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POSTNOTE

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Negative Emissions Technologies

If emissions of greenhouse gases are not sufficiently mitigated, it may become necessary to artificially accelerate the rate at which they are removed from the atmosphere in order to restrict global warming. This POSTnote provides an overview of some technologies that could remove atmospheric CO_2 and summarises the environmental, social and economic issues they raise.

Overview

- Negative emissions technologies (NETs) are novel processes that aim to remove greenhouse gases from the atmosphere and hold them in long-term storage.
- Implementation of NETs may become necessary in order to avoid the worst effects of climate change.
- No single NET can be seen as a solution to climate change. All NETs have social, environmental and economic side effects.
- Public awareness of NETs is low, but when explained, they are generally considered preferable to other forms of geoengineering.
- Predicting the costs and efficacy of NETs is challenging. Some commentators stress that there could be a significant risk associated with deflecting investment in mitigation towards NETs.
- There is no specific international regulatory framework for NETs, but some methods are covered by existing agreements.

Background

International policy discussion has been framed around limiting global warming to 2°C above pre-industrial levels.[1] This has been considered an upper limit to avoid the worst effects of climate change.[2,3]

According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), in 2011, 38 gigatonnes (Gt) of CO_2 was emitted from human activity; cumulative human emissions reached 1,947 Gt.[4] In order to have more than a 50% chance of not exceeding 2°C warming relative to the year 1750, cumulative emissions will have to be limited to less than 4,437 Gt CO_2.[4] There is a 33-66% chance that it will be necessary to remove greenhouse gases from the atmosphere to achieve this.

Negative emissions technologies (NETs) are forms of geoengineering (intervening in the climatic system to moderate global warming). 'NETs' is a term that is used to describe technologies and processes for removing greenhouses gases from the atmosphere. These methods can also be called 'greenhouse gas removal'. Most research has focussed on 'carbon dioxide removal'.

Processes

Some of the most discussed NETs are described below. NETs have various limitations to their potential on a global scale.[4] Estimates given below for the potential annual CO_2 removal by NETs are subject to considerable uncertainty. If NETs were implemented, it is likely that it would take at least 20 years for them to be scaled up to a level where they could have any material effect on the levels of greenhouse gases in the atmosphere.[5]

Ocean Liming

Ocean liming would involve heating limestone until it breaks down into its constituent parts; CO_2 – which would be captured and stored geologically (Box 1) – and lime, which would be spread over ocean waters. The lime would react with CO_2 dissolved in seawater to form bicarbonate, enabling the seawater to absorb additional atmospheric CO_2. Ocean liming would be highly scaleable and could in theory remove around 10 Gt CO_2 a year.[6,7]

Enhanced Weathering

When silicate-containing rocks dissolve in seawater or rainwater, CO_2 is drawn into the resultant solution. Certain aquatic organisms, such as crabs and shrimp, can incorporate this carbon into their shells and skeletons, which sink into the deep ocean when the organisms die.[8] Enhanced weathering would involve applying finely ground, silicate-containing rocks to seawater[9] or soils[10] to augment this process. This method is largely conceptual as the weathering rates achieved in lab experiments are yet to be replicated in field trials, where weathering is typically 2-4 orders of magnitude slower.[11] If the difficulties involved in spreading silicate minerals in remote, densely forested areas could be overcome, use of enhanced weathering on land in tropical areas might annually capture up to 3.7 Gt CO_2.[12]

Ocean Fertilization

Adding nutrients to seawater would enhance the growth of photosynthesizing organisms that remove CO_2 from seawater, allowing the ocean to absorb additional atmospheric CO_2. When the organisms die, a small proportion would sink, storing carbon deep in the ocean for centuries.[13] Ocean fertilization may be able to sequester up to 1 Gt CO_2 a year.[7] However, most scientists agree that ocean fertilization cannot be considered a viable NET until there is stronger evidence that it consistently removes atmospheric CO_2 for a quantifiable period.[14]

Forestation

Earth's forest ecosystems store roughly twice the carbon in the atmosphere and more carbon could be stored by increasing the area of land covered by forest. Foresting an area of 2.64 million km^2 (an area larger than the UK) might store 0.7-1.54 Gt CO_2 per year.[15]

