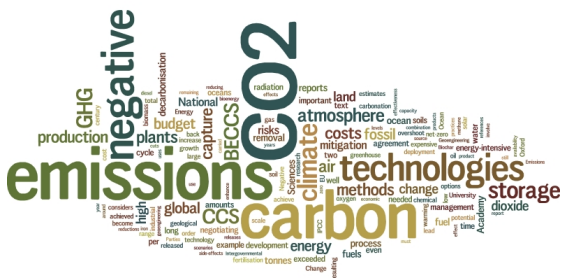


Negative greenhouse gas emissions Assessments of feasibility, potential effectiveness, costs and risks

SUMMARY

The negotiating text for the new international climate agreement contains several references to 'net-zero' carbon emissions. This level of emissions is to be achieved some time in the second half of this century to avoid the dangerous levels of global warming that would result from high greenhouse gas concentrations in the atmosphere. Since some carbon emissions cannot be avoided completely (for example in agriculture, aviation and iron production), carbon dioxide (CO₂) would have to be removed from the air, resulting in 'negative emissions' that compensate for the remaining emissions. Negative emissions may also be needed to reduce atmospheric greenhouse gas concentrations if safe limits are exceeded. Most of the climate stabilisation scenarios of the Intergovernmental Panel on Climate Change assume the use of negative emission technologies.

Recent reports by Oxford University and the US National Academy of Sciences assess available and emerging negative emission technologies, along with their benefits and risks. The reports agree that negative emission technologies are not a substitute for substantial cuts in emissions, but they are expected to play an important role in climate stabilisation by compensating for the remaining emissions. The cheapest and least risky approaches in the short to medium term are forestation and soil carbon enhancement. Bioenergy with carbon capture and storage may play a big role later in this century. Other technologies are still considered too expensive, risky and energy-intensive. Questions of financing and governance remain unresolved.



In this briefing:

- Carbon budgets and emission trends
- The carbon cycle
- Approaches and technologies for carbon dioxide removal
- Expert and stakeholder views
- Outlook
- Main references

Carbon budgets and emissions trends

There is consensus among climate scientists that it is very likely that human activity, notably through the emission of greenhouse gases (GHG), causes climate change. In the 2009 [Copenhagen Accord](#), the world's nations agreed a target to 'hold the increase in global temperature below two degrees Celsius' (2°C). The same target underpins the EU objective of reducing GHG emissions by 80–95% by 2050, compared with 1990 levels.

The Intergovernmental Panel on Climate Change (IPCC) states that cumulative global carbon emissions since 1860 (also known as the 'carbon budget') must not exceed one trillion tonnes of carbon (3.67 trillion tonnes CO₂ equivalent) if aiming for a two-thirds chance of keeping warming below 2°C. With 515 billion tonnes having already been emitted by 2011, the remaining carbon budget comes to less than 500 billion tonnes. According to the IPCC, to stay within this budget, worldwide carbon emissions would have to be cut by 40-70% between 2010 and 2050, and become zero or negative by 2100.

Emission reductions on such a scale would require a radical transformation ('decarbonisation') of the economy, and notably of the energy system which accounts for about two-thirds of global GHG emissions. While such fast decarbonisation might be technically possible, it would imply historically unprecedented reductions in carbon intensity (GHG emissions per unit of GDP) and energy efficiency. Analysis by [PricewaterhouseCoopers](#) indicates that global economies would have to reduce their carbon intensity by 6.2% every year from now until 2100 – more than five times the rate currently achieved.

In reality, there are social, economic and political factors that hold back the speed of decarbonisation. These comprise finance, information and skills, raw materials, time-consuming planning processes, inertia, concerns about competitiveness, population growth and rising living standards. Paradoxically, both high and low rates of economic growth can hinder decarbonisation. As economic activity is not completely decoupled from energy use and emissions, high growth rates are linked to higher emissions. On the other hand, a low-growth environment hinders investments in low-carbon technologies.

