Greenhouse gas removal

SUMMARY

THE ROYAL SOCIETY

ROYAL ACADEMY OF ENGINEERING

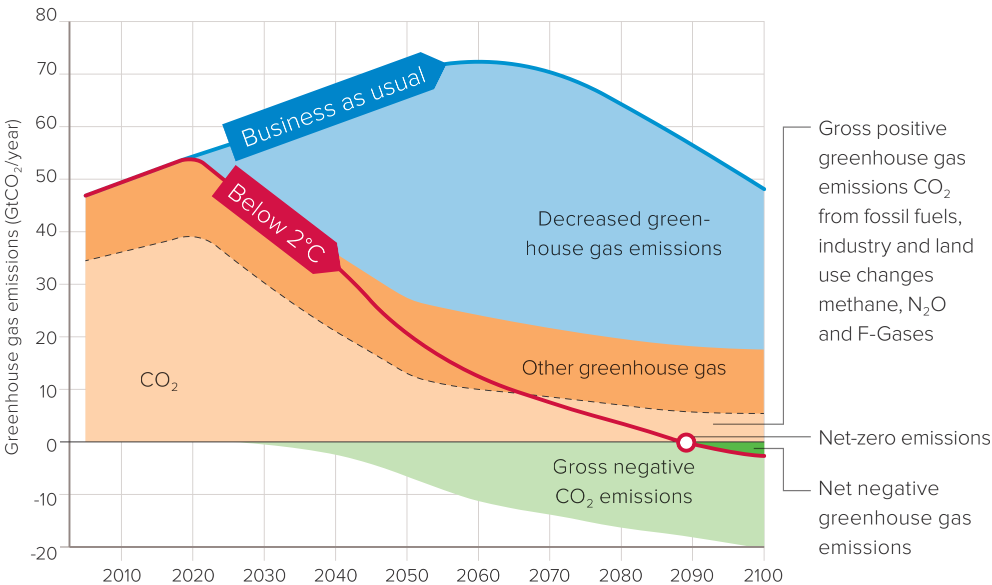
Summary

The Royal Society and Royal Academy of Engineering were invited by the Department for Business, Energy and Industrial Strategy to consider scientific views on greenhouse gas removal (GGR). This summary report is a distillation of the key findings from an exploration of the opportunities and barriers for GGR methods in both a UK and global context.

In 2015 governments from around the world met to agree a framework that would minimise the negative consequences of climate change. The Paris Agreement sets a goal to limit global average temperature increase to 'well below 2°C above preindustrial levels', and to 'pursue efforts' to limit it to 1.5°C.

FIGURE 1

Future emissions and removals of CO_2. To meet the 2°C goals of the Paris Agreement requires rapid and dramatic decreases in emissions (in blue), but also active removal of greenhouse gases from the atmosphere (in green), commencing in the next decade.



Source: UNEP Emissions Gap report 2018.

This is an ambitious task requiring rapid decreases in emissions and, by the second half of the century, ‘net-zero emissions’. In some sectors, notably agriculture and aviation, greenhouse gas emissions will be difficult to eliminate entirely, so we will need technologies to compensate by removing greenhouse gases from the atmosphere. Modelling of future energy systems suggests this removal would need to be at a large scale, with removal of about one quarter of present annual emissions each year.

Greenhouse gas removal

GGR methods involve two main steps: the removal of greenhouse gases from the atmosphere and their storage for long periods. The process is best established for carbon dioxide (CO_2) removal. Removal is achieved through a wide variety of approaches, involving either biology, accelerating natural inorganic reactions with rocks, or engineered chemical processes. The carbon is then stored in land-based biomass, sub-surface geological formations, the oceans, or the built environment.

GGR methods require resources, like land, energy or water, placing limits on the scale and location of their application, and leading to resource competition between them, and with other human activities, such as food production. Some GGR methods also provide co-benefits which could assist, or even be the primary reason for, deployment; these can include crop productivity and biodiversity enhancements.

A portfolio of approaches

Achieving the desired level of GGR will be best achieved by using a portfolio of approaches. Increased forestation and bioenergy with carbon capture and storage (BECCS) are often considered as major routes to deploy GGR, but they are limited by available land area, resource requirements and potential impacts on biodiversity and social equity. Deployment of these as part of a suite of methods would decrease likely environmental and social impacts anticipated at large scale.

More to learn

Some GGR methods are already in use today, while others require significant development and demonstration before they can remove emissions at scale. When considered at the scale required, none of the methods have been fully evaluated across their life cycle. GGR methods impact the environment in different ways. As such, their development will require careful assessment of environmental implications, during demonstration pilot studies, ramp-up, and full deployment. These sustainability issues will be among those that influence public perception of GGR, which ranges widely depending on the method and location, and may place constraints on their applicability.

