# Fighting Fire with Fire: Geoengineering to Fight Geoengineering

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

Michael Chou

March 25, 2025

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

Advisor
Caitlin D. Wylie, Department of Engineering and Society

**Introduction:**

Climate change has devastating effects on the environment that have lasting effects on society. One such effect is the rise of global warming charged superstorms that wreak havoc on infrastructure and cost billions of dollars in damages each year (NASA Science Editorial Team, 2020). In addition, the heavy storm damage also adversely impacts human health physically through the spread of waterborne illnesses and mentally, leading to socioeconomic problems such as financial burdens and depression (National Institute of Environmental Health Sciences, n.d.). As factories, aircraft, and livestock continue to provide for human necessities, the emissions produced unintentionally geoengineer the climate to be more hostile. Without a way to reduce and remove these greenhouse gases, society will continue to be battered by the effects of climate change.

One solution is geoengineering, which can be defined as human alteration of the climate. The same concept that poisoned the Earth will now be analyzed in this paper as a possible short-term solution for climate change. Currently, the two different geoengineering methods for combatting climate change are Carbon Dioxide Removal (CDR) and Solar Radiation Management (SRM). CDR focuses on removing the carbon dioxide greenhouse gas from the atmosphere, while SRM focuses on reducing the amount of solar radiation that gets absorbed on the surface of the Earth (Royal Society of London, 2009).

A utilitarian analysis – which focuses on maximizing the happiness of all people involved in an action, or from a technology – will be used to analyze the benefits and drawbacks of these geoengineering methods (Reuter, n.d.). However, there are also drawbacks to this method of analysis since it has a people-centric perspective of analysis. Climate change is a global and

environmental issue, and although it has impacts on people, it affects the planet's ecosystems much more.

This paper will argue that geoengineering is a beneficial short-term solution for climate change by deep diving into the details, benefits, and limitations of CDR and SRM, analyzing shortcomings of Utilitarianism while introducing better theories, and providing a rebuttal for an argument against investing in geoengineering.

**The Argument for Carbon Dioxide Removal**

Anthropogenic Carbon Dioxide emissions are the driving force behind global warming, and even if emissions slowed significantly, the Earth would continue to heat up for several more years (Alexaidis, 2007). With that problem in mind, several geoengineering solutions have been proposed that all involve removing Carbon Dioxide from the atmosphere. Carbon Dioxide Removal (CDR) is the method of removing carbon dioxide from the atmosphere through artificial or plant-based means, and has already been well established in research with known consequences. (Royal Society of London, 2009). It's also arguably one of the best methods of geoengineering because removing carbon dioxide directly from the atmosphere helps restore balance to the carbon cycle.

One example of CDR is the removal of carbon dioxide for the production of a more sustainable concrete. Calcium carbonate ($CaCO_3$) is an important filler used in strengthening concrete and can be created by combining carbon dioxide with quicklime (calcium oxide, CaO) and ammonium salts ($NH_4X$) that help improve solubility with carbon dioxide (Hargis, 2021). When carbon dioxide is passed through the solution of ions, a precipitate of calcium carbonate is created. The remaining solution consists of the dissolved ammonium salts that can be reused to

create more calcium carbonate. This method is both effective in removing the greenhouse gas and also reduces the amount of resources needed to produce concrete, limiting the amount of emissions released in producing regular concrete.

$$2NH_4Cl_{(aq)} + CaO_{(s)} + H_2O_{(l)} \rightarrow 2NH_4OH_{(aq)} + CaCl_{2(aq)}$$

$$2NH_4OH_{(aq)} + CaCl_{2(aq)} + CO_{2(g)} \rightarrow (NH_4)_2CO_{3(aq)} + CaCl_{2(aq)} + H_2O_{(l)}$$

$$(NH_4)_2CO_{3(aq)} + CaCl_{2(aq)} \rightarrow 2NH_4Cl_{(aq)} + CaCO_{3(s)}$$

*Figure 1: Chemical equations that show how sustainable concrete is produced, from Hargis's research paper (Hargis, 2021)*

