The Case for Geoengineering

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The world community can act immediately to stabilise planetary temperature in the decade of the 2020s if governments agree to implement a major collaborative research program on geoengineering by Solar Radiation Management (SRM).

We are in a climate emergency. The dangerous trends of global warming, extreme weather, rising sea levels and collapsing biodiversity must all be reversed. Rapid action to cool the planet is the essential starting point. An intensive geoengineering program can prevent temperature rising above the 1.5° C target. Political, moral, technical, ecological and economic arguments must be made for the urgent necessity of geoengineering as a crucial factor in cooling. This document begins to make this case.

The recent 6th Assessment Report of the IPCC on physical science (WG1 TS.8) states "investigations have consistently shown that SRM could offset some of the effects of increasing greenhouse gases (GHGs) on global and regional climate." And yet widespread public suspicions remain, enough to prevent field research, and contributing to the surprising omission of geoengineering from the IPCC AR6 WG1 Summary. These popular doubts reflect a combination of legitimate political and practical concerns together with serious misconceptions.

Public understanding can be improved through a robust strategic analysis of alternative planetary paths. We need to compare a future without geoengineering to a future where this innovative technology research is supported. Which path is more dangerous? SRM could be like a planetary vaccine, mitigating extreme climate risks, just as COVID-19 vaccines have prevented the worst effects of the viral pandemic through cooperative technology and leadership.

The key issue should be whether the expected benefits of geoengineering justify investment in field research. To answer this question, it is essential to establish an unbiased view about geoengineering's capabilities and risks, countering popular myths that now undermine public debate. The effects of misinformation are serious: the widely held view of geoengineering as only a last resort creates major risk of delaying necessary research, leaving the world dangerously exposed, unable to deploy technology based on sound information.

SRM has major benefits. It can reduce temperatures on the whole planet, and can mitigate numerous harms and risks from global warming such as methane release, sea level rise, severe weather events and biodiversity loss. The debate is already shifting in recognition of these benefits, with the US National Academies of Sciences, Engineering, and Medicine producing a major report in 2021 calling for geoengineering research.

Geoengineering can use both natural cooling processes and technological approaches. Methods that should be intensively studied to determine their safety and efficacy include the following.

- Marine Cloud Brightening (MCB) can mitigate extreme weather by adding salt to the air. Brighter clouds cool the ocean surface, cutting the intensity of storms, refreezing the poles and helping manage local impacts of ocean heat on drought and flood and

ecosystems. MCB trials are currently funded by the Australian Government to cool the Great Barrier Reef to stop coral bleaching.

- Mirrors for Earth's Energy Rebalancing (MEER Reflection) offer local and regional cooling solutions based on deployment of arrays of mirrors on the earth's surface.
- Wind driven sea water pumps could increase Arctic winter ice formation, slowing summer ice melt and methane release.
- Floating Sand is a localized technique to improve polar ice reflectivity.
- Iron Salt Aerosol can extend the numerous natural cooling effects of iron-rich dust, cutting methane, brightening clouds and increasing ocean biomass productivity.
- Stratospheric Aerosol Injection, copying the major natural cooling effect of volcanic eruptions, could be the single most cost-effective planetary cooling method, subject to proof of safety.
- Cirrus Cloud Thinning could reduce heat trapping in the upper atmosphere.

Key factors in assessing whether to consider these proposals include the reality of accelerating climate change, the manifest inadequacy of current approaches under the Paris Accord, and the likelihood of strong ecological and economic benefits of proposed cooling technologies. Serious consideration of these factors suggests that geoengineering research should be our first resort, not our last, and that geoengineering deployment is likely to be far more effective than decarbonisation as a main climate response.

It appears that only geoengineering can have the immediate cooling effects needed to stop the looming danger of tipping points leading to a hothouse earth. The suffering caused by climate change - droughts, floods, storms, ecosystem collapse, economic stress and resulting conflict - can only be mitigated in the short term by concerted action to brighten the planet and remove excess heat.

Direct cooling measures require new integrated thinking about world politics. Humanity has caused climate chaos, and now has the responsibility to create climate order by regulating the brightness and composition of the atmosphere. Geoengineering offers essential cooperative means to promote planetary peace and security, establishing a path toward planetary restoration. Such a cooperative international program, preferably led by the G20, would build confidence between great powers, reduce risks of economic collapse and military conflict, protect biodiversity and strengthen environmental justice for the world's poor.