Bioenergy with Carbon Capture & Storage

Known as BECCS, this technology involves combining two technologies commonly associated with mitigation efforts: bioenergy and CCS. Bioenergy crops take up carbon dioxide as they grow and are then burned to produce energy or converted to fuels such as ethanol. 80-90% of the CO_2 released during combustion or conversion can be captured using CCS.[16] By 2050, 0.8-3.2 Gt CO_2 could be pumped into geological storage annually through use of BECCS, assuming a biomass supply of 126 exajoules (EJ) a year.[17] For comparison, current transnational trading of oil is about 112 EJ a year respectively.[18]

Biochar

Biochar is made by heating biomass (which has removed atmospheric CO_2 through photosynthesis) to temperatures between 350-800°C without oxygen. This can produce renewable energy while simultaneously storing carbon for centuries in biochar, which can be used to improve soils. Biochar production could store a maximum of 1.8-3.3 Gt CO_2 a year.[19]

Soil Carbon Management

Soil is a substantially larger carbon pool than the atmosphere and biomass combined.[20] Proposed methods for enhancing soil carbon storage include reduced tillage of cropland and certain grazing practices. Calculating atmospheric CO_2 removal by these approaches is challenging. Indeed, there is no conclusive evidence that these methods increase overall carbon storage in all soils.[26,27] Implementation of different tillage and grazing practices might sequester CO_2 at peak rates of 0.77 and 0.55 Gt per year respectively.[28] However, as soils would eventually become carbon-saturated, sequestration would not continue indefinitely.[27]

> **Box 1. Geological CO_2 Storage**
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> Several NETs are dependent on geological storage of compressed CO_2 pumped into disused oil and gas fields or saline aquifers, just as in conventional carbon capture and storage (CCS).
>
> **Availability and Cost**
>
> - The UK might have up to 70 Gt CO_2 storage, but currently less than 2 Gt is proven.[21,22] The Energy Technologies Institute aim to prove more than 8 Gt of storage by 2040.[22]
> - An EU study conservatively estimates that 117 Gt CO_2 storage is available across Europe.[23]
> - Cost estimates for geological storage span two orders of magnitude depending on the site.[24]
>
> **Current Implementation of Geological CO_2 Storage**
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> - Geological injection of CO_2 for enhanced oil recovery has been practiced for around 40 years.
> - Globally, 16 geological storage projects were operational or under construction in 2012 (none in the UK). According to the European Academies Science Advisory Council, only a few of these have adequate monitoring and verification of permanent storage.[25]
>
> **Existing Geological CO_2 Storage Policy**
>
> An EU Directive (2009/31/EC), transposed into the UK Energy Act 2008, includes the following guidelines for geological CO_2 storage:
>
> - There must be no significant risk of leakage or damage to human health or the environment
> - Operators must monitor storage for 20 years after ceasing injection, then responsibility is transferred to the State

Direct Air Capture

Several methods for directly capturing atmospheric CO_2 have been proposed. All include the following three steps:

- CO_2 is captured from air as it passes a chemical sorbent, which either absorbs (becomes permeated by) CO_2 or adsorbs it (meaning CO_2 adheres to its surface)
- the sorbent is then heated or washed to release the CO_2
- the CO_2 is stored geologically.

The most significant limitation, besides social and economic factors, to the potential of direct air capture is the availability of geological storage (Box 1). Direct air capture technologies might be highly scaleable, and could theoretically remove around 10 Gt CO_2 per year.[7]

Other

There are numerous other proposed NETs. For example, in the construction industry, timber, carbon negative cement and concrete made using hemp fibres could be used as negative emission building materials. Creation of wetlands and burying biomass at sea or on land are further examples of 'biological' NETs. However, few proposed NETs have received as much research attention as those discussed above.

Environmental Effects

All NETs affect the environment, with some techniques disrupting oceanic ecosystems, others changing land uses or affecting soil quality.

Oceans

The ecological effects of NETs on the oceans remain poorly understood. Oceanic circulation would spread the effects of NETs over large areas, making long-term assessment and verification of the effects of NETs on oceanic ecosystems problematic.[29] Potential impacts of oceanic NETs include:

- inadvertent ocean fertilization if the dissolving of rocks through enhanced weathering methods released nutrients which are normally limited[30]
- locally enhanced alkalinity, the effects of which are unknown and could be negative
- damaged ecosystems 'downstream' of fertilized areas as essential nutrients besides those being added are over-consumed in fertilized areas.

Alongside these potentially negative effects, NETs may have benefits. For example, ocean liming could be used to reduce acidification around coral reefs. Ocean fertilisation might increase fish stocks.

NETs that involve dispersing materials in seawater would be subject to international regulations (Box 2).