From a Utilitarian and Actor Network perspective, this method of CDR benefits almost all of the parties involved. By definition, the Actor Network Theory analyzes issues by looking at all actors, or groups/parties of people, involved in the issue (Birbak, 2023). The calcium carbonate produced and mixed into the concrete strengthens the concrete and provides sturdier homes for the people living in housing made from this material (University of Tokyo, 2024). The people living around the factories see a benefit in health from the capture technology reducing emissions. Those living around the quarries that mine the limestone (calcium carbonate) that is already used in concrete benefit from the reduction of quarry activities that produce dust particulates and combustion engine emissions that negatively impact human health. The only party that would be negatively affected would be the people whose primary source of income is from working at the quarries. However, it could be argued that other construction-oriented job

opportunities could be open and that their long-term health would be better off by not breathing in harmful pollutants produced from digging at quarries.

That statement above, however, would be used as an argument against the Utilitarian generalization of people based on the Kantian ethical principle that people can not be treated as a means to an end (Alexander, 2007). That being said, the means of targeting one group of people and taking away jobs from those who work at the quarry would not be ethical, even with the end goal of reducing emissions and providing better health for those living around the quarries. The Utilitarian argument in the statement above, where other jobs could be found, also undermines the skills and abilities of people. Quarry work can be niche, and many other construction jobs might not have the same type of construction skills used, even if they both involve excavation and demolition.

Other examples of CDR involve more organic solutions. One such solution that has gained popularity is an algae-filled box that, although looking drab, has benefits over trees by being both space-saving and relatively fire-resistant compared to the traditional trees that line city streets, according to Popular Mechanics (Grossman, 2019). A Texas-based company, Hypergiant, has been optimizing the algae box by giving it machine-learning capabilities to adapt to light and other environmental factors, allowing it to maximize oxygen production. However, I am a bit skeptical about this source because the Vice President of Future Science and Research at Hypergiant, Kristina Libby, is also a contributor at Popular Mechanics magazine. This raises questions on how much influence a profit-driven company would have in a scientific magazine, and how much of the information given is pure optimism versus already working prototypes.


*Figure 2: Hypergiant's algae box, from Adele Peters reporting on Hypergiant's algae box development (Peters, 2019)*

Although a lot of bias with companies and news connections are present in this source, algae have been proven to be a significant contributor of oxygen worldwide and grow quickly, allowing for rapid development of these algae tree boxes. According to an article written by Chapman in the journal Mitigation and Adaptation Strategies for Global Change, algae provides about 50% of all oxygen in the atmosphere (Chapman, 2013). In addition, algae have had billions of years to evolve and become as efficient as they are now, and are also capable of reproducing and spreading quickly. In addition to the benefits of removing carbon dioxide from the

atmosphere, algae research is also prominent in pharmaceutical usage as well as for sustainable biofuels.

The Popular Mechanics source was used to show that because of how stable and sustainable this option for CDR is, larger companies have begun optimizing this method in the form of machine learning to provide more oxygen and therefore reduce carbon dioxide in the air. However, one argument against the algae box CDR method is that it doesn't provide the same benefits that traditional trees do. Although it is more space-saving than trees, it doesn't provide the shelter and shade that trees give for both humans and animals. The sunlight hitting the bare concrete sidewalk can also raise temperatures in cities during the summer, causing thousands of homes to use more power to prevent heat exhaustion. Although the challenges to algae boxes are real, algae have been proven to be more space efficient, and as a result purely for CDR methods, a proven and reliable method.

**The Argument for Solar Radiation Management**

Solar Radiation Management (SRM) is the other main type of geoengineering described by the Royal Society of London. Its primary way of combatting climate change is redirecting solar energy away from the Earth by creating reflective surfaces through cloud seeding or constructing large artificial structures to counter the effects of global warming and cool the Earth (Royal Society of London, 2009). Due to the grandeur and scale of these projects, SRM is often included in works of science fiction. However, I would argue that SRM is worth investing research in because its projects have additional benefits in addition to stopping global warming.

For example, one proposed method of SRM is placing large reflective mirrors, or a collection of many small mirrors, into space to direct sunlight away from the Earth. This

prevents solar energy from scattering in the atmosphere by preventing it from reaching the Earth at all. In addition to reducing the amount of solar energy reaching the Earth, these mirrors could also be designed to beam light directly at specific spots on the Earth giving it the ability to prolong solar plant operations even after the sun has set (Pultarova, 2024).

