Carnegie Climate Geoengineering Governance Initiative

An initiative of Carnegie Council for Ethics in International Affairs

GEO-GOVERNANCE MATTERS

Governing Carbon Removal

Carbon Removal (CDR) approaches address the cause of climate change, by lowering the atmospheric concentration of CO_2—the greenhouse gas most responsible for anthropogenic global warming. They cover a variety of techniques, with different effects.

Some governance issues are common to all, including:

- **Moral Hazard** in which assumptions about the effectiveness of these technologies might reduce the sense of urgency in policy circles to reduce greenhouse gas emissions. Their inclusion in IPCC models may be providing an inflated sense that achieving a 1.5-2°C pathway is manageable, thereby delaying urgent action to avoid catastrophic temperature rise.
- **Market viability** may not be in place for these technologies to thrive. They may require a carbon tax, or cap and trade systems.
- **Accurate carbon accounting** from carbon removal is very difficult.

Specific techniques also face specific governance challenges:

- **Afforestation and land use management**
  Land diverted from productive uses, such as food and fibre; may threaten biodiversity; short-term; affects planetary albedo; requires ongoing management.
- **Biochar**
  Biochar dust provides potential health hazard; alters the property of the soil and can also lead to increased production of methane; fired could re-release CO_2
- **Biomass energy with carbon capture and storage (BECCS)**
  Massive land use, water and fertilizer constraints, potential effect on food security. Land diverted from other productive uses.
- **Direct air capture**
  Expensive, likely requiring a carbon tax to be commercially viable; high water requirements.
- **Enhanced weathering**
  High cost; small particles can harm health; runoff could have transboundary effects by altering the pH of river systems
- **Ocean alkalinity enhancement**
  Likely to perturb ecosystems; high cost; massive mining requirements.
- **Ocean fertilization**
  Controversial; London Convention/London Protocol (LC/LP) restrict activities to small-scale scientific experiments, Convention on Biological Diversity also restricts activities.

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Afforestation, Reforestation and Land Use Management

Afforestation and Land Use Management involves increasing the amount of carbon stored on land, in the form of organic material in biomass both above and below the ground. During photosynthesis plants capture CO_2 from the air and convert it into organic compounds. These organic compounds act as a store of carbon and are constituent parts of the biomass (roots, branches and leaves) generated.

Afforestation involves increasing the amount of carbon stored on land by the planting of trees in areas which have either been previously deforested or in areas that have never been forested. Land Use Management involves a range of proposed techniques to enhance the amount of carbon stored in soils such as through managing grazing patterns. Afforestation and land use management techniques are already deployed at a scale that is large in terms of land area, but small in terms of potential impact on climate change

Constraints

- Land that is photosynthetically active has other value apart from storing carbon, such as food, fuel and fibre production, its ability to support biodiversity, and cultural and aesthetic amenity value. Afforestation and land use management techniques at sufficient scale to tackle climate change is likely to result in significant trade-offs.
- Carbon storage through such techniques is generally short-term. The planting of a forest on land that is currently barren can increase the amount of carbon stored as the forest grows, but if the forest is felled or burns down then the carbon will be re-released. The creation and maintenance of forest needs to be an active process.
- Afforestation as a technique to remove carbon from the atmosphere in the long term may not be robust to anticipated climate change. Areas that are afforested now may not be able to remain forested as the planet warms significantly—some models predict that the Amazon will transform from a net carbon sink to a net carbon source as the planet warms and that similar effects can be anticipated in other afforested areas.
- Large-scale deployment of afforestation will affect planetary albedo. Some models indicate that afforestation at high latitudes would lead to a net warming; in winter unforested snow-covered land has a much higher albedo than forested land.
- Changes in albedo resulting from large-scale afforestation would lead to changes in rainfall patterns. At the scale required to have a material impact on climate change it would have a material impact on rainfall patterns.

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Biochar

Heating biomass in an oxygen-deficient environment results in incomplete combustion and the production of a char, which has a high carbon content. If this char is buried, carbon in the char is sequestered away from the atmosphere.

Plants, in growing, remove carbon dioxide from the atmosphere and the charring process transforms a proportion of the carbon in the biomass into a recalcitrant form which is resistant to being re-released back into the atmosphere. The addition of biochar to soils can often have co-benefits in terms of enhancing soil quality and crop yields.

Biochar is already routinely produced for use as charcoal and as a soil improver. As such, large-scale production is already practised. What is less well-established is the long-term behaviour of biochar as a means of storing carbon away from the atmosphere.

Constraints

- The proportion of recalcitrant carbon in a biochar is a function of many factors: the biomass feedstock, the method of producing the biochar and the characteristics of the soil into which the biochar is placed. The longevity of the stored carbon is also a function of these factors.
- The availability of biomass to produce the biochar.
- Biochar dust poses a potential hazard to human health.
- The addition of biochar to soils alters the property of the soil. In many cases it can lead to enhanced crop yields, but it can also lead to increased production of methane.
- The addition of large amounts of biochar to soils may result in reduced albedo, thereby counteracting some of the benefit of removing carbon dioxide.
- If a land area into which biochar has been added is affected by fire (which may be a result of a warming climate), then the carbon stored may be released back into the atmosphere.