Land use

Large-scale implementation of forestation, BECCS or biochar NETs would necessitate converting large areas of land to plantations. These NETs would thus compete with conservation and agricultural land uses, and share common potential challenges, such as:

- increased competition for water and nitrogen[31,32]
- inadvertent enhancement of climate warming (particularly at high latitudes) as forests reflect less sunlight than croplands (in tropical forests this is offset by strong evaporative cooling)[33,34]
- decreased forest productivity with increasing global temperatures and the risk of deforestation burning[35,36]
- threats to biodiversity, particularly where natural forests are converted to plantations.[37] Establishing plantations on previously degraded land may deliver less biodiversity benefits than restoration of natural habitats.[38]

According to some NGOs, demand for biofuels plantations has in the past resulted in 'land-grabbing' with detrimental environmental and social impacts, particularly for farmers in developing countries.[39,40] Investment in biomass production can deliver social and biodiversity benefits if well-managed.[41] The UK has regulation to promote sustainably produced biomass (Box 3).

Because of population growth and changing diets, an additional 2 million km^2 (an area more than 8 times the size of the UK) may be needed for food production by 2050. Without significant intensification of agriculture, almost 10 million km^2 (an area larger than the US) may be required.[42] All NETs will have to compete with this demand for cropland. For example, achieving the full CO_2 capture potential of biochar would require the establishment 5.56 million km^2 of plantations (an area more than half the size of the US).

The sequestration potential figures given above for BECCS and biochar could not be achieved simultaneously,[43] but it may be possible to implement these NETs in ways that avoid land-use challenges. For example, BECCS could utilise marine biomass (if its cultivation were demonstrated to have acceptable environmental effects), while small, mobile biochar production units could utilise invasive or diseased biomass.

Box 2. Regulation of Marine NETs

Marine NETs are currently prevented (at anything beyond pilot scale) under the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, commonly known as the London Convention (1972):

- Prevents ocean disposal of wastes that could create hazards to human health or marine life and amenities, or interfere with other legitimate uses of the sea
- Revised by the 1996 Protocol which prohibits dumping of wastes or other matter not listed in Annex 1 without a permit
- An amendment proposal to be discussed in October 2013 would enable regulation of marine NETs and as a first step, permit ocean fertilization research activities. The proposal would establish a mechanism to facilitate further amendments to enable regulation of additional NETs such as oceanic enhanced weathering and ocean liming

The Conference of Parties to the Convention on Biological Diversity requests that oceanic NETs not be implemented (beyond small-scale, controlled research) until justified by an adequate scientific basis.[44]

Soils

Soils are complex ecosystems and their manipulation can have multiple effects. Biochar and reduced-tillage farming may deliver increased yields through improved moisture and nutrient retention, reducing demand for irrigation and carbon-intensive soil-amendments while also reducing water pollution in agricultural areas.[45,46] Both biochar and enhanced weathering NETs could be used in place of agricultural soil liming. However, it will not be possible to remove biochar or silicate minerals from soils should negative side-effects arise. For example, application of certain types of silicate rocks to agricultural land might result in crop uptake of toxic metals.[47] While biochar could reduce soil emissions of nitrous oxide and methane greenhouse gases, reduced tillage practices could increase them.

Social Issues

Further to the land use issues described above, large-scale deployment of any NET would involve diverting investment and resources that could have been used to meet other needs. For example, using ocean liming to capture 3.7 Gt CO_2 a year would require an industry larger than the current global cement industry.[48] NETs may also be visually intrusive.

In the UK, public awareness of geoengineering approaches is extremely low.[49] NETs are often considered preferable to approaches that reduce the amount of solar radiation reaching Earth's surface.[49] Techniques that are portrayed as 'working with nature' may be more popular, but there is a divergence of opinion on whether geoengineering should be understood as preserving and restoring nature or a threat to it.[50,51] Research has suggested that people are more likely to be supportive of genoengineering if they are concerned about climate change and feel it is caused by humans.[49]

Box 3. Sourcing Biomass Sustainably

Regulation

The EU Renewable Energy Directive 'RED' (2009/28/EC) established a set of sustainability criteria for transport biofuels and bioliquids used for electricity and heat (including those imported into the EU). In 2010, the European Commission published a non-binding report regarding sustainability criteria for solid biomass and biogas fuels.[52]

The UK has introduced mandatory sustainability criteria for transport biofuels and bioliquids liquid biofuels as required by 'RED' and is also introducing sustainability criteria for biogas and solid biomass used for electricity and heating that include:

- a minimum 60% GHG emission saving for electricity or heat generation relative to the EU average for fossil fuels
- criteria to ensure that biomass is sourced from sustainably managed land.

