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Going Negative: The Next Horizon in Climate Engineering Law

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As the global community struggles to turn the Paris Agreement's commitments into meaningful emission reductions and the United States turbulently reverses its climate policies, the potential role of "negative emissions technologies" and other climate engineering approaches is drawing increasingly serious attention. These technologies are engineering on the grandest scale: climate engineering seeks to offset the effects of anthropogenic climate change by either altering the solar radiation reaching the earth's surface or changing the composition of the atmosphere itself. Specifically, negative emissions technologies would directly remove greenhouse gases (GHGs) from the ambient air and help to remove accumulated atmospheric carbon dioxide (CO_2) caused by historical emissions. After over a decade of debate, substantive research and planning associated with negative emissions technologies and solar radiation management have begun to inch forward. But this movement is happening in unexpected ways, and some of the most important decisions and commitments are occurring outside of the spotlight.

Although proposed climate engineering approaches recently have grown into a bewildering array of potential technologies, most proposals tend to fall into two distinct categories: solar radiation management (SRM) technologies and CO_2 removal (CDR). SRM technologies would seek to reduce the amount of solar radiative energy that reaches (or stays) at Earth's surface. This type of "sunscreen" has been proposed in many forms, including the distribution of space-based mirrors to deflect sunlight or modification of cirrus cloud structures to reduce their retention of reflected radiation. The SRM approach attracting the most attention, however, is the dispersal of aerosol particles in the stratosphere, probably by airplanes. By artificially mimicking the haze created naturally by major volcanic eruptions, SRM arguably could lower the surface temperature of Earth's surface quickly and (comparatively) cheaply without altering the composition of its lower atmosphere or reducing the amount of GHGs already present from historical emissions.

By contrast, CDR removal strategies seek to remove large amounts of GHGs from the ambient atmosphere, resulting in negative emissions. This strategy also relies on a growing number of varying technologies, including bio-energy with carbon capture and storage (BECCS), accelerated weathering of minerals, increased biochar production, and local methane capture from destabilized permafrost. The CDR approach getting the most attention is large-scale direct air capture (DAC) of CO_2 by BECCS. This technology captures CO_2 through growing large amounts of biomass and then burning that biomass in a combustion power plant that can capture the resulting CO_2 from its emissions. The plant would then sequester the CO_2 through underground storage or other means. This process results in a power source that effectively removes CO_2 as it generates power. BECCS already has become a fixture in proposed strategies for nations to attain their commitments to reduce their total GHG emissions in conjunction with mitigation technologies to control ongoing emissions from other sources. But, as discussed below, serious concerns have been raised about the costs, effectiveness, reliability, and environmental side effects of BECCS.

Although SRM and CDR offer vastly different approaches to climate engineering, the two strategies often are indiscriminately lumped together under the single rubric of geoengineering, leading to confusion. At its heart, SRM provides a comparatively inexpensive, fast-acting, and highly risky approach to immediately respond to some of the urgent dangers posed by rising surface temperatures, but it does little to offset the underlying causes of climate change or its other damaging effects (such as ocean acidification). CDR, by contrast, tackles the ambient concentrations of GHGs that cause climate change, but it would act very slowly to create measurable effects, could be enormously expensive (depending on technological development), and would generate a staggering waste disposal challenge for the captured GHGs.

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Despite their differences, both approaches share important drawbacks. Each remains unproven at the scale needed to affect significantly global climate change processes. Both need extensive studies and monitoring to verify their safety and effectiveness, as well as substantial financial support. Both technologies also lack any international or national governance system that expressly identifies who will control their deployment, bear the risks of liability for damages that they cause, and give affected stakeholders an opportunity to have their concerns heard and addressed. The unknowns about technologies and side effects have hobbled the consideration of climate engineering options as potential strategies to respond to climate change, and, as a result, SRM and CDR have remained secondary considerations in international climate discussions until now. As they must, governments, corporations, nongovernmental organizations, and individuals have focused instead on strategies to reduce GHG emissions and to adapt in anticipation of inevitable risks and challenges of impending additional climate change.

Recent Changes in the Climate Engineering Landscape

As the challenge of responding effectively to climate change has grown steeper because of a rash of extreme events, the discoveries of new hazards from climate change, and some countries' weakening or abandonment of their GHG reduction goals, climate engineering approaches—particularly negative emissions technologies—are stepping out of the policy shadows. The increased interest in negative emissions technologies reflects the reality that anthropogenic GHG emissions cannot possibly reach zero even under the most optimistic scenarios because of inevitable deforestation, methane releases from multiple sources, and the continued use of fossil fuels. Society almost certainly will need some type of negative emissions strategy to lower ambient CO_2 levels already in the atmosphere as well as to offset these continuing emissions.

