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Geoengineering & Climate Change

The term *geoengineering* encompasses a wide range of ideas- from utilizing the radiative forcing effects of aerosols, to putting *mirrors* in space. The idea behind it is to essentially compensate for the warming we have caused by removing CO2 from the atmosphere or reflecting solar insolation that would otherwise be hitting the earth, warming it further (Burns, 2013). Though broad; its official definition is humans' intentional altering of planetary-scale processes (Caldeira et al., 2013). Our alterations are essentially what got us into this mess, so maybe they could help us fix things, right? We've already released more than our fair share of CO2 emissions from rapid industrialization and deforestation, and now we must do something about it. Perhaps the most controversial aspect of deciding whether to implement *geoengineering* as this solution is the ethics- what is the appropriate extent of human intervention in the management of planetary systems? As Keith (2000) puts it, "we would be wise to begin with a renewed commitment to reduce our interference in natural systems rather than to act by balancing one interference with another." In this review of scientific literature, I will discuss the primary areas of focus for geoengineering research, as well as the potential downsides and risks to implementation.

There are two main methods of geoengineering: solar radiation management and carbon capture/removal. Solar radiation management (SRM) deals with albedo, or the reflectivity of surfaces. The idea is to reflect a small portion of sunlight away from the earth and back out to space, or increase the amount of re-radiated solar energy escaping our atmosphere. This method of addressing climate change does not hit the root of the problem, but instead aims to “break the link” between concentrations and temperature changes (Harvard). To effectively offset the positive radiative forcing of CO2 emissions, would require a diversion of approximately 1.8% of incoming solar radiation, or an increase of solar radiation reflected by the planet from current 107 to 111 W/m2 (The Royal Society, 2009). This can be done in a number of ways, including surface albedo approaches- making the planet reflect more insolation by making the land-surface brighter, such as with ‘white roof’ methods in urban areas; however, this is a highly localized approach, and furthermore the vast majority of earth’s surface is covered by oceans. This makes land-surface albedo approaches patchy, and possibly ineffective even if deployed at their maximum potential. Another SRM option would logically be ocean and/or cloud albedo enhancements, since much more surface area would be covered; however, this has its drawbacks as well. Feasibility is uncertain, with deployment and replenishment posing an issue, as well as a lack of much research on the implications of this method (The Royal Society, 2009). Yet another method of solar radiation management is stratospheric injection of aerosol particles. There have been studies on deliberately injecting sulfuric acid particles into the stratosphere to mimic volcanic interjections, to scatter solar radiation back to space (Pope et al., 2012). However, the substance of the sulfuric acid particles is debatably not optimal for scattering solar radiation, and there is still much research to do on the possible adverse effects on the ozone layer and other residual effects (Pope et al., 2012; The Royal Society, 2009). It seems we've got plenty of ideas on solar radiation management approaches, but there are numerous kinks that need to be further fleshed out.

The other (and likely more well-known) branch of geoengineering schemes is carbon dioxide removal, also known as carbon capture & storage. This method maintains the use of fossil fuels for energy, while still reducing the amount of carbon emitted to our atmosphere. CO2 is captured upon release from a factory/plant, then moved to storage in deep geologic formations or the ocean. Though technologically feasible, this is a relatively expensive mitigation option- costing approximately $200-250 per ton of carbon (Anderson & Newell, 2004). The technology available allows capture to take place either post-combustion, taken directly from the flue gas from smokestacks, or pre-combustion, which requires a bit more modifications to plant functioning. Either way, this process entails compressing the captured CO2 to a "supercritical state" where it behaves as a liquid and can then be transported through a pipeline and injected deep underground (Rubin et al., 2012). Ocean-storage options are a bit more uncertain, while deep aquifers and/or depleted oil & gas reservoirs are viable options, with further research.

In theory, geoengineering sounds like a pretty decent idea; however there are quite a few drawbacks to this approach. From issues of moral authority to unintended side effects, there are plenty of reasons this may be a very bad idea. First off, who would control such a planetary-scale operation? Does the USA have a means or a right to take this into our hands? We would most certainly encounter opposition as SRM approaches not only affect our own country, but the entire *globe*. In fact, there is currently a treaty in place explicitly prohibiting “military or any other hostile use of environmental modification techniques having widespread, long-lasting or severe effects as the means of destruction, damage, or injury to any other State Party.” Any geoengineering scheme that adversely affects regional climate, for example, producing warming or drought, would/could therefore violate this ENMOD (environmental modification) treaty (Robock, 2008). Furthermore, investment in either branch of geoengineering (SRM or CDR) takes time and money away from investing in renewable resources such as solar or wind that would address the root of the climate change problem. This could undercut human resolve to deal with the original cause of the problem (Blackstock et al., 2009). In addition to the cost and time consumption, we must also take into account deployment methods for such approaches. We might have the knowledge to understand that changing the amount of insolation hitting the globe would do well to mitigate the effects of climate change, but how would we go about planting particles in the stratosphere, for example? Any system capable of injecting aerosols that far up into the stratosphere would likely cause enormous environmental damages (Robock, 2008). The cure might be worse than the disease. With any solar radiation management option, there are still impacts of climate change left unaddressed. We know little-to-nothing about a wide range of other ecological and climate parameters, such as regional precipitation, atmospheric and oceanic circulation, ecosystem productivity, etc.. For instance; terrestrial ecosystems play a critical role in the global carbon cycle. According to Govindasamy et al. (2002), photosynthesis of plants is impacted by increased levels of carbon dioxide (the so-called CO2 fertilization effect) and reduced levels of solar input. At lower levels it is known that increased CO2 concentrations can enhance physiological effects on plants' productivity and water use efficiency; however, these benefits diminish with increasing CO2 concentrations. Another overlooked problem is increasing ocean acidity with rising CO2 concentrations, which would not be solved by decreased insolation.

In short, there are countless complex systems interconnected and occurring simultaneously across the planet. There are many less-than-obvious downstream effects that we just can't account for. We simply *don't know* the extent to which geoengineering could help or hurt us, other organisms, and ecosystems. To date we have really only tested these processes virtually by programming climate models, which has in fact shown us some of these unintended consequences. For instance, modeling has suggested that injection of aerosols into Arctic air would help with global warming and melting of ice sheets, but it would concurrently disrupt global patterns of precipitation, which could further alter areas of drought and monsoons (Denny, 2017). This goes to show that *if* we were to utilize geoengineering to mitigate effects of climate change- we still have a long way to go with gathering research. And, with increasing impacts of global climate change, we cannot rely too heavily on a method that does not address the root cause of the problem. Taking action by geoengineering the world's climate could potentially offset warming, but should be undergone with caution, helping only to provide additional time to reduce human dependence on fossil fuel energy sources- not as a long-term solution (Wigley).

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