Climate Megaprojects: Geoengineering for the Future

ENERGY INNOVATION REPORT

ENERGY IMPACT CENTER

The Clock is Ticking for Ambitious Solutions to the Climate Crisis

In the fight to slow climate change, scientists gave the world a stark warning: if emissions are to be limited to 2°C of warming, the world must cut planet-warming emissions in half by 2030 and reach a "carbon-neutral" state by 2050.[1] While nearly 200 countries have pledged to tackle this ambitious goal under the Paris Climate Agreement, 80% of all energy and transportation needs are still met by fossil fuels, a figure that has not budged significantly since the 1970s.[2, 3]

To this end, scientists and engineers are racing to find solutions to slow and reverse climate change. There are two main paths to reduce global warming: (1) reduce the amount of greenhouse gases (GHGs) that trap the Sun's energy in our atmosphere and (2) reduce the amount of the Sun's energy reaching Earth.[4] Measures such as carbon capture technologies or afforestation follow the first path. The second path features efforts to fundamentally alter the way our environment interacts with the sun.

Megaprojects to Remove CO_2 from the Atmosphere

Carbon dioxide (CO_2) is a major greenhouse gas, which not only captures energy from incoming solar radiation, but also prevents reflected solar energy from exiting the earth's atmosphere, causing temperatures to rise. Two approaches, which remove CO_2 from the atmosphere, are discussed: biomass energy with carbon capture and storage and direct air capture.

Biomass Energy with Carbon Capture and Storage

Fuel derived from biological material (biomass), like crops and trees, have been used for centuries to power residential, commercial, and industrial activities. Biomass energy has the potential to be carbon "neutral." Unlike the carbon stored in fossil fuels, which has been sequestered underground for millions of years, biomass carbon comes from plants that pull carbon from the atmosphere. However, efficiently growing and converting biomass into biofuels can be a challenge; the process is energy intensive and, if not implemented well, can consume fossil fuels in excess.[5]

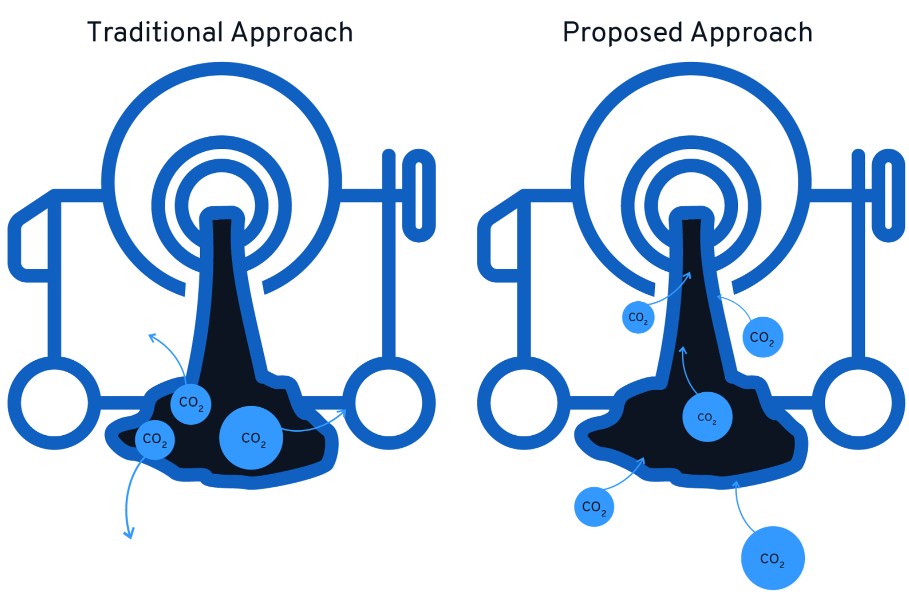
Thus, scientists are exploring methods for combining biomass energy with carbon capture and storage technologies to create a carbon neutral or even carbon negative energy source. The goal is to sequester carbon by growing crops, burn the resulting biomass for energy, and capture and store the CO_2 that results from the combustion. However, current agricultural practices are energy intensive. The emissions associated with the growing, harvesting, transporting, and processing biomass must be carefully managed to ensure emissions do not outweigh the carbon captured.[6] Furthermore, widespread deployment of biomass energy would require large amounts of water and land for growing crops.[7] This presents problems for nations with limited access to freshwater or land.

Direct Air Capture

Engineers and scientists have explored technologies to capture and remove CO_2 directly from the atmosphere. Without these technologies, carbon neutrality will be difficult to achieve. Two prominent approaches include direct capture from air scrubbers and cement curing.

Direct air capture pulls CO_2 from the atmosphere and either stores the trapped carbon or converts it into a commercial product, like hydrocarbon fuels. One company, Climeworks, is developing a system to isolate CO_2 from the atmosphere. The isolated carbon transported underground for storage, where it is converted into carbonate rocks. The process is not cheap and few markets exist to support the costs of geological storage.[8] Carbon Engineering, which deploys a similar direct air capture technology, directly converts CO_2 into hydrocarbon fuels. The approach is marketed as a carbon neutral alternative to fossil fuels.[9] While the company would prevent new carbon from being emitted into the atmosphere from fossil fuels, it would not reduce the current atmospheric levels of CO_2. A more detailed consideration of direct air capture technologies can be found in EIC's Energy Innovation Paper on the topic.[10]

Figure 1: CO2 in Traditional vs. New Carbon Curing



Investors are promising large amounts of capital for innovative ideas to open new markets for captured carbon. The XPrize Carbon competition is offering $25 million for "breakthrough technologies to convert CO_2 emissions into usable products."[11] One common approach proposed by a few of the competition's finalists targets a major source of CO_2 emissions, cement curing. Traditionally when cement is mixed and cured a major byproduct is CO_2. Given the massive scale cement is manufactured globally, the industry alone releases roughly 5% of global CO_2 emissions.[12] The new curing approach would flip the equation. Rather than producing CO_2 during the curing process, the new curing approach directly captures CO_2 from the air.[13] Cement would essentially go from a CO_2 emitting industry to a CO_2 sequestering industry.

