Overview of Climate Engineering

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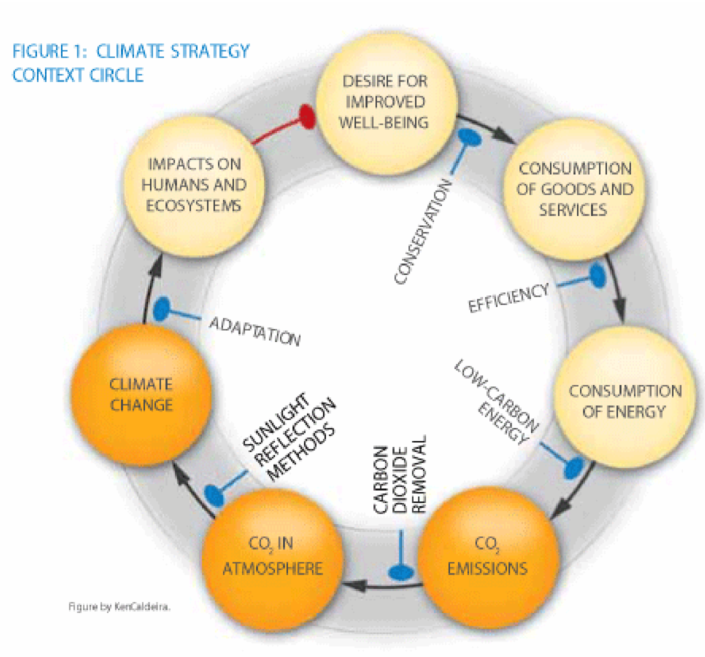
Top science institutions around the world, including the U.S. National Academies and the U.K. Royal Society, to endorse studies into deliberate tinkering with the planet's climate or atmosphere to partially offset global warming, known as climate engineering or geoengineering. Various characteristics distinguish the two major varieties of geoengineering: solar radiation management, or SRM (e.g. orbiting sunshades, spraying aerosols in the stratosphere) and carbon dioxide removal or CDR (e.g. carbon-sucking machines, catalyzing oceanic algae growth at sea). The number of scientists studying both is steadily increasing. The US has yet to follow the lead of a number of European countries which have dedicated programs for geoengineering research. Several companies are conducting engineering research on carbon dioxide removal (CDR) in this area.

Efforts at global carbon dioxide pollution abatement remain stalled even as the effects of a warming planet become increasingly apparent. Meanwhile recent findings suggest that the planet may be closer to global tipping points than previously thought. As the global climate crisis intensifies, old taboos held by scientists and policymakers are falling by the wayside. Adaptation, the organized response to a warming planet and its myriad local impacts, was once viewed by top officials as a distraction from the main priority of mitigating global greenhouse gas emissions. Now local and national governments around the world are creating plans to respond and adapt to warmer temperatures, higher seas and other environmental challenges. And so it goes with a radical form of adaptation known as geoengineering – the deliberate tinkering with global systems to partially reverse global warming or its effects. The publication of a controversial paper by Nobel prize winner Paul Crutzen entitled "Albedo Enhancement by Stratospheric Sulfur Injections: A Contribution to Resolve a Policy Dilemma?" in 2006 lent credibility onto a discussion that had heretofore existed largely in the shadows of academia jumpstarted discussion on geoengineering. (Crutzen, 2006)

Every credible researcher or policy expert who studies climate engineering believes that cutting greenhouse gas emissions is at least as important as developing such geoengineering technologies, if not more urgent. It is useful to consider abatement, carbon dioxide removal and solar radiation management in proper context with one another (See figure)



Three abatement steps – using less energy, using energy more efficiently, and producing energy less carbon-intensively -- serve together to lower global greenhouse gas emissions. CDR goes a step further. By pulling gases out of the atmosphere it gets at the heart of the problem: if lowering emissions is akin to removing smelly garbage causing a stink, CDR is like filtering a room's air. SRM, by contrast, does not change the level of CO2 in the atmosphere but instead serves to emeliorate its climatic effects, of which temperature is the most prominent, by reducing the amount of solar energy absorbed by the planet. Perhaps the metaphorical equivalent is spraying perfume to cover an odor.

Both CDR and SRM techniques attempt to mimic natural processes that scientists mostly understand. But that is where their similarities end. In their technical aspects, the political dynamics that might govern their deployment, and their feasibility the differences between them are stark. (That's one big reason that many scientists try to avoid using the terms "geoengineering" or "Climate engineering" to generalize between the two.)

Planetary Sunblock: Solar radiation management

SRM is "Fast, cheap, imperfect and uncertain," is how Harvard physicist David Keith, one of the leading thinkers on both methods, puts it (Keith, 2011). The most commonly explored technique for blocking sunlight from the planet is to mimic the natural cooling effect of volcanoes by spreading particles in the stratosphere. *Fast*: The 1991 eruption of the Mount Pinatubo volcano sprayed 5 million tons of sulfur aerosol into the stratosphere as SO2, which scattered light away from Earth and cooled the planet by 0.5 deg C. Modeling studies (ie, Caldeira and Matthews 2007) suggest that if a similar quantity of aerosol were to be injected there artificially, the cooling could be essentially instantaneous. *Cheap:* A recent study by an aerospace research firm suggests that the costs of deploying a global SRM scheme to offset anthropogenic warming "are comparable to the yearly operations of a small airline" (McClellan 2010) *Imperfect:* A number of modeling studies have suggested various side effects of this technique, including depriving the planet of solar energy that drives rainfall, leading to less precipitation (Ricke 2010.) That could disrupt the southeast Asian monsoon or weather in south American. *Uncertain*: since so many aspects of the climate system are not fully understood, tinkering with a fundamental variable that drives the system, the amount of solar energy entering it, may have unexpected or unintended consequences.