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Biomass Energy with Carbon Capture and Storage

Biomass Energy with Carbon Capture and Storage (BECCS) involves growing biomass, harvesting it, combusting it in power plants to generate electricity and then capturing and storing the CO_2 produced in geological formations. By this means CO_2 is captured from the air through photosynthesis and is stored deep underground, whilst at the same time generating electricity.

The IPCC assumes widespread deployment of BECCS in its models for a 1.5°-2°C temperature rise. However, the technology is still in its infancy, and nowhere near ready at scale. There are a small number of demonstrator units which capture CO_2 from ethanol production plants and store CO_2 in geological formations. The component parts of BECCS—the production of biomass, the use of biomass to generate electricity, the capture of CO_2 from the resulting flue gases and the geological sequestration of CO_2—have all been practised, so the combination of these component parts is achievable. However, the social and environmental challenges associated with attempting to scale up this technique have not been comprehensively examined.

Constraints

- As with afforestation and land use management techniques, BECCS relies upon the usage of photosynthetically active land, which has other value to society. The amount of land available to BECCS and biofuel crops depends upon the amount of land that is required to grow food, which is a function of population and diet.
- The increased production of biomass required for this technique would require significant amounts of land—some analysts have suggested scales at 1-3 times the size of India. This is likely to have significant social and environmental consequences, in particular, for food security
- BECCS may require significant water and fertilizer use.
- BECCS will compete with geological storage space with CCS from large stationary plants. The storage space needed to contain the amount of carbon draw down that makes a material difference in the atmosphere would be massive; some scientists say that storage space of that size could only be in the deep ocean.

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Direct Air Capture

Direct Air Capture (DAC) involves using chemical processes to directly capture carbon dioxide from ambient air. Typically this will involve using an alkaline material (such as sodium hydroxide) which reacts with carbon dioxide or a material which adsorbs the carbon dioxide.

Further treatment will release the carbon dioxide in pure form and will regenerate the sorbent for repeated use. The pure carbon dioxide is then ready for geological sequestration. This results in carbon dioxide being transferred from the atmosphere to long-term storage underground in suitable geological formations.

There are about a dozen proposed DAC technologies—not all of them in the public domain—which have been demonstrated at small scales. Technically the process works; the removal of carbon dioxide from ambient air in submarines and spacecraft has been practiced for decades.

The real question is about the carbon balance of the systems (is more carbon dioxide emitted during the life-cycle of the technology than is removed by the process) and the economics. Analysis by American Physical Society indicates costs greater than USD600 per tonne of carbon dioxide removed. This is hotly contested by leading proponents who believe that a long-term cost goal of less than USD100 per tonne of carbon dioxide is achievable. In either case, this price is significantly higher than the current carbon price.

Constraints

- The amount of energy required to run such systems may be high.
- Given the low initial concentration of carbon dioxide in ambient air, it is necessary to treat 1.4 million cubic metres of air to remove a single tonne of CO_2. The scale of the machinery is likely to be large, with significant resource implications.
- Many, but not all, such techniques have a significant water requirement.
- It is unlikely that DAC from ambient air is likely to be cost competitive with CCS. The exception would be if large quantities of ‘stranded energy’ were available in locations close to geological storage sites—in which costs associated with extracting CO_2 from a lower concentration could be counterbalanced by lower energy and sequestration costs.
- DAC will compete with geological storage space with CCS from large stationary plants.
- DAC will require a carbon price to be deployed on a large scale.

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Enhanced Weathering

As minerals weather they absorb carbon dioxide. The natural weathering of silicate minerals results in the formation of carbonate minerals, which acts to remove carbon dioxide from the atmosphere. These reactions tend to occur very slowly and have a small beneficial impact on carbon dioxide levels in the atmosphere. Enhanced Weathering seeks to accelerate this process.

The main way in which it is proposed that weathering can be accelerated is by grinding appropriate minerals (such as olivine (magnesium silicate)) into a fine dust which, due to the resulting higher surface-area-to-volume ratio, will react more quickly than they would naturally.

Enhanced Weathering has been studied in the laboratory and has been modelled, but it has had little research in the open environment. Proponents of Enhanced Weathering have sold some ground olivine as a soil additive, whilst marketing it as a means of removing carbon dioxide from the atmosphere. Technical and theoretical modelling of the particle sizes indicate that while there would be some carbon dioxide drawdown, it is far less than has been claimed.