Most projections of future energy use and emissions do not predict rapid global decarbonisation. The International Energy Agency's [World Energy Outlook 2014](#) sees continued use of fossil fuels until 2040, and an overshoot of the carbon budget consistent with a 3.6°C increase in global temperatures. The [BP Energy Outlook](#) sees GHG emissions rise until at least 2035. The UNEP [Emissions Gap Report](#) concludes that the carbon budget would be exceeded even if countries achieve their current pledges for emission cuts.

Moreover, even if wide-ranging decarbonisation is achieved, some sectors are unlikely to reach zero emissions in the medium term. These include iron and steel production (coke is needed not just for heat, but also to extract metal from the ore), aviation, shipping, agriculture (rice cultivation and cattle farming cause methane emissions), some transportation and mobile machinery, and cement production (CO₂ is released as part of the chemical process).

As CO₂ remains in the atmosphere for a very long time, even reduced emissions will have a large cumulative effect; therefore the carbon budget will eventually be exceeded. Such an overshoot would have to be compensated by negative emissions.

Indeed most of the IPCC's scenarios that limit global warming to 2°C combine ambitious decarbonisation with negative emissions technologies. Most of the scenarios involve a temporary overshoot of the carbon budget and rely on widespread afforestation and bioenergy with carbon capture and storage (BECCS) in the second half of the century.

Net-zero emissions in the UNFCCC negotiating text

For the post-2020 period, a [new climate agreement](#) applicable to all Parties to the United Nations Framework Convention on Climate Change is under negotiation, and is expected to be adopted by the December 2015 21st Conference of the Parties in Paris. The [negotiating text](#) for the agreement, drafted in February 2015, leaves many options open, reflecting the different negotiating positions of the Parties. Several of the options in the text refer explicitly to 'zero', 'net-zero' and even 'negative' GHG emissions, while other options are less ambitious, mentioning substantial cuts in GHG emissions or near-zero emissions.¹

Even if the world's nations conclude a climate agreement with ambitious mitigation commitments, it is likely that decarbonisation alone will not be enough and that negative emissions technologies would be needed to achieve these commitments.

The carbon cycle

The most important GHG is carbon dioxide (CO₂), which persists in the atmosphere for thousands of years. Other important GHGs are methane (CH₄), nitrous oxide (N₂O) and fluorinated gases. This briefing focuses on CO₂, which has the largest impact on climate change. In 2014, the average atmospheric concentration of CO₂ was almost 400 parts per million (ppm), up from 280 ppm in pre-industrial times.

The carbon cycle is the flow of carbon through the earth's systems. Carbon is released by plants, soils and oceans, and taken up by plants and oceans, and over very long time periods (thousands of years) also by rocks. A CO₂ molecule, made up of one carbon atom and two oxygen atoms, is created when carbon reacts with oxygen, for example in the burning of wood or when humans and animals breathe. CO₂ is destroyed when the carbon is separated from the oxygen, for example by plants through photosynthesis.

Figure 1: The carbon cycle (flows and storage in billions of tonnes of carbon)