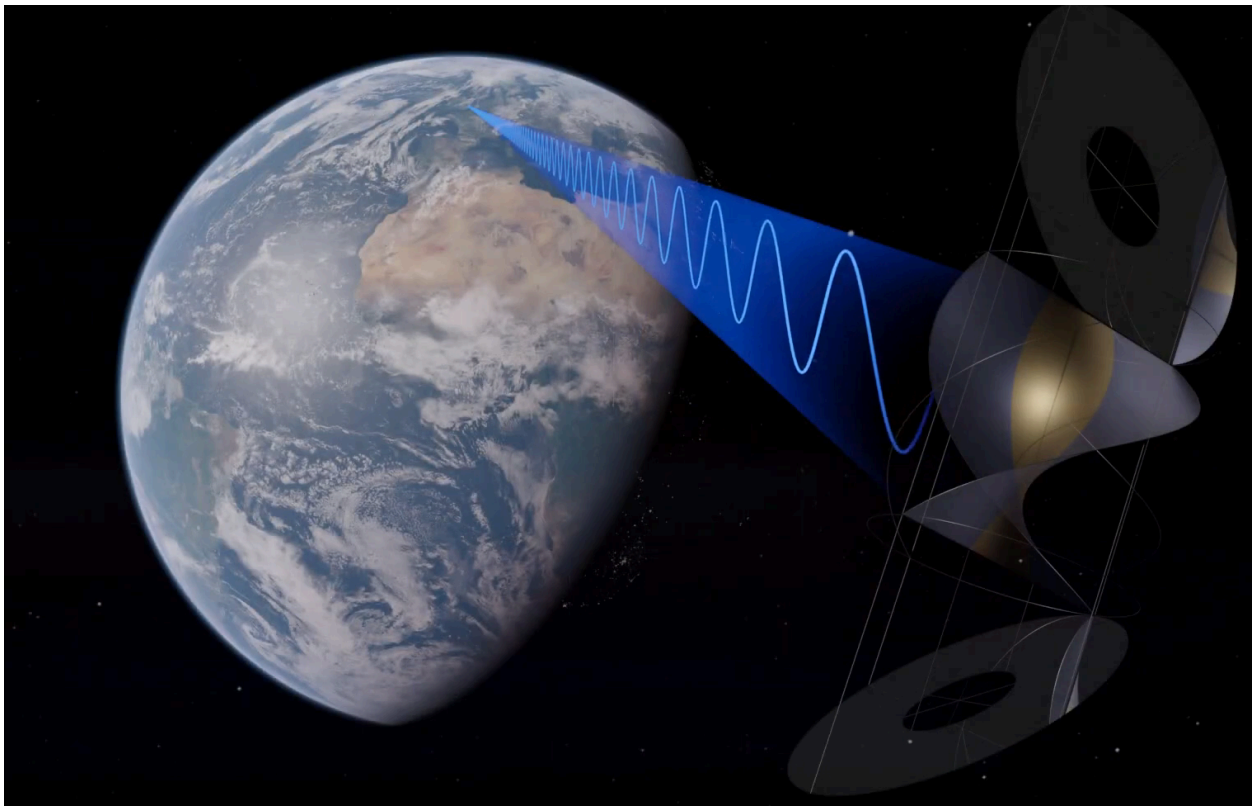

*Figure 3: Image from a concept video showing how mirrors in space can prolong solar farm operations (Pultarova, 2024)*

Although this source reports on Reflect Orbital, a profit-driven company at a conference, hosted by this website's organization, this source itself is useful in seeing that this type of project – sending mirrors into space – has become much more feasible and worth investors' money in the last two decades since the Royal Society of London wrote its publication on geoengineering. Additionally, a Utilitarian perspective can be used to argue in favor of this method of SRM.