Since Crutzen's landmark paper, research into SRM has evolved from proof-of-concept modeling efforts to more sophisticated efforts. As part of the Geoengineering Model Intercomparison Project (GeoMIP) nineteen differently global climate models have participated in a modeling effort built on a set of four standardized scenarios in which solar radiation management is deployed in different ways (Kravitz 2011) Since different climate models employ different assumptions, characteristics and physics, by using different models given the same initial conditions, the thinking goes, more robust results about the environmental effects of various SRM strategies may be obtained. One example of the increasingly sophisticated modeling research on stratospheric aerosols is a recent study that found that sulfate aerosols deployed to offset warming caused by a doubling of CO2 concentrations would make the sky 3 to 5 times brighter than it is currently (Kravitz, 2012)

The most visible and tangible project to explore stratospheric approaches through actual experimentation is the Stratospheric Particle Injection for Climate Engineering (SPICE) project, led by Bristol University and supported by the British government at £1.6 million for 3.5 years. Along with designing particles and computer modeling, the project included a planned field experiment to spray 150 liters of water 1000m in the air to test how a balloon would behave in the wind during spraying. The field experiment was cancelled after concern about lack of regulations in place on SRM, as well as worries over a patent application that one of the participants in the research had filed before receiving UK funds for the project (Watson, 2012). Meanwhile David Keith and Harvard colleague James Anderson, an atmospheric chemist, plan "to develop in situ experiments to test the risk and efficacy of aerosols in the stratosphere (Keith 2012)"

Thinning our Greenhouse Layer: Carbon dioxide removal.

Scientists have proposed a variety of techniques for removing carbon dioxide from the atmosphere. These range from engineering forests to be more carbonaceous, to growing massive algae blooms at sea, to sucking carbon dioxide out of the atmosphere.

Few credible scientists believe CDR techniques to be a panacea, but the approach has attracted somewhat less attention and different kind of controversy than SRM, which Keith calls "Slow, expensive and effective (Keith, 2011)." *Slow:* 500 billion tons of anthropogenic CO2 has accumulated in the atmosphere and global yearly emissions of CO2 are 34 million cubic metric tons. Relying heavily on CDR as part of a climate response strategy means creating a massive industry – perhaps the biggest engineering project in human history -- to slowly remove this mass of gas from the atmosphere one molecule at a time. *Expensive:* A 2011 study by the American Physical Society concluded that the collecting CO2 directly from the atmosphere "is not currently" economically viable and that despite "optimistic" technical assumptions the basic cost of a system that could be built today would be about $600/ton, an order of magnitude more than cost estimates of low-carbon energy. *Effective:* CDR methods build off commercial techniques that work in submarines and space shuttles to clean air of CO2 gas, and promise fewer side-effects than CDR methods.

A number of startups have sprung up focusing on different techniques for CDR. In 2007 Sir Richard Branson launched a $25 million contest called the Virgin Earth Challenge to encourage the development of technologies "which will result in the net removal of anthropogenic, atmospheric greenhouse gases each year for at least ten years without countervailing harmful effects. (Virgin, 2007)" The eleven finalists in that contest represent a decent survey of leading commercial entities in this space, including firms that seek to sequester carbon in biochar added to soil, directly capturing CO2 via chemical methods from the atmosphere, or burning biofuels and sequestering the resultant CO2 in the ground.

The State of Geoengineering Research Policy

European governments have more organized programs to support climate engineering research than US. Studies on the governance of climate engineering approaches are underway by a coalition co-led by the UK Royal Society (SRM Governance initiative), an Oxford university group on a two-year grant (Climate Geoengineering Governance project) and the "European Trans-disciplinary Assessment of Climate Engineering" project, led by the Institute for Advanced Sustainability Science in Potsdam, Germany.

Meanwhile, work on the ethics of climate engineering have yielded, among other work, the so-called "Oxford Principles," proposed to restrict research into SRM and CDM (Rayner, 2009). They include the following guidelines: 1) That SRM be regulated as a public good 2) That the public be involved in research related to SRM decisions, including field experiments 3) That research plans and results be transparent and shared publically 4) That bodies independent of researchers studying climate engineering should assess the environmental and socio-economic impacts of research 5) That decisions about deploying technology on a global scale should be made only when "robust governance structures" to oversee such efforts are in place.

A number of expert panels (e.g. Long, 2011) have urged the U.S. to create dedicated research efforts in this area. But while the National Science Foundation has supported a handful of studies on SRM, and funds from various agencies have supported work applicable to CDM approaches, no integrated, organized effort yet exists in the federal government.

Several studies exploring public opinion on climate engineering technologies have been published. In August 2011 Cardiff University released results of a quantitative public engagement research project involving about 35 people that met for a day and a half. “Very few people were unconditionallypositive about either the idea of geoengineering, or the proposed [SPICE] field test. However, most were willing to entertain the notion that the test as a research opportunity should be pursued.” An internet poll of 3105 American, Canadian and British individuals published in 2011 found that 8% and 45% of respondents correctly defined the terms “geoengineering” and “climate engineering” respectively (Mercer, 2011). In the same survey, respondents were asked to rate statements from 1, for “strongly disagree” to 4, for “strongly agree”. For the statement “If scientists find that Solar Radiation Management can reduce the impacts of global warming with minimal side-effects, then I would support its use” the average response was 3.01. The statement “Solar Radiation Management will help the planet more than it will hurt it” received an average response of 2.49.

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