Refreezing the Arctic should be the first goal of a cooperative geoengineering program. Sir David Attenborough recently expressed the urgency of the Arctic situation, saying

> "Refreezing the Arctic, were it possible, would be a huge defence against the global catastrophes currently threatened by continued global warming".

New political thinking to refreeze the Arctic could be led by G20 nations as part of a new vision for our planet. The G20 could begin to oversee deployment of methods to refreeze the Arctic within two years. Such cooperation to enhance planetary brightness will require new multilateral governance arrangements which will also be suited to cutting the level of GHGs in the atmosphere. A planetary strategic vision on climate policy should

begin with SRM and also support GHG removal and emission reduction as a feasible threefold path, a three-legged stool, with the goal to secure durable planetary stability.

An emergency SRM response can prevent accelerating feedbacks that are now amplifying global warming. Such an approach can be the start of a new sustainable relationship between humanity and our planetary home. If it proves possible to stabilise the climate with SRM, humanity will then have an ongoing global regulatory challenge to cut GHGs to safe levels and stop them from ever rising to dangerous levels again.

SRM should be the starting point for a shift to a truly sustainable planetary civilization, supporting a path to lasting peace and prosperity for all. Geoengineering with SRM will require practical international cooperation with benefits for global security, stability and confidence. The aim should be to integrate care for nature with care for humanity, the ethical objective set by Pope Francis in his 2015 encyclical *On Care For Our Common Home*.

The short-term political cooperation required for SRM can be leveraged to develop deeper ongoing technical partnerships. Greenhouse Gas Removal (GGR) technologies are needed in the medium term to produce a durably stable and fertile climate, and will need global cooperation to scale up. Such a political vision of climate stability requires formulation of a critical path from our current situation, integrating transformative technology with a realistic appreciation of existing institutional and economic structures.

The root cause of the climate emergency is greenhouse gas emissions. Yet addressing the root cause is only part of the required response. A popular myth holds that deploying SRM technology would weaken commitment to decarbonisation. Known as moral hazard, this political opposition to geoengineering is grounded in the false view that cutting GHG emissions could be sufficient to address the climate crisis. The problem with this view is that climate change is a far bigger problem than just our current emissions, so cutting emissions alone cannot possibly be enough. Moral hazard reasoning fails to understand that SRM, GGR and decarbonisation are mutually supportive, like three legs of a stool. Emission reduction is essential as the third leg of the stool to shift to a sustainable world economy, but does not have the urgency of SRM as the first step on the critical path, or the scale of climate impact of GHG removal. SRM buys essential time to develop GGR methods that will address the root cause of warming.

The root cause of warming is the committed warming from past emissions. Earth System Equilibrium theory suggests that any given level of GHGs in the atmosphere has a corresponding stable planetary temperature with no radiative forcing. The ESE for the current GHG load is several degrees of temperature and tens of metres sea level rise higher than our current climate.

Measured for carbon dioxide equivalent level of carbon (C), human industry has added an estimated 664 billion tonnes C to the atmosphere, and is now adding about 18 billion tonnes C per year. This table shows the estimated rate of increase.

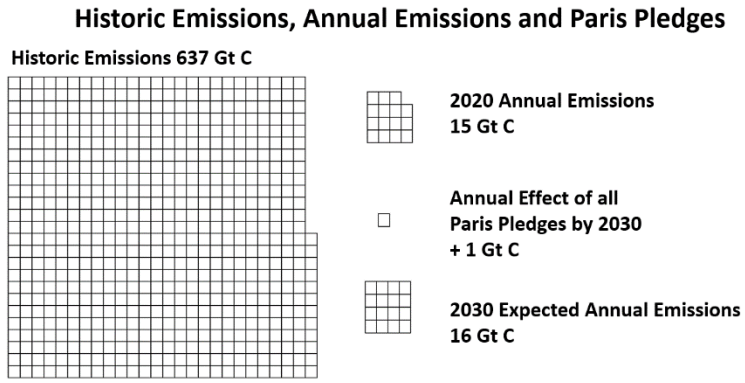
663,579,757,000	tonnes Carbon emitted 18 Nov 2021
663,579,792,000	tonnes C one minute later
35,000	tonnes C per minute
2,100,000	tonnes C per hour
50,400,000	tonnes C per day
18,408,196,800	tonnes C per year
Data from	https://www.globalwarmingindex.org/

Moral hazard thinking rules out SRM research as a slippery slope to deployment, as seen with the recent cancellation of the Scopex trial. The moral hazard theory effectively threatens to allow dangerous tipping points such as Arctic melting which could only be prevented by SRM. Such thinking wrongly prioritises the means of emission reduction above the end of planetary restoration.