Deployment

Early deployment of GGR methods and their rapid ramp-up would make it easier to achieve climate targets, and help to avoid a damaging climate 'overshoot'. Biological approaches for land carbon storage can be applied quickly, but these will saturate after some decades so other GGR methods are expected to become critical later in the century.

To be economic and, therefore, to be pursued at adequate scale, most GGR methods require a price for carbon or other incentive system. Future projections of carbon prices of $100 per tonne of CO_2, if realised, would make many GGR methods economically feasible.

The report which accompanies this booklet is structured in three parts, which are summarised below and on the following pages:

GGR methods: a description of each method, under set subheadings that capture critical issues, such as scalability, cost, and environmental risk.

Cross-cutting issues: a summary of the issues (resource, economic, societal and others) involved in establishing a suitable portfolio of GGR methods.

Scenarios: development of two example GGR scenarios; for the UK to achieve net zero emissions by 2050, and for global temperatures below 1.5°C in 2100. in 2100.

GGR methods

Forestation – Growing new trees and improving the management of existing forests. As forests grow they absorb CO_2 from the atmosphere and store it in living biomass, dead organic matter and soils.

Habitat restoration – Restoration of peatlands and coastal wetlands to increase their ability to store carbon. This also prevents carbon release through further degradation, often providing a number of other co-benefits.

Soil carbon sequestration – Changing agricultural practices such as tillage or crop rotations to increase the soil carbon content.

Biochar – Incorporating partially-burnt biomass into soils. Biomass is grown and burned in the absence of oxygen (pyrolysis) to create a charcoal-like product which can stabilise organic matter when added to the soil.

Bioenergy with carbon capture and storage (BECCS) – Utilising biomass for energy, capturing the CO_2 emissions and storing them to provide lifecycle GGR.

Ocean fertilisation – Applying nutrients to the ocean to increase photosynthesis and remove atmospheric CO_2.

Building with biomass – Using forestry materials in building extends the time of carbon storage of natural biomass and enables additional forestry growth.

Enhanced terrestrial weathering – Ground silicate rocks spread on agricultural land react with CO_2 to remove it from the atmosphere.

Mineral carbonation – Accelerating the conversion of silicate rocks to carbonates either above or below the surface to provide permanent storage for CO_2.

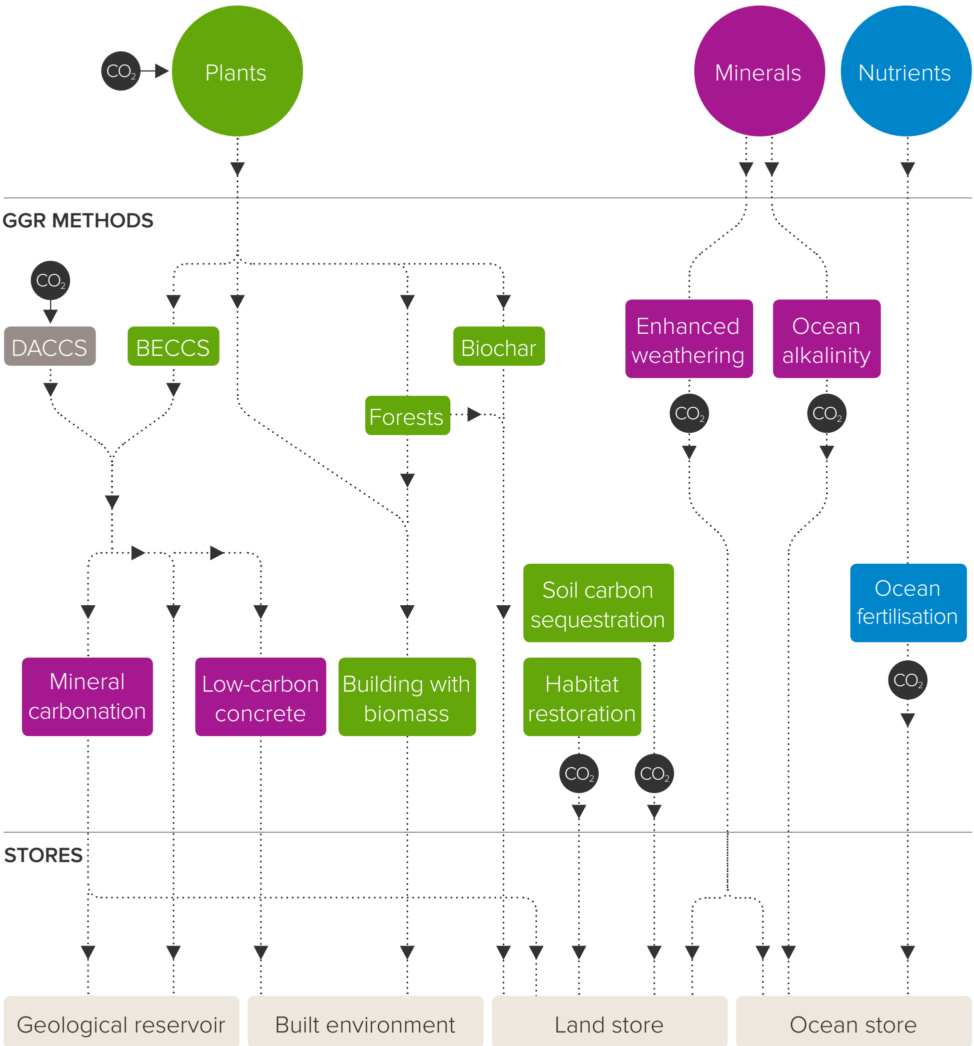
Ocean alkalinity – Increasing ocean concentration of ions like calcium to increase uptake of CO_2 into the ocean, and reverse acidification.