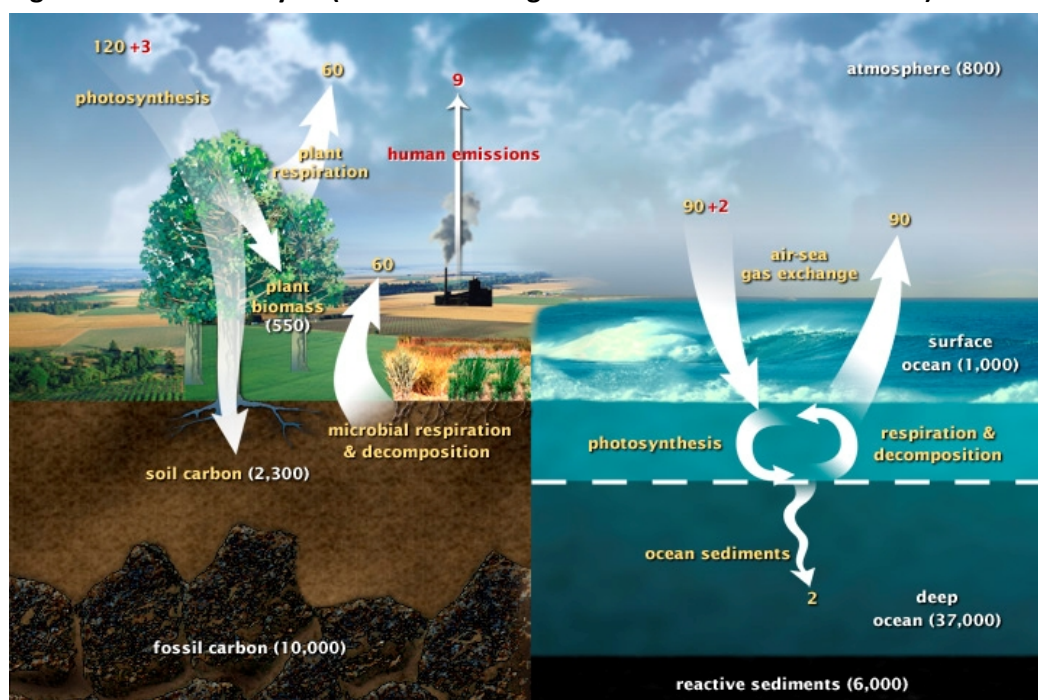


Image source: [The Carbon Cycle](#), NASA Earth Observatory.

Human activities lead to additional releases of carbon, from the burning of fossil fuels, deforestation and land use change, as well as cement production. About half of this additional carbon is taken up by plants and oceans, while the rest remains in the atmosphere as CO₂. However, the take-up of CO₂ in plants and oceans appears to be slowing down, as these carbon stores become saturated.

Carbon dioxide removal would involve modifications of elements of the carbon cycle to enhance the uptake and storage of CO₂ in biomass, soils, oceans and geological formations.

Approaches and technologies for carbon dioxide removal

This section summarises the main approaches for removing CO₂ from the atmosphere. The focus is on CO₂ because it is the most important GHG and only few methods have been proposed for removing other GHGs. Recent reports from [Oxford University](#) and the US [National Academy of Sciences](#) have surveyed and assessed methods for carbon dioxide removal.

Geoengineering

Climate geoengineering refers to methods for modifying the earth's systems in order to counteract climate change. Geoengineering methods fall into two broad categories: carbon dioxide removal (covered in this briefing) and solar radiation management. Solar radiation management aims to counteract global warming by reducing the amount of sunlight (solar radiation) that reaches the earth's surface, as happens after volcanic eruptions. For example, this could be achieved at relatively low cost by injecting aerosols that reflect solar radiation into the atmosphere. However, such interventions are likely to cause undesired side effects, such as a change in local rainfall patterns. This could lead to international conflict if it is carried out unilaterally by one country and has negative effects in another region. Moreover, as the effect lasts only for a short time, these interventions would have to be carried out continuously.

The US National Academy of Sciences opposes the near-term deployment of solar radiation management, but advocates further research that also deepens our understanding of the climate system and its human dimensions. It coined the term 'climate intervention', as it feels that 'geoengineering' is misleading, since 'engineering' suggests precision and predictability.

Forestation

Afforestation and reforestation would involve planting forests on unused land. As the forest grows, it stores carbon in its biomass and in the soil. Some of the carbon may be released when trees die. Net cost estimates range from US\$1 to US\$100 per tonne CO₂.

Biochar

Biochar is a product resulting from the pyrolysis (heating in the absence of oxygen) of biomass. Biochar is a stable product that can be added to soils to improve soil quality. It has been used by indigenous people in the Amazon for hundreds of years (*terra preta*). Net cost estimates range from US\$0 to US\$135 per tonne of CO₂ (tCO₂).

Soil carbon management

Agricultural land management practices such as reduced tilling, cover crops and certain grazing practices increase organic carbon levels in soils. As these practices can also increase yields, net costs may be negative, or be as high as US\$100/tCO₂. Raising water tables or converting croplands back to wetland can enhance CO₂ storage, but can also lead to the release of methane, a powerful GHG.

