stimulates the development of low-carbon energy, is the single most important tool for achieving that. In addition, the risk that DAC-facilities will lead to a low local carbon dioxide concentration, which can be harmful to plants, must be further investigated. If that is the case, facilities would have to be placed around low-productive land.

These potential problems are, however, not reason enough to dismiss DAC. With the IPCC, the American National Academy of Science, Engineering and Medicine, and the Royal Society highlighting carbon dioxide removal as an important technology for meeting climate goals, the consequence of not using carbon dioxide removal could be that those climate goals are missed, with very serious global warming as a result.

Policy options and recommendations – a market-based approach

Direct air capture (DAC) with carbon storage is the carbon dioxide removal technology with the highest potential. Politicians should, therefore, keep the door open to DAC. But in the end, it shouldn't be up to politicians to decide if DAC will be implemented or not. From a Liberal perspective, there is a risk if the state becomes too active and begins to choose the technology for the future. It is difficult to know which technologies will be possible to develop on a large scale, and innovations that we don't know about today could change the playing field. Instead of investing in some chosen technologies, policymakers should create conditions for a market with negative emissions. Companies can then compete in the market on which has the most effective method of reducing carbon dioxide. In order to create a market for carbon dioxide removal, technology-neutral economic incentives are needed. Emissions trading is the EU's most important tool for fighting climate change, and is a market-based one. It would, therefore, be interesting to use it to facilitate negative emissions. More details can be found in the Negative emissions trading section below.

In addition to market-based solutions, more research is also needed. Negotiators from the European Parliament and the Council have agreed that 35% of EU's research funding should go to climate-friendly technologies.[47] Due to the need for carbon dioxide removal it would be reasonable if a part of the research funding would go to research on carbon-dioxide removal, including DAC.

Negative emissions trading

In the EU's emission trading system (ETS), there is a cap on the amount of greenhouse gases the companies in the system can emit together. The companies can buy and sell emissions allowances between them: companies that emit more than they initially have allowances for therefore must buy more allowances from companies that are able to decrease their emissions and can therefore sell emissions allowances. The total amount of emissions allowances in the system decreases over time, leading to fewer emissions.[48]

The EU's emissions-trading system doesn't create an initiative for negative emissions.[49-50] One possible solution could be that an operator that takes a certain amount of carbon dioxide out of the atmosphere and stores it gets an allowance that can be sold.

At present, emissions reductions are cheaper, per tonne of carbon dioxide, than, for example, DAC. Therefore, inclusion of carbon dioxide-removal technologies in the EU ETS would, in the short term, not be a strong incitement. But, if the price of allowances increases and the cost of carbon dioxide removal technologies decreases, then there could be a situation where it is cheaper for companies to fund carbon dioxide removal by purchasing emission allowances from a carbon dioxide removal technology company rather than reducing their emissions directly.

To what extent global warming can be limited through emission reductions or carbon dioxide removal technologies can be up to the market to decide, as long as emissions are still decreasing. It can also be seen as desirable if carbon-dioxide removal is available within the market as an alternative to emissions reductions, since competition between different ways of achieving climate goals means that market players can choose the cheapest solution, and that would lead to a stronger climate gain per euro given cheaper climate policy could lead to more climate action.

As a result, it should be further investigated if, and how, negative emissions such as direct air capture, should be included in the EU ETS or if a separate policy tool to incentivise negative emissions is preferable. It is, however, clear that negative emissions policy tools are lacking at an EU-level.

Ursula von der Leyen, President of the European Commission since December 1st 2019, writes in the document *Political guidelines for the next Commission* (2019-2024) that she wants to see changes in the EU ETS. She wants, for example, it to cover emissions from transportation as well.[51] This change in the system can also be an opportunity to include negative emissions.

Tax credits, carbon utilisation and cryptocurrency

There are also other possible policy tools other than emissions trading.

When it comes to tax credits, the US is an interesting example. Companies there will get a tax credit on $31 for every tonne of carbon dioxide they store, and the tax credit will increase to $50 in 2026.[52] One related idea could be that companies that finance carbon dioxide removal should be allowed to avoid paying carbon taxes: financing the removal of 1 unit of carbon dioxide should then allow the company to not pay tax on carbon dioxide for the same amount of its emissions.

As previously mentioned, DAC can also be used for carbon utilisation. When carbon dioxide that has been captured from the atmosphere is used, for example in a fuel, and the carbon dioxide is subsequently released and returned to the atmosphere, that carbon dioxide should not be taxed in the same way as carbon dioxide that comes from fossil fuels should be, because no new carbon dioxide has been added to the atmosphere. This difference in cost thus creates financial incentives for DAC and carbon utilisation as well as other mitigation technologies.

Another option, as proposed by Germany's FPD Party, is that companies that withdraw carbon dioxide emissions from the atmosphere are being paid in a new cryptocurrency, Arbil. The value of Arbil would then correspond to the certificate value for 1 tonne of carbon dioxide.[53]

Footnotes

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2 Parliamentary Office of Science and Technology (2018), *p.3.*
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6 Ibid, *p.17.*
7 Global Carbon Project.
8 Royal Society (2018), *p. 104-113.*
9 IPCC (2018), *p.14*.
10 National Academies of Sciences, Engineering, and Medicine (2019a), *p.22-23.*
11 Ibid, *p. 97-99.*
12 Pikaar, I. et al., (2018).
13 National Academies of Sciences, Engineering, and Medicine (2019a), *p. 176.*
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Glossary

BECCS Bio energy with carbon capture and storage

CER Certified Emissions Reduction

CCS Carbon capture and storage

CDR Carbon dioxide removal

CO^2 Carbon dioxide

DAC Direct air capture

DACCS Direct air capture with carbon storage

EJ Exajoule

ETS Emission trading system

GHG Greenhouse gases

IPCC The United Nation's Intergovernmental Panel on Climate Change

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Taking Back Emissions
Using the market to capture carbon dioxide from the atmosphere

December 2019

Editor: Elias Rosell

Designer: ACW, London

Proofreader: Annalisa Tulipano

With special thanks to: Mattias Goldman and Mette Kahlin McVeigh

Published by the European Liberal Forum asbl. Co-funded by the European Parliament.

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