While Reflect Orbital is primarily profit-driven and seeks to charge consumers more for the elevated energy generated during peak energy use hours of twilight, the development of this technology allows competing companies to be created that force down the prices to acceptable consumer levels. In addition, government economic regulations can prevent Reflect Orbital from becoming a twilight solar power monopoly. From a Utilitarian perspective, with the assumption that companies are much more in tune with the ethics and equity of their products, Reflect Orbital's increased energy generation can provide more clean energy during peak twilight electricity use hours that benefit many groups of people. This increased solar energy cuts the amount of pollutants released by nonrenewable power plants. This increases air quality in the surrounding areas, benefiting not only recipients of increased power but also residents near nonrenewable energy plants.

Another method of SRM is cloud seeding. This works by spraying chemicals or particulates into clouds to encourage the nucleation of water droplets (Nicholson, 2020). The water droplets in the atmosphere then form bright white clouds that reflect solar radiation back into space. Although it is still considered experimental, it is already being used by 8 of the US states and the United Arab Emirates, but not for the purposes of solar radiation reflection. These areas use cloud seeding for the additional benefits of water. The denser clouds with artificially created water droplets can cause rain to fall sooner in places that have experienced droughts.

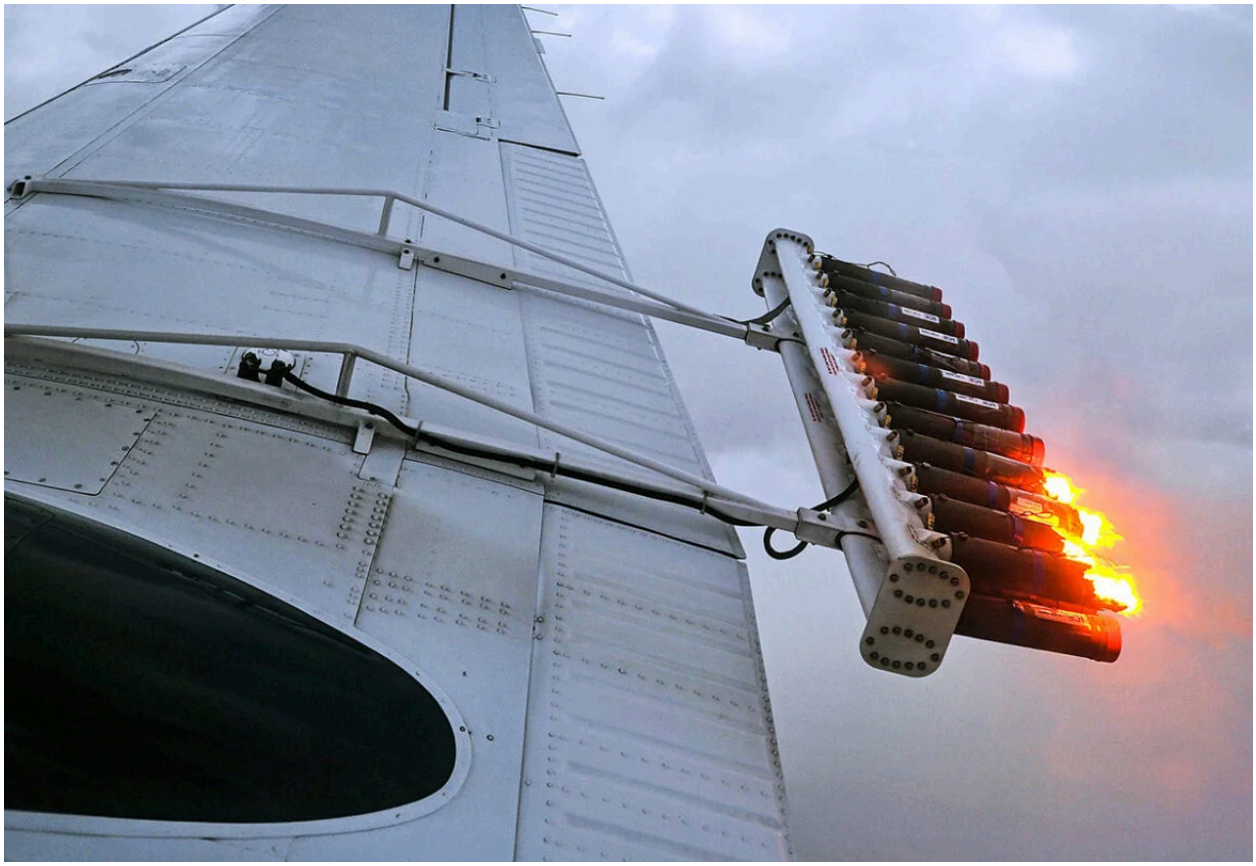

*Figure 4: Ignited flares burning salts into the atmosphere to encourage cloud formation, from Anup Maurya reporting on cloud seeding (Maurya, 2024)*