Ocean fertilisation

Ocean fertilisation involves adding nutrients (especially iron) to the ocean to stimulate the growth of planktonic algae and other microscopic plants² that take up CO₂. After their death, a small proportion of the carbon-rich biomass would sink into the deep ocean where it could be stored for centuries. However, this long-term storage effect is not guaranteed, and ocean fertilisation has side-effects that are not well understood. The costs are highly uncertain, and may be up to US\$500/tCO₂. The US National Academy of Sciences considers ocean fertilisation as an immature technology with high costs and risks. The [London Convention](#) on the Prevention of Marine Pollution has established an [Assessment Framework for Scientific Research Involving Ocean Fertilization](#).

Enhanced weathering and mineral carbonation

Enhanced weathering implies the application of finely ground silicate or carbonate minerals to seawater or soils. When they dissolve in water, they absorb CO₂. Applied on a large scale, these methods would require the mining of massive amounts of minerals – 100 billion tonnes to capture one year's CO₂ emissions. Ocean liming is a similar method involving calcium oxide (lime). However, lime production releases CO₂ and is energy-intensive. Mineral carbonation is a similar process carried out on land, resulting in a solid material. It involves the transport and storage of massive amounts of material, as well as high energy use, so that the total cost would be around US\$1000/tCO₂. [Sea urchins](#) and [ants](#) have methods for capturing and storing CO₂ that may inspire innovation to enhance the effectiveness of industrial processes for mineral carbonation.

European research and development

A number of companies are developing negative emissions technologies. Four European companies are among the 11 finalists selected by the [Virgin Earth Challenge](#), a competition offering a US\$25 million prize for a workable way of removing a billion tonnes of CO₂ from the atmosphere every year.

[European firms](#) are developing processes for CO₂ utilisation, and several European [projects](#) and [networks](#) carry out research in CO₂ utilisation.

Bio-energy with carbon capture and storage (BECCS)

Another approach combines two well-known technologies associated with climate change mitigation: bio-energy and carbon capture and storage (CCS). The BECCS process achieves negative emissions by storing the CO₂ resulting from the combustion of plants, which have previously removed CO₂ from the air through photosynthesis. Cost estimates range from US\$45 to US\$250/tCO₂. BECCS would be subject to the EU [Renewable Energy Directive](#) which sets out sustainability criteria for transport biofuels and bioliquids used for electricity and heat.

Although BECCS has significant potential for negative emissions, the production of bioenergy crops is limited by the available land, for which it competes with food production and the conservation of biodiversity. Another limit is the amount of accessible carbon storage which depends on the development of CCS technology in general. Although the EU has a legal framework for CCS ([Directive 2009/31/EC](#)), there are no operational CCS projects in the EU, and only six are planned. High costs and negative public opinion are the main impediments. As long as fossil fuels are used in power plants and other industrial installations, CCS in combination with bioenergy (BECCS) has no advantages over CCS in combination with fossil fuels.

Direct air capture

This refers to industrial methods for removing CO₂ from the air by putting the air in contact with a chemical sorbent that captures the CO₂ molecules. The CO₂ is then separated from the sorbent and stored. Because CO₂ concentrations in the air are very low (around 400 parts per million), huge amounts of air must be moved, requiring large land areas and amounts of energy. Cost estimates range from US\$40 to US\$1000/tCO₂, considerably higher than capturing carbon from 'point sources' like power stations. As long as fossil fuels continue to be used in such places, it would be far more effective to capture and store carbon from these sources than to employ expensive and energy-intensive direct air capture technologies. The US National Academy of Sciences considers direct air capture to be an immature technology with high costs that requires an energy source without CO₂ emissions to maximise negative emissions.

Carbon storage and CO₂ utilisation

Both BECCS and direct air capture need carbon storage to achieve permanent removal of the carbon from the atmosphere. The most common method is geological storage in depleted oil and gas fields, coal beds and saline aquifers; however total storage capacity is uncertain and requires further geological studies. Storage in the mid-depth ocean (1 000-3 000 metres) is another possibility, but may have side effects such as increasing ocean acidity.