These controls would only apply to biochar where it is produced in conjunction with energy generation.

Importing Biomass

The UK's limited land mass (relative to population size) necessitates a global approach to biomass sourcing. Assuming natural forest is not cleared for plantations, approximately 1.2 tonnes of atmospheric CO_2 could be removed overall per tonne of U.S. biomass imported for use in BECCS in the UK[53] (equivalent to approximately 28% of the atmospheric CO_2 captured by the biomass).[54,55]

Several NETs rely on geological CO_2 storage (Box 1). The Commons Science and Technology (S&T) Committee have emphasised the importance of early public engagement in dialogue about geological CO_2 storage.[56] A geological storage project in the Netherlands was abandoned because of local opposition arising from fears about safety and inadequate involvement of local stakeholders in the formal decision-making process.[57,58] Geological storage projects elsewhere in Europe have been stalled or abandoned for similar reasons.[59] As the UK has abundant geological storage offshore, public opposition may be less pronounced. Without knowledge of its purpose, most people in the UK either have no opinion or a negative perspective of offshore storage. With provision of even limited information on the role of geological storage in reducing atmospheric CO_2, opinion becomes more supportive.[60]

Costs

Decisions on implementing NETs are likely to be influenced by how much they cost, particularly when compared to the costs of climate change mitigation or damage caused by climate change. According to the Stern Review, these costs are approximately $27 and $85 per tonne of CO_2 respectively, though the underlying assumptions of these figures are debated.[61] As NETs are generally incipient technologies yet to be demonstrated at scale, their costs are very uncertain.[62] There is currently no standard testing platform for assessing costs of NETs and existing estimates are dependent on input assumptions. For example, some studies estimate the costs of BECCS to be well below $85 per tonne CO_2 stored, while other estimates are 300% higher.[7] Cost estimates for direct air capture methods vary greatly, partly because some adapt existing technology from scrubbing towers[63,64,65] while others utilise novel technology that may become cheaper in the future.[66] Most commentators doubt that NETs will become sufficiently affordable in the near term to cause a reduction in mitigation efforts.[67]

It has been suggested that NETs could be financed through inclusion in carbon markets such as the EU Emissions Trading Scheme (ETS). This would provide financial incentives to accelerate their development, but it could potentially create certain challenges:

- NETs would be deployed as offsets, enabling reduced mitigation efforts. As NETs have limited capacity, this would to some extent sacrifice the ability to use NETs to achieve absolute reductions in atmospheric greenhouse gas concentrations.[7]
- Different NETs sequester CO_2 for different (often not precisely known) periods of time and may therefore have different values per tonne of atmospheric CO_2 removed.
- Because it may be impossible to develop accurate carbon accounting for processes such as enhanced weathering, ocean liming and soil carbon management, including these NETs in carbon markets may not be feasible.[7]

Even if NETs were to be included in the EU ETS, they would not be economically viable under foreseeable carbon market conditions. Current EU ETS carbon prices, even when combined with the UK's Carbon Price Support are well below even the most optimistic cost estimates for NETs.[7]

Governance

NETs would need to be deployed at large-scale for at least 100 years to be able to significantly reduce atmospheric CO_2 concentrations.[4] Although investment in NETs may become necessary, there could be substantial risk associated with reducing investment in mitigation efforts and depending instead on NETs.[5] Predicting the efficacy of NETs and how rapidly they could be implemented at scale is difficult. Some NETs would have to pass through lengthy national and local planning approval processes. Implemented at scale, NETs would have transboundary effects and would thus necessitate the establishment of international regulatory frameworks, including targets and verification regimes. Oceanic NETs in particular could have deleterious transboundary side-effects.

The Commons S&T Committee and The Royal Society have both recommended that a UN body review how existing international conventions and treaties could be applied to NETs, then identify and develop mechanisms to address any regulatory gaps. A group of academics has suggested a set of principles that might guide decision-making on geoengineering (including NETs). These 'Oxford Principles' were welcomed by the Commons S&T Committee as a basis for discussion of geoengineering regulation:[68]

- regulation as a public good, with private sector involvement
- public participation in decision-making
- full public disclosure of research plans and results
- independent assessment of impacts
- governance before deployment.[69]

Endnotes

For references, please see:
http://www.parliament.uk/documents/POST/postpn447_Negative-Emissions-Technologiesreferences.pdf

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