However, because cloud seeding draws moisture directly from the atmosphere, regions downwind of the seeding location can experience their own water shortages due to the moisture in the atmosphere being used prematurely. In addition to this consequence, cloud seeding also uses harmful chemicals such as sulfur dioxide that can break down stratospheric ozone critical to absorbing and keeping harmful UV rays from hitting the Earth's surface (Crutzen, 2006). From a Utilitarian perspective, this shows that SRM, in the form of cloud seeding, is not a good solution to combating climate change.

**Why Doesn't Utilitarianism Work By Itself?**

Utilitarianism has a critical analytical flaw where it only focuses on human well-being and happiness. This can leave environments and entire ecosystems out of the beneficial analyses of Utilitarianism. This brings us to the perspective of the Environmental Ethics Theory. This perspective argues that we should protect the environment as a part of engineering design, in addition to ourselves (Stanford Encyclopedia of Philosophy, 2007). With regards to the issue of cloud seeding, the extra shade from the reflective clouds has helped offshore reefs off the coast of Australia recover from bleaching, and the extra moisture can create fog and low-level clouds that give redwoods and other tall trees the moisture needed to survive in a drying environment (Temple, 2017). Both of these environments benefitting from the effects of SRM shows the limitations of using the theory of Utilitarianism in analyzing climate change effects.

A counterargument for Utilitarianism's lack of environmental concerns can also be made using Utilitarianism. Specifically, the argument that benefitting the environment benefits human happiness. From the environmental examples above, Australian reefs are a huge source of tourism and keeping the reefs healthy would continue to benefit the local tourism industry. According to the Great Barrier Reef Foundation, the largest of Australia's offshore reefs, the Great Barrier Reef, is estimated to be worth $56 billion in terms of a total economic, social, and icon asset value (Great Barrier Reef Foundation). Losing the Great Barrier Reef would not only mean losing a large biodiverse ecosystem but also 64,000 Australian jobs. Large redwoods and other moisture-absorbing trees provide oxygen and absorb toxins in the atmosphere, leading to better health for all people. This leaves the argument that although cloud seeding has significant drawbacks and unknown consequences, it provides a short-term solution for combatting climate

change by providing water for drought-affected populations, and by preserving environments and ecosystems through added moisture or reducing temperature.

**The Reason Against, and For Geoengineering**

Geoengineering provides short-term solutions for combatting the effects of climate change, but its technological novelty means that efforts to construct and enact the projects are often more expensive. On the flip side, education and government policies target the source of climate change – greenhouse emissions from individual and industrial use. A study done by Dr. Eugene Cordero, a professor from the Department of Meteorology and Climate Science at San José State University, showed that if climate change education were given to hundreds of millions of primary and secondary school students, an estimated 18.8 gigatons of CO2 emissions can be reduced in 30 years (Cordero, 2020). The knowledge of individual carbon-reducing practices is also transferable from student to parent, peer to peer, and via advertisements and posters which can further spread the knowledge of greener practices. These greener practices also often target the reliance on the power grid, not only reducing the homeowner's carbon footprint but also saving money on electricity bills. This leads to the argument that education and policy efforts are more effective at reducing the effects of climate change and that funding should be invested in education and policy efforts instead of geoengineering.

As shown in the Figure 5, education is a largely effective method for encouraging carbon reduction, but Cordero has also accurately placed concern on the effectiveness of education depending on the actions of individuals. However, the graphic also shows that there are still many different ways CO2 emissions can be reduced at their source without the need for geoengineering. Rooftop solar and offshore wind provide power with less reliance on traditional

combustion power plants; LED bulbs and home insulation are methods that reduce a residence's reliance on power from the grid by increasing efficiency and decreasing power consumption; and afforestation, the establishment of trees/forest where there was none before, is a much cheaper and natural alternative to the organic CDR solutions.