A moral approach to climate should identify and implement the measures best able to prevent planetary damage. That means researching deployment of SRM to prevent climate disruption. The moral case for SRM can gain agreement for climate action from many people in the broader community who now rightly observe that decarbonisation strategies are expensive and ineffective.

Decarbonisation alone is grossly inadequate as a world climate response. Current projections are that emissions in 2030 will be 16% higher than in 2010, despite the intensive efforts to shift to renewable energy. This situation reflects the reality that cutting emissions cannot be the dominant factor in climate stability, and a political switch is needed to a geoengineering-led approach.

This diagram (R Tulip, 2019, unpublished) sets the committed warming of past emissions against the scale of annual emissions, and the expected increase of annual rate to 2030. It suggests that GGR requires eventual scale forty times bigger than all annual emissions in order to return the planet to stable Holocene atmospheric composition.



Emission reduction addresses the relatively small warming effect of new emissions (right), not the main warming effect of past emissions (left).

Pitting decarbonisation against SRM and GGR is a recipe for climate disaster. All three are essential. A cooling trajectory based on SRM can be developed alongside cooperative gradual reform of the existing energy system, helping to take the partisan heat out of the political debate on climate while GGR technologies are developed. By focusing only on ending fossil fuel use, the decarbonisation agenda generates strong political polarisation. The decarbonisation agenda has no prospect of achieving its climate goals, for the simple reason that preventing warming is impossible without geoengineering. SRM is a climate response that once understood can gain widespread consensus based on practicality, despite the relatively low level of current awareness about it.

People actually increase their commitment to emissions reduction when they understand geoengineering. Thinking about geoengineering gives more reality and hope to climate action, through a justified expectation that global warming is an entirely soluble problem. Geoengineering provides a path with practical answers to the current culture of despair that sees achieving a safe climate as impossible.

Far from creating a moral hazard, research into geoengineering would actually enhance support for decarbonisation. Indeed, this is exactly why the Trump Administration and Saudi Arabia combined to prevent UN geoengineering research in 2019. Understanding the need for geoengineering enables people to see our planetary predicament in a systematic scientific way, recognising the potential utility of different cooling methods.

Geoengineering through SRM is easily the fastest, largest and cheapest way to deliver rapid cooling in this decade. Brightening the planet with SRM is therefore the only immediate way to reverse the momentum of climate change, mitigating numerous risks brought by warming as part of an integrated scientific program of planetary restoration.

A medical analogy can help to understand the options for emergency climate stability. A person who has just had a heart attack or stroke or major accident needs immediate surgery to prevent death and disability. In such an emergency, doctors take urgent action to prevent the worst outcomes and restore patient health. We don't treat heart attacks in the short term by improving diet and exercise, important as these are over time. Nor do hospitals generally refuse surgery to people with bad habits as some sort of moral blame. However, ruling out geoengineering as an emergency climate response is the equivalent of refusing emergency medical treatment, with similar disabling and unethical consequences.

Extreme weather has steadily worsened in recent years, hitting countries around the world with record heatwaves, wildfires, floods and storms. As a result, more people are realising that cutting CO2 emissions is too small, slow and contested to prevent dangerous climate change. GGR has been proposed as a possible answer but is also far from enough. The scientific reality is that it will take many decades for emission reduction and GGR to have material effect on temperature.

We do not have decades to wait and watch the havoc of rising temperatures. The only immediate solution to mitigate extreme weather is to test and deploy proven SRM technologies to increase planetary brightness and remove heat, reflecting more sunlight back to space to reverse the warming trajectory.

Incoming solar radiation now exceeds outgoing radiation, creating a situation known as radiative forcing. Public funds for climate action should be prioritised for the most cost-effective ways to cut radiative forcing while also supporting living standards and environmental health. The concept of carbon credits should be extended to include radiative forcing credits, enabling investment in geoengineering to offset emissions.