Direct air capture and carbon storage (DACCS) – Using engineered processes to capture atmospheric CO_2 for subsequent geological storage.

Low-carbon concrete – Altering the the constituents, the manufacture, or the recycling method of concrete to increase its storage of CO_2.

FIGURE 2

Diagram of CO_2 capture and storage for each GGR method.



Cross-cutting issues

Resources
Resources like land, energy, minerals or water are required for each GGR method, placing limits on the scale and location of their application, and leading to resource competition between them and with other human activities.

Storage
GGR methods either have built-in storage (forestation, soil carbon sequestration) or require a separate activity to store the CO_2 (BECCS, DACCS).

Environmental
Some GGR methods provide co-benefits to the environment which could assist, or even be the primary reason for, deployment; whilst others could have detrimental impacts, directly or across their lifecycle.

Science and technology
Cost, scalability, security, and environmental impacts of GGR methods are often poorly understood, limiting their application and requiring research and development.

Economics
Many of these GGR methods are expensive to deploy. Economic mechanisms could establish markets and assist efficient resource allocation.

Legislation
Emissions and removals (and their reporting) are governed under national and international legislation.

Social aspects
Society will interact with these methods in multiple ways. Opposition, or insufficient support, could limit their deployment.

Each of these elements will influence the GGR methods deployed and their location. Deploying a suite of GGR methods spreads influence of each of these issues.

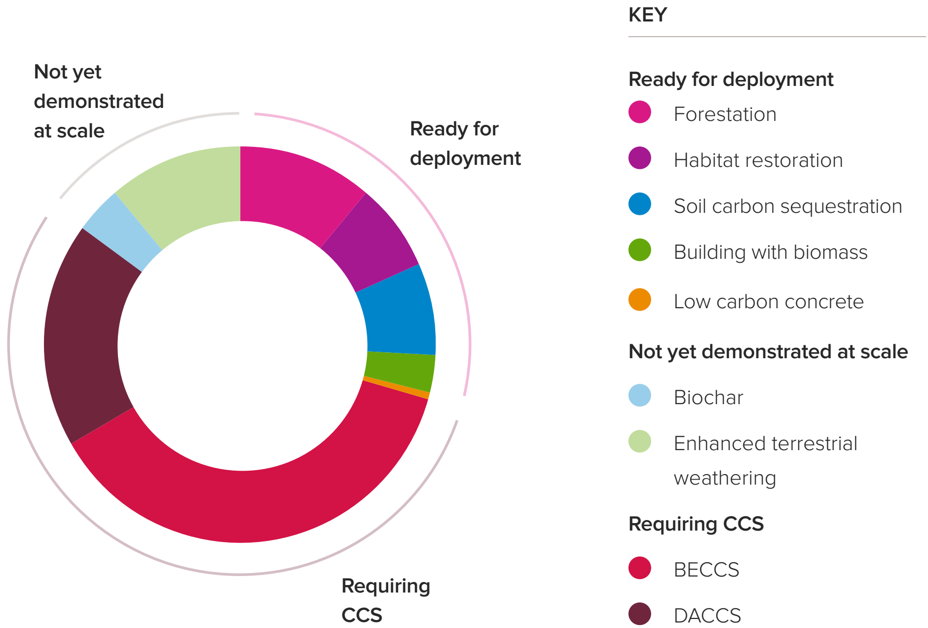
Scenarios

A UK and global scenario for ambitious application of a suite of GGR methods were considered by a diverse group of experts.