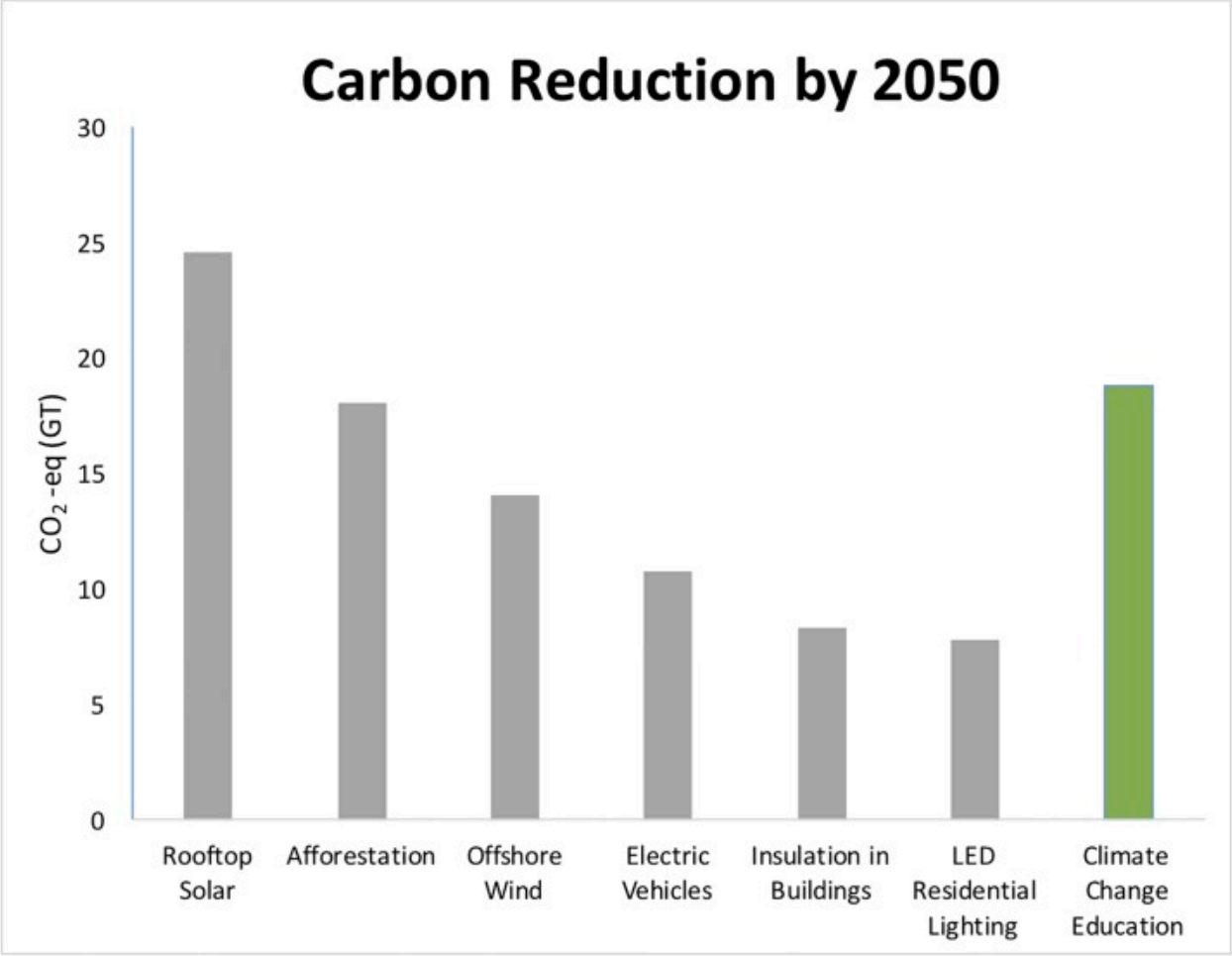


*Figure 5: Carbon reductions by 2050 according to estimates by Cordero (Cordero, 2020)*

Although education and these other efforts show their investment worth, it takes time for their change to show. Figure 5 itself shows this issue since it will take at least 30 years for the total tonnage of CO2 shown to be reduced. In addition, large fossil fuel companies often lobby against stricter regulations in favor of profit, leaving government policies and regulations at the

mercy of personal gain and corruption (Institute at Brown for Environment and Society, 2020). Misinformation, whether intentional or unintentional, also plays an important role in slowing the effectiveness of education and policies.