Constraints

- The energy and cost requirements for grinding appropriate minerals sufficiently to enhance weathering are high.
- The particle size to which such minerals need to be ground to in order to enable a material increase in the rate of weathering is often (depending on the mineral) smaller than 10 microns in diameter - a size which can cause harm to health.
- There is an upper limit as to the amount of carbon dioxide that can be sequestered via this method. This is determined not by the reaction of the magnesium silicate in dilute carbonic acid (rainwater), but by the saturation state of silicic acid that is produced when the magnesium silicate reacts.
- The weathering of large quantities of ground olivine will lead to the introduction of trace metals present in the olivine, a change of pH and potentially changes to soil structure (which may be positive or negative). The places currently identified as most suitable for enhanced weathering (tropical areas that have high rainfall and high temperatures) are also some of the most important areas for biodiversity globally.
- While Enhanced Weathering would occur on territory under the jurisdiction of individual states, runoff from Enhanced Weathering could have transboundary effects by altering the pH of river systems and potentially enhancing the saturation state of silicic acid in coastal waters.

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Ocean Alkalinity Enhancement

Ocean Alkalinity Enhancement (OAE) seeks to enhance the chemical capacity of the oceans to draw down carbon dioxide, by the introduction of alkaline materials that increase the pH of the ocean and allow more carbon to be stored as Dissolved Inorganic Carbon (DIC) in the ocean.

Various methods have been proposed—adding limestone (calcium carbonate), hydrated lime (calcium hydroxide) or finely ground olivine (magnesium silicate) or by electrolysis of seawater. These techniques differ widely in application, but all have the same net effect—enhancing the amount of DIC in the ocean.

OAE has been studied in the laboratory and has been modelled, but it has not been researched in the open environment. The processes required to generate alkaline materials are well established and practised at an industrial scale, but the application of alkaline materials to the ocean has not been undertaken.

The principles of how DIC behaves in the ocean in response to increased pH are well understood. What are not well understood—and cannot be established without experimentation—are the impacts on the environment—both positive and negative—of increasing ocean pH.

Constraints

- The addition of large quantities of alkaline material to the ocean is likely to perturb natural ecosystems. The increase in pH will favour those organisms that thrive at the perturbed level over those organisms that would thrive at the pre-existing level. This is a similar argument to the perturbation of OF, but differs in that the current pH is itself perturbed from historic norms, and so the addition of alkaline materials could be expected to restore the pH. What would not however be restored is the calcium and magnesium ion concentrations—these would increase (though very marginally).
- The process for obtaining alkaline materials is likely to be costly both in economic and energy terms. There are few naturally occurring deposits of alkaline materials that could be added to the ocean to have the intended effect; they may be possible to manufacture.
- To have a material impact on the concentration of carbon dioxide in the atmosphere would require a massive mining, mineral processing and distribution industry.
- The application of OAE would involve perturbing a global commons which creates governance challenges. An amendment (currently in progress) to the LC/LP would permit small scale research activities, but deployment would require further amendments.

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Ocean Fertilisation

Ocean Fertilisation (OF) involves enhancing the biological capacity of the oceans to draw down more CO_2 from the atmosphere. Photosynthesising organisms incorporate carbon dioxide that originates in the atmosphere into themselves as they grow and multiply. Some of this carbon will eventually end up in the deep ocean where it will be effectively stored away from the atmosphere for a sufficiently long period of time that it no longer has an impact on the climate.

Some parts of the ocean are deficient in micronutrients such as iron, the absence of which limits the growth of photosynthesising organisms. By enhancing the iron level in those parts of the ocean, more photosynthesis can occur and more carbon can be transported from the atmosphere to the deep ocean.

A small number of OF experiments have been undertaken—most with approval of national research establishments, but some without such approval. Those experiments that have been undertaken without approval have been highly controversial and have created a backlash against the technique as a whole. The results of the officially approved OF experiments have indicated, at least in some instances, that there has been net carbon drawdown, but there are still many unanswered questions as to the long-term effects of this technique.

Constraints

- OF is physically constrained by the area of ocean that is deficient in micronutrients and the effect that relieving that constraint would have on the net transfer of carbon from the atmosphere to the deep oceans.
- Serious environmental concerns have been raised about OF. The introduction of micronutrients into the ocean will alter the ecology of the oceans, favouring certain organisms at the expense of others. Increased photosynthetic activity could lead to increased ocean acidification and a decrease in dissolved oxygen.
- The efficacy of the process has been challenged. It is not sufficient for photosynthetic activity to increase—it is also necessary that carbon is transferred from the atmosphere to the deep ocean. Some studies show that a large fraction of the carbon removed from the atmosphere in the initial photosynthetic bloom is released back into the atmosphere as the algae die or enter the food chain.
- The governance issues relating to OF are complicated. Rules established by the London Convention/London Protocol (LC/LP) restrict activities to small-scale scientific experiments, while the Convention on Biological Diversity (which many commentators believe are acting beyond their remit) also seeks to restrict such activities.