UK scenario: Net-zero in 2050

In the UK, reducing greenhouse gas emissions to the greatest degree considered feasible would leave around 130 $MtCO_2$ pa by 2050. Offsetting these emissions with GGR to reach 'net-zero' for the UK is possible, but very challenging. It involves deployment of many different GGR methods, and import of biomass. To achieve this level of GGR requires a ramp-up of forestation, habitat restoration and soil carbon sequestration now, research and development of currently unproven but promising GGR methods and establishment of substantial infrastructure and capacity for carbon capture and storage (CCS).

FIGURE 3



Key actions for UK net-zero

- Pursue rapid ramp-up of forestation, habitat restoration, and soil carbon sequestration, across large UK land-areas.
- Establish an incentive or subsidy system to encourage changes of land practice, particularly for soil carbon sequestration. This could form part of the framework put in place to replace the EU Common Agricultural Policy.
- Encourage changes in building practice to use wood and concrete manufactured with carbonated waste (while recognising overall limited potential for GGR of these approaches).
- Develop monitoring and verification procedures and programmes to track the effectiveness of GGR delivered by each method.
- Grow and import sustainable biomass at large scale to meet the need for both energy and GGR demands.
- Pursue research into the GGR potential of enhanced weathering and biochar in UK agricultural soils, and into BECCS and DACCS for longer term deployment. This should include assessment of the co-benefits, social and environmental risks, monitoring and evaluation, and include field-based pilot demonstrations.
- Capitalise on UK access to suitable reservoirs for CCS, and relevant engineering and industry expertise, to establish substantial infrastructure for transport and storage of CO_2.

Right:

Global cumulative GGR compatible with 1.5°C by 2100

Integrated assessment models provide evidence that a cumulative GGR of around 810 $GtCO_2$ is expected to be required from now until 2100 to limit the rise in temperature to 1.5°C on pre-industrial times. This is the equivalent to about 15 years of 2017 greenhouse gas emissions. The large land area available globally for potential GGR deployment make this global target achievable, but still highly challenging. Many natural sinks will become saturated in this time frame, requiring a diversity of GGR approaches. Monitoring and maintenance will be required to prevent carbon being released from storage. Trading schemes could help action to be taken in the most effective and economical locations.

Considering a global response enables significant potential for GGR but action across national borders would likely require a political solution.

Below:
Rendering of Carbon Engineering's air contactor design. This unit would be one of several that would collectively capture 1 $MtCO_2$ pa. © Carbon Engineering Ltd.

Recommendations

Greenhouse gas removal (GGR) from the atmosphere will be required to fulfil the aims of the Paris agreement on climate change. This report recommends the following international action to achieve this GGR:

RECOMMENDATION 1

Continue and increase global efforts to reduce emissions of greenhouse gases. Large-scale GGR is challenging and expensive and not a replacement for reducing emissions.

RECOMMENDATION 2

Implement a global suite of GGR methods now to meet the goals of the Paris Agreement. This suite should include existing land-based approaches, but these are unlikely to provide sufficient GGR capacity so other technologies must be actively explored.

RECOMMENDATION 3

Build CCS infrastructure. Scenario building indicates that substantial permanent storage, presently only demonstrated in geological reservoirs, will be essential to meet the scale required for climate goals.

RECOMMENDATION 4

Incentivise demonstrators and early stage deployment to enable development of GGR methods. This allows the assessment of the real GGR potential and of the wider social and environmental impacts of each method. It would also enable the process of cost discovery and reduction.

RECOMMENDATION 5

Incentivise removal of atmospheric greenhouse gases through carbon pricing or other mechanisms. GGR has financial cost at scale and so will require incentives to drive technological development and deployment of a suite of methods.

RECOMMENDATION 6

Establish a framework to govern sustainability of GGR deployment. Undertake rigorous life cycle assessments and environmental monitoring of individual methods and of their use together.

RECOMMENDATION 7

Build GGR into regulatory frameworks and carbon trading systems. In the UK, as an example, active support for GGR implementation (soil carbon sequestration, forestation, habitat restoration) should be built into new UK agricultural or land management subsidies.

RECOMMENDATION 8

Establish international science based standards for monitoring, reporting and verification for GGR approaches, both of carbon sequestration and of environmental impacts. Standards currently exist for biomass and CCS, but not for GGR methods at large.

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Cover image:
Visualisation of global carbon dioxide surface concentration by Cameron Beccario, earth.nullschool.net, using GEOS-5 data provided by the Global Modeling and Assimilation Office (GMAO) at NASA Goddard Space Flight Center.

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