On top of those political drawbacks, the world is still industrializing. From a mixed perspective of Dependency Theory and Justice Theory, an argument can be made that underdeveloped countries have a right to industrialize without restrictions just as developed countries have. Dependency Theory states that unfair treaties and restrictions imposed by developed countries prevent underdeveloped countries from developing (Munro, 2025). Justice Theory states that individuals or groups should make choices that ensure equal opportunity for all (Rawls, 2003). Together, these theories argue that climate change laws – while good for the environment and health of the planet – are unfair to developing countries attempting to industrialize. The increased cost of greener technologies that developing countries would have to use would keep those countries dependent on industrialized countries for resources and technologies. If the developing countries are fairly allowed to industrialize, the developed countries would have to take the burden of industrialization to maintain climate change mitigation efforts. This increased burden would mean that the developed countries would essentially have to stop all emissions resulting in job losses, travel limitations, and almost all funding towards green technology research versus necessary infrastructure to keep a nation running. To prevent this ethical dilemma, short-term solutions are needed to keep all nations of the world running fairly. The short-term solution that can combat the effects of hundreds of years of pollution from geoengineering would be geoengineering itself.

**Concluding Remarks**

Based on the evidence given in the arguments above, geoengineering is an effective short-term solution to combatting the effects of climate change. Since the Industrial Revolution, we have already geoengineered our planet to fuel superstorms and droughts with runoff pollution and greenhouse gases. At the rate that we as a human race are developing and producing, completely cutting off production for the result of a healthier climate would be catastrophic to society. While we continue to develop cleaner and more efficient energy sources, geoengineering needs to be the temporary solution that keeps the damaging effects of an accelerating climate clock in check. However, it should also be noted that some questions for further research come up following this argument. How long will geoengineering be a “temporary” solution? Since we didn’t know the effects of industrialization, what implications of geoengineering might we be overlooking?

**References**

Alexander, L., & Moore, M. (2007). *Deontological Ethics*. Stanford Encyclopedia of Philosophy. https://plato.stanford.edu/entries/ethics-deontological/?trk=article-ssr-frontend-pulse_x-social-details_comments-action_comment-text#DeoTheKan

Alexiadis, A. (2007). *Global warming and human activity: A model for studying the potential instability of the carbon dioxide/temperature feedback mechanism*. Ecological Modelling, 203(3), 243–256. https://doi.org/10.1016/j.ecolmodel.2006.11.020

Bijker, W. (2017). *Constructing Worlds: Reflections on Science, Technology and Democracy (and a Plea for Bold Modesty)*. Engaging Science, Technology, and Society, 3, 315–331. https://doi.org/10.17351/ests2017.170

Birbak, A. (2023). *Actor-Network Theory*. Obo. Retrieved April 29, 2025, from https://www.oxfordbibliographies.com/display/document/obo-9780199756384/obo-9780199756384-0266.xml

Brennan, A., & Lo, N. Y. S. (2024). *Environmental Ethics*. In E. N. Zalta & U. Nodelman (Eds.), The Stanford Encyclopedia of Philosophy (Summer 2024). Metaphysics Research Lab, Stanford University. https://plato.stanford.edu/archives/sum2024/entries/ethics-environmental/

Chapman, R. L. (2013). *Algae: The world's most important "plants"—an introduction*. Mitigation and Adaptation Strategies for Global Change, 18(1), 5–12. https://doi.org/10.1007/s11027-010-9255-9

Cordero, E. C., Centeno, D., & Todd, A. M. (2020). *The role of climate change education on individual lifetime carbon emissions*. PLoS ONE, 15(2), e0206266. https://doi.org/10.1371/journal.pone.0206266

Crutzen, P. J. (2006). *Albedo Enhancement by Stratospheric Sulfur Injections: A Contribution to Resolve a Policy Dilemma*? Climatic Change, 77(3), 211–220. https://doi.org/10.1007/s10584-006-9101-y