CO₂ utilisation is based on the concept of treating CO₂ as a resource instead of a waste product. The most common use is enhanced oil recovery, where CO₂ is used to boost the production of oil fields. Other uses for CO₂ are: the production of chemical solvents and fertilisers; the decaffeination of coffee; and the carbonation of beverages. However, the total market for these uses is only around 1% of total CO₂ emission, and in most cases the CO₂ is released back to the atmosphere. However, there is active [research and development](#) of new uses for CO₂. Many [experts](#) believe that new CO₂-based products will use only a small fraction of CO₂ emissions, but [others](#) claim that large amounts of CO₂ can be used as feedstock for agricultural and industrial production.

Technological breakthroughs – too good to be true?

The media is full of reports about new technologies that promise to remove carbon dioxide from the atmosphere, while delivering energy as well as products made from CO₂. A recent example is the [announcement](#), by carmaker Audi, of a process for producing diesel fuel from water and CO₂. While this appears to address climate change and energy supply at the same time, a closer [analysis](#) shows that the process is actually rather energy-intensive and releases CO₂ back to the atmosphere when the fuel is used in a vehicle. As a result, it will only be carbon-neutral if it relies on a zero-carbon energy source. But then it may be more energy-efficient to use the zero-carbon energy directly to power a battery-equipped electric vehicle than to use an energy-intensive process to produce, from water and CO₂, diesel fuel to be burned in a diesel engine which is much less efficient than an electric engine.

Announcements of revolutionary breakthroughs should be taken with a grain of salt, keeping in mind that the new technologies might not scale up from laboratory experiments to industrial-scale deployment, and that costs may be high and hard to reduce.

Expert and stakeholder views

The US [National Academy of Sciences](#) recommends focusing on reducing GHG emissions and adapting to climate change, instead of relying on immature negative emissions

technologies. It calls for investment in research and development to improve the methods, understand the risks and lower the costs.

[Climate scientists](#) warn that policymakers should not rely on the availability of BECCS and other negative emissions technologies before the costs, risks and trade-offs with food security, water availability and biodiversity conservation are better understood. [Sustainable development researchers](#) fear that widespread BECCS deployment would lead to large-scale 'land grabs', mostly from poor people.

The [Oxford University](#) report favours the deployment of 'no regrets' technologies (such as forestation, soil carbon improvements and biochar) that have low capital costs, few uncertainties and do not depend on carbon sequestration. It points out that an emission overshoot increases the risk of crossing irreversible tipping points, from which the climate system may not recover, and therefore gives priority to deep emission reductions over negative emission technologies.

On the question of CCS, Oxford University points out that CCS for emissions from fossil fuel plants must be developed first, to have the CCS technology ready for BECCS, but that fossil fuel CCS uses up finite geological storage capacity. On the other hand, the US National Academy of Sciences argues that it makes no difference whether CCS is used in combination with fossil fuels or with bio-energy, as long as fossil fuel plants are still in use.

The NGO [Biofuelwatch](#) opposes BECCS, synthesising the arguments against biofuels (land use and 'land grabs', doubts about carbon neutrality) and against CCS (considered as dangerous and expensive, and used in enhanced oil recovery).

The [European chemical industry](#) regards CO₂ as an important feedstock for products and considers that European initiatives are needed.

Outlook

The discussion about negative emissions technologies has evolved in the last year. Previously, they were generally regarded as geoengineering methods to be used only as a last resort if mitigation efforts should fail. In fact, there have been [concerns](#) that the potential availability of such technologies could undermine mitigation efforts.

More recently, as it has become clear that the carbon budget is likely to be exhausted or even exceeded, the interest in negative emissions technologies has grown. The IPCC considers the use of BECCS as a way to achieve net-zero or negative emissions later in this century. The negotiating text for the new UNFCCC climate agreement mentions net-zero and negative emissions as options. Two major reports published in 2015 assess the risks and benefits of these methods.