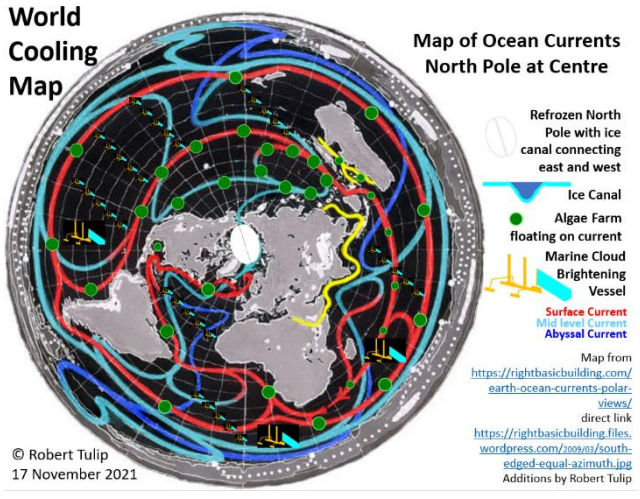
Geoengineering is absolutely necessary if we want a healthy planet and a better future for everyone. With the world currently warming at around 0.25° C per decade, emissions reduction alone, or even together with a major GGR effort, cannot keep temperatures below the 1.5° C target, which in any case is too high to avoid dangerous risks. On current trends the 1.5° target will be breached before 2040. Only SRM gives a good chance of keeping the global mean temperature within safe limits, buying time to scale up the renewable energy transition and GGR. Once GHGs are on a path back toward their stable Holocene level through large scale removals, SRM will no longer be needed and can be gradually phased out.

Only an integrated approach to SRM, GGR and emission reduction, a three-legged stool, can stabilise the climate. Implementing a major international SRM program, preferably led by the G20, will stabilise the climate as a world security priority. The benefits of political cooperation on the shared strategic goal of returning the planet to a liveable state through geoengineering will significantly cut tensions and misunderstanding between nations. The security dimension includes the benefits of international cooperation on projects such as refreezing the Arctic, and also the risk mitigation brought by lessening extreme weather. GGR and emission reduction can then work as slower and more sustainable solutions, stabilising the temperature over decades, and reversing chemical imbalances such as ocean acidification.

GGR could eventually operate at far higher level than ongoing world emissions, especially as commercial methods are scaled up to transform CO_2 into valuable stable commodities such as cement, soil, roads, buildings and industrial fabrics. GGR is needed to address the committed warming from past emissions, which causes an estimated 40 times as much ongoing warming as the incremental effect of each year's new emissions.

Humans have added about 2,500 gigatonnes (Gt) of carbon dioxide and equivalents such as methane to the atmosphere. We continue to add about 50 Gt CO_2e each year, worsening radiative forcing by about 2% each year. The goal of GGR could be to transform 100 Gt of CO_2 each year into valuable commodities, alongside gradual cuts to emissions, eventually cutting radiative forcing to zero and allowing phase down of SRM. That ambition would enable return toward the stable Holocene CO_2 level of about 280 parts per million in this century.

The world could cut GHG emissions by 22 Gt per year from 2015 to 2050 under the optimistic scenario of Climate Action Tracker. That highly ambitious result would still cause ongoing warming, and would still leave the bulk of work to achieve net zero emissions to future GGR technologies such as algae. It is important to note in this context that in reality there is no remaining 'carbon budget'. Climate stability will require driving the CO_2e level down well below its current amount of about 500 parts per million, removing far more than all future net emissions.



Rapid world cooling could be achieved with the systems shown in this World Cooling Map, with the North Pole at the centre and main ocean currents (map source). Cooling methods shown are large scale algae farms floating on ocean currents, fleets of Marine Cloud Brightening autonomous vessels, and a refrozen Arctic wilderness, funded by construction of a shipping canal across the North Pole to connect the eastern and western hemispheres of the world ocean.

These proposals could be investigated by the G20. An ice canal would be of major advantage to the world economy, and must be integrated with systematic scientific methods to cool the planet. My suggestion to use ocean currents to float algae farms involves the use of the large stable ocean currents as trade routes, not only for algae but also for other commodities, as a carbon-removing transport method replacing bulk tankers. Algae farms can be loaded near shore with CO2 from coal fired power stations and nutrient-rich Deep Ocean Water, and then allowed to float on currents to a collection point. This could also allow movement of algae farms into stable gyres such as the Sargasso Sea and the Great Pacific Garbage Patch. The fibre material for such floating farms would serve as a carbon sink, manufactured from produced algae, and would need to be big enough to withstand ocean conditions.