Gadikota, G. (2021). *Carbon mineralization pathways for carbon capture, storage and utilization*. Communications Chemistry, 4(1), 1–5. https://doi.org/10.1038/s42004-021-00461-x

Grossman, D. (2019). *The Machine That Uses Algae to Eat Carbon Dioxide*. Popular Mechanics. https://www.popularmechanics.com/technology/infrastructure/a29329352/machine-uses-algae-eat-carbon-dioxide/

Hargis, C. W., Chen, I. A., Devenney, M., Fernandez, M. J., Gilliam, R. J., & Thatcher, R. P. (2021). *Calcium Carbonate Cement: A Carbon Capture, Utilization, and Storage (CCUS) Technique*. Materials, 14(11), 2709. https://doi.org/10.3390/ma14112709

*Human Health Impacts of Climate Change*. (n.d.). National Institute of Environmental Health Sciences. Retrieved October 29, 2024, from https://www.niehs.nih.gov/research/programs/climatechange/health_impacts

Lee, D. S. et al. (2021). *The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018*. Atmospheric Environment, 244, 117834. https://doi.org/10.1016/j.atmosenv.2020.117834

Maurya, A. (2024, May 10). *What Is Cloud Seeding? How Does It Works And It's Cost*? - TECHARGE. https://techarge.in/what-is-cloud-seeding-how-does-it-works-and-its-cost/

Munro, A. (2025, March 7). *Dependency Theory*. Encyclopedia Britannica. https://www.britannica.com/topic/dependency-theory

NASA Science Editorial Team. (2020, March 10). *How Climate Change May Be Impacting Storms Over Earth's Tropical Oceans*. NASA Science. https://science.nasa.gov/earth/climate-change/how-climate-change-may-be-impacting-storms-over-earths-tropical-oceans/

Nicholson, S. (2020, September 30). *Solar Radiation Management*. Wilson Center. https://www.wilsoncenter.org/article/solar-radiation-management

Peters, A. (2019, September 17). *This "personal carbon sequestration" device uses algae to remove CO2 from the air*. Fast Company. https://www.fastcompany.com/90404556/this-personal-carbon-sequestration-device-uses-algae-to-capture-co2

Pultarova, T. (2024, April 24). *Mirrors in space could boost solar power production on Earth. Here's how*. Space.Com. https://www.space.com/orbiting-mirror-boost-solar-power-production

Rawls, J. (2003). *A theory of justice (Rev. ed., 5.-6. printing)*. Belknap Press of Harvard Univ. Press. https://www.production.hup.harvard.edu/file/feeds/PDF/9780674042582_sample.pdf

Rueter, S. (n.d.). *Ethical Theories: Virtue Ethics, Utilitarianism, and Deontology*. Philosophos.Org. Retrieved November 8, 2024, from https://www.philosophos.org/ethical-theories-virtue-ethics-utilitarianism-deontology

Royal Society of London (Ed.). (2009). *Geoengineering the climate: Science, governance and uncertainty*. https://royalsociety.org/-/media/policy/publications/2009/8693.pdf

Temple, J. (2017, April 20). *Scientists Consider Brighter Clouds to Preserve the Great Barrier Reef*. MIT Technology Review. https://www.technologyreview.com/2017/04/20/5006/scientists-consider-brighter-clouds-to-preserve-the-great-barrier-reef/

*The Value of the Reef*. (n.d.). Great Barrier Reef Foundation. Retrieved February 9, 2025, from https://www.barrierreef.org/the-reef/the-value

*Understanding Delay on Climate Change* | Institute at Brown for Environment and Society | Brown University. (2020, October 07). Retrieved March 30, 2025, from https://ibes.brown.edu/news/2020-10-27/climate-change-delay

University of Tokyo. (2024). *Researchers fabricate calcium carbonate concrete blocks strong enough for construction use*. Retrieved April 29, 2025, from https://techxplore.com/news/2024-08-fabricate-calcium-carbonate-concrete-blocks.html

US EPA, O. (2021, August 23). *End-of-Life Solar Panels: Regulations and Management [Guidance (OMB)]*. https://www.epa.gov/hw/end-life-solar-panels-regulations-and-management