These reports make clear that negative emissions technologies are not an alternative to the reduction of GHG emissions. They are expensive (in terms of investment or land use), have limited capacity, and have known as well as unknown side-effects. More research, development and demonstration are needed to better understand the potential, costs and risks of the various technologies.

European Institutions

The [European Commission](#) considers it is too early for a definitive assessment of negative emissions technologies, but supports research projects. Some negative emissions technologies were included in assessments of energy systems undertaken by the Commission's Joint Research Centre.

In 2011, the [European Parliament](#) expressed its opposition to large scale geoengineering, in the context of developing a common EU position for the Rio+20 earth summit.

As with mitigation commitments, the question arises as to who should pay for negative emissions infrastructures that would require investments on a truly massive scale and would not provide a corresponding financial return. There is no reason to assume that negotiations about financing negative emissions would be any easier than the current negotiations about emissions reductions and climate finance.

Nonetheless, as there is a risk that the carbon budget will be exceeded and some GHG emissions will persist, despite the best decarbonisation efforts, negative emissions technologies will likely become part of the mitigation toolbox. They should not be seen as a silver bullet. When taking costs, side-effects, effectiveness and feasibility into account, conventional mitigation technologies are, in most cases, more attractive.

Main references

[Climate Intervention: Carbon Dioxide Removal and Reliable Sequestration](#), Committee on Geoengineering Climate, National Academies Press, Washington D.C., 2015.

[Stranded Carbon Assets and Negative Emissions Technologies](#), Ben Caldecott, Guy Lomax and Mark Workman, University of Oxford, February 2015.

[Negative Emissions Technologies](#), Jonathan Wentworth, UK Parliamentary Office of Science and Technology, POST-PN-447, October 2013.

[Can sucking CO₂ out of the atmosphere really work?](#), Eli Kintisch, MIT Technology Review, October 2014.

[The emissions gap report 2014](#), United Nations Environment Programme (UNEP), November 2014.

[Climate change 2014: synthesis report](#) (IPCC Fifth Assessment), Intergovernmental Panel on Climate Change, 2014.

Endnotes

¹ Among proposals for the preamble of the agreement, there is an option for 'zero emissions within the second half of this century'. The third section starts with 'The objective of this agreement is to achieve net-zero greenhouse gas emissions', without giving a time frame. Later in the same section, there is an option for 'reductions of at least 70-95 per cent below 2010 levels by 2050 and negative emissions of CO₂ and other long-lived greenhouse gases before 2080'. The section on GHG mitigation contains a number of options that refer to zero or negative emissions, either globally or for developed countries, and with different time frames: 'long-term zero emissions sustainable development pathway'; 'carbon neutrality/net-zero emissions by 2050, or full decarbonisation by 2050 and/or negative emissions by 2100 [for developed countries]'; 'zero net emissions by 2050' (page 9); 'at least a 70-95 per cent reduction in global greenhouse gas emissions below 2010 levels by 2050 and zero emissions of CO₂ and other long-lived greenhouse gases in the period 2060-2080'; 'full decarbonisation by 2050 for developed countries' (page 10); 'reduce net emissions to zero by 2050' (page 10); 'Low emission strategies of developed countries should have a time frame for zero emissions' (page 15).

² A study has found that [whales](#) play a role in distributing nutrients in the oceans, similar to ocean fertilisation.

Disclaimer and Copyright

The content of this document is the sole responsibility of the author and any opinions expressed therein do not necessarily represent the official position of the European Parliament. It is addressed to the Members and staff of the EP for their parliamentary work. Reproduction and translation for non-commercial purposes are authorised, provided the source is acknowledged and the European Parliament is given prior notice and sent a copy.

© European Union, 2015.

Photo credits: page 1: image created with [Wordle](#); page 3: image courtesy of [NASA](#).

eprs@ep.europa.eu

<http://www.eprs.ep.parl.union.eu> (intranet)

<http://www.europarl.europa.eu/thinktank> (internet)

<http://epthinktank.eu> (blog)