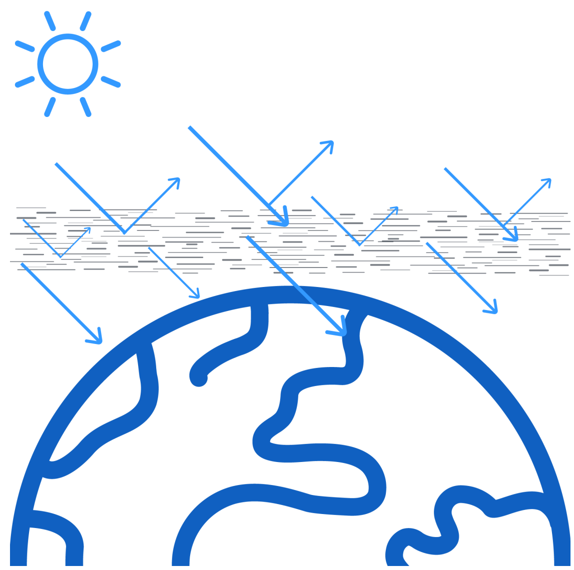
Megaprojects to Reduce the Energy Reaching Earth

In addition to reducing greenhouse gases in the Earth's atmosphere, scientists are looking to stop warming at the source: the Sun. Energy enters the Earth's atmosphere from solar radiation. Thus, technologies are being considered to reflect a fraction of this energy to help cool the globe. Two proposals are discussed: injection of aerosols into the stratosphere layer and mirrors in space.

Stratospheric Aerosol Injection

Scientists are exploring an option for releasing small particles, or aerosols, into the Earth's stratosphere to reduce the amount of energy absorbed by the Earth. By placing the aerosols 20 km above Earth's surface, a portion of the Sun's energy would be reflected, thus cooling the atmosphere (Figure 2). The approach mimics the effects of a volcanic eruption, which can release a blanket of sulfur dioxide into the stratosphere. In 1991 the eruption of Mount Pinatubo, which released 20 million tons of sulfur-dioxide (SO_2), cooled the planet by 0.5°C for around 18 months.[14]

Figure 2: Stratospheric Aerosol Reflection



This project would require a monumental effort. A team of researchers from Harvard University calculated that over a 15-year period, a fleet of up to 100 planes would need to fly between 4,000 to 60,000 missions annually to meet projected goals.[15]

While the overall cost is expected to only reach nearly $2 billion a year, new plane technology would be necessary to operate at the 20 km height, which is well above the elevation traveled by typical passenger airplanes.[16] High altitude balloon experiments are on-going to examine their feasibility. However, the approach remains controversial, given concerns for the human and ecological impacts.[17] In a 2015 review, a National Academy of Sciences committee of experts recommended against large scale injections, warning it could "carry risks that are poorly identified in their nature and unquantified."[18] Examples include potential reductions in ozone levels, which could increase the amount of harmful UV-B rays reaching the Earth's surface, and global precipitation patterns and amounts.

Space Solar Shield

Looking beyond the Earth's atmosphere, scientists are considering the feasibility of large mirror-like structures in space to reflect away the Sun's energy. Scientists estimate approximately 2% of the Sun's light would need to be continuously blocked to reverse the warming caused by the greenhouse gases released since the Industrial Revolution.[19] One proposal would send large reflective materials into Low Earth Orbit (LEO), the region of space just beyond Earth's atmosphere. The proximity of LEO to Earth would make transporting the materials relatively easy, however this region is home to many commercial satellites, the international space station, and plenty of space debris, which may interfere with the reflective infrastructure. Further, the materials would need to be regularly tended to, as solar radiation would slowly push the materials back into Earth's atmosphere.[20]

Scientists are setting their sights further into space. Between the Earth and the Sun, nearly 1/10 the distance to the Sun from Earth, there is a point where the gravitational pull of the Sun counteracts the Earth's.[21] This quasi-stable point, called the L1 Lagrange point, is being targeted as a location for deploying an array of reflective material to deflect incoming solar radiation from the Sun.[22]

The challenge, however, is that an area of approximately 4.5 million kilometers would need to be covered;[23] that is roughly half the surface area of the continental United States. Still, an astronomer from the University of Arizona would like to deploy 20 million tons worth of small reflective flyers, each the size of a large butterfly, to cover the necessary area.[24] Deploying these flyers, at a rate of 20 every 5 minutes for 10 years, would require new and emerging launch technology, at an expected annual cost of nearly $100 billion.[25]

Conclusion

Geoengineering could provide a rapid and large-scale solution to climate change, bridging the gap that adaptation and mitigation measures have been unable to fill. However, the risks of these megaproject interventions need to be fully assessed and weighed against their potential impacts. If financial cost, environmental externalities, and technological sophistication render these projects prohibitive, they may cause more problems than they solve. The solutions presented above may seem far-fetched today, but they offer a glimpse into how geoengineering may change the future.

Endnotes

Further information, references, and hyperlinks

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