Gideon Rachman in the Financial Times has just mentioned the work of the Cambridge Centre for Climate Repair on refreezing the Arctic. The fleets of Marine Cloud Brightening vessels shown in the map can assist with this refreezing by cooling the ocean currents flowing into the Arctic. Opening the Arctic Ocean as a world trading route with an ice canal would connect the east and west hemispheres of the ocean, of major economic interest and value in cutting shipping time between Asia and Europe. The G20 might be the best organisation to investigate this possibility, integrating it with measures to re-freeze the pole, cool the oceans and build the ocean algae industry.

In the Arctic, temperatures are rising far faster than elsewhere. Changes to polar weather patterns and conditions have wide effects, destabilising the jet stream, melting the Greenland icesheet and putting Atlantic Ocean currents at risk. SRM is the only way to reverse these dangerous trends. The Greenland icesheet contains enough water for seven metres of sea level rise. In the absence of SRM, Greenland's massive glaciers are now melting at one million tonnes per minute, six times faster than in the 1990s, and could prove more sensitive and fragile than predicted by the IPCC consensus. Sudden collapse of ice sheets would cause sea level rise much faster than generally expected. Sea level rise in the absence of SRM is likely to flood all existing beaches, ports, atolls and low-lying land this century. SRM is the only insurance against these severe economic, social and ecological impacts. Otherwise the world will see climate refugees on a vast scale with resulting suffering and political instability. Nations at most risk of sea level rise should combine to support SRM to refreeze the North Pole.

SRM protects biodiversity. All who are concerned about extinction trends should support SRM. Biodiversity conservation requires measures to protect and enhance habitats which are now under severe pressure, facing warming far faster than species can adapt. SRM to slow temperature increase is the only immediate way to reduce the extinction pressure from poleward migration and other factors caused by warming.

The climate forcing from GHGs is causing the Earth system to take us rapidly away from the equilibrium of the Holocene era in which human civilization evolved. SRM techniques will take us fully into the Anthropocene as we begin to restore earth system equilibrium. Regulating the planetary climate will undo much damage to natural systems caused by anthropogenic emissions and will help protect ecosystems from further collapse. Cooling the sea and air with SRM will help stop damage to habitats and enhance biodiversity conservation. GHG levels can then be gradually reduced over the next century, returning the planet to a sustainable, safe, biodiverse and productive state.

Before GGR becomes feasible at scale, we need urgent SRM action to help stop the immediate threats of extinction and ecosystem collapse.

The common idea that solving climate change requires vast expenditure and cuts to living standards by making energy more expensive can be challenged by a focus on SRM. Geoengineering offers a program that can allow the energy transition to occur over a longer time frame in ways that do not disrupt economic growth, while also changing the nature of growth to bring it into harmony with nature, supporting the Sustainable Development Goals of the United Nations.

Once geoengineering is generally accepted, the political risks of SRM should be much lower than the risks of decarbonisation, in view of the insistence of major world powers on continued use of fossil fuels. The world economy has numerous complex systems that have to be maintained through active institutional regulation. Geoengineering takes this need for cooperation to a higher level, something that is essential as humanity moves into sustained global civilization.

SRM is affordable. Against the massive costs of sea level rise, hurricane damage and other impending dislocations, the investment required for SRM will deliver certainty and stability, cooling the planet at far lower price than planned subsidies for decarbonisation. MCB and SAI are relatively inexpensive for the amount of cooling power and weather protection they can produce, an actuarial balance that should be understood and funded by the insurance industry.

SRM supports climate justice. Global warming has hitherto exacerbated differences between the richest and poorest nations. SRM would serve to reduce these differences. Global warming has been largely caused by the richest nations, so they and their industries should pay for SRM to rectify the injustice.

The COVID-19 pandemic has shown the human capacity to cooperate and invest to adapt to sudden wrenching change. The underlying question for climate change is how to maintain world security and stability and minimise the risk of drastic change. Without SRM, the world faces far higher risks of abrupt system change, resulting in instability and insecurity, than with SRM, which is entirely suited to cut these risks.

Thomas Paine, one of the Founding Fathers of the USA, wrote in his essay *Common Sense* that "we have it in our power to begin the world over again." Now is a similar time for bold optimism, looking to how humanity can secure the lasting future of our planetary civilization by using all the great powers of our shared intellects. Support for geoengineering will apply the great benefits of technology to cooperate in stabilising, protecting, restoring, repairing and enhancing our planetary climate.

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