This reality has surfaced already in the latest climate computer modeling. When the international community reached the historic Paris Agreement in 2015, it agreed to limit global average surface temperature increases to 2°Celsius (C) (3.6° Fahrenheit (F)) at a minimum and to strive for a more ambitious target of 1.5°C (2.5°F). At this point, essentially every serious climate model that attains the Paris Agreement's 2°C goal (much less the more ambitious 1.5°C target) already requires large reductions through use of negative emissions strategies. In particular, the UN Intergovernmental Panel on Climate Change's (IPCC's) most recent Integrated Assessment Model's suite of 900 scenarios could find only a narrow band of 76 pathways that showed a substantial chance to stay below 2°C. The majority of those 76 models required the use of negative emissions technologies, and all of those relied heavily on the use of BECCS. Kevin Anderson and Glen Peters, *The Trouble with Negative Emissions,* 354 Science 182, 183 (2016). This technology, however, has enormous and potentially fatal side effects. It would require the use of stupendous amounts of arable land to grow crops for fuel—by some estimates, one to two times the area of India, or over 1.1 gigahectares of prime agricultural land, or up to 50 percent of the world's natural forests. Lena R. Boysen et al., *The Limits to Global Warming Mitigation by Terrestrial Carbon Removal,* 5 Earth's Future 1, 1–12 (2017). This land use, in turn, would have dramatic effects on water consumption, fertilizer demand, and population distribution. The land use impacts of full-scale deployment of BECCS could cause terrestrial species losses equivalent to a 2.8°C temperature rise. Phil Williamson, *Emissions Reduction: Scrutinize CO_2 Removal Methods*, 530 Nature 153 (2016). Moreover, no one has yet built a full-scale BECCS plant that can fully capture its emissions in a cost-effective fashion for permanent storage or disposal, and efforts to install carbon capture and sequestration projects at conventional power plants have suffered from daunting technical challenges and rapidly escalating costs.

The IPCC models that meet the Paris goals thus rely on a vast scale-up of an unproven technology where the consequences of either failure or success could be devastating, but the models' reliance on BECC is little known. To help shed light on these issues and provide greater transparency, the IPCC's upcoming special report on how to achieve the 1.5°C goal likely will focus considerable attention on the use of BECCS and other negative emissions technologies as an important tool to include in climate change response planning.

The IPCC's new attention to BECCS reflects a larger breakthrough in the logjam on research into negative emissions technologies. In the United States and elsewhere, SRM and CDR research has remained stuck in hiatus for over a decade, partly because of the political backlash that arose in response to early research proposals. For example, when Dr. John Holdren, the science advisor to President Obama, informally suggested in 2009 that the federal government should explore possible support for climate engineering research, the swift negative response led the White House to back away quickly from the concept. Henry Fountain, *White House Urges Research on Effects of Geoengineering,* N.Y. Times, Jan. 11, 2017, at A14. This political reluctance only reinforced fears that some of the climate engineering proposals (including field research tests of SRM) potentially could cause widespread environmental harm with little governmental oversight.

With growing concerns that unabated GHG emissions and reversals of national commitments on climate policy will undermine the feasibility of traditional mitigation and adaptation strategies, this reluctance toward climate engineering options is fading. For example, the National Research Council released a report on SRM and CDR climate intervention technologies in 2015 that recommended funding for further research and work on governance issues. The U.S. Global Change Research Program recommended in its *National Global Change Research Program 2012–2021 Triennial Update* that the federal government should sponsor research on techniques to detect when a climate intervention has occurred and to determine the smallest reasonable scale of experimentation.

Other nations also have expressed a new desire to spur climate engineering research on negative emissions technologies. For example, the United Kingdom's Natural Environment Research Council recently announced a research initiative into negative emissions technologies that would dedicate £8.6 million to 40 UK universities and research partners. This work could sponsor up to 100 researchers and support a broad portfolio of research projects that would identify and test numerous negative emissions technologies in numerous settings. *See* Press Release, Natural Environmental Research Council, £8.6 Million UK Research Programme on Greenhouse Gas Removal, (Apr. 20, 2017), www.nerc.ac.uk/press/releases/2017/09-greenhousegas.

Some forms of negative emissions technologies have begun to inch out of the laboratories and into field tests thanks to a surge in commercial interest. For example, ClimeWorks recently unveiled the first commercial CDR unit in Zurich. This facility uses waste heat from power production to capture ambient carbon dioxide and then routes the captured gas by pipeline to agricultural greenhouses, where it helps boost plant growth. Christa Marshall, *In Switzerland, a Giant New Machine is Sucking Carbon Directly from the Air,* Science, June 1, 2017, www.sciencemag.org/news/2017/06/switzerland-giant-new-machine-sucking-carbon-directly-air. This test unit will run for three years, but ClimeWorks intends to construct numerous additional units to capture CO_2 for use in food and pharmaceutical production. Other leaders in the field include Carbon Engineering, Inc., under Dr. David Keith, which has constructed a test unit in Squamish, British Columbia, to demonstrate a high-volume, high-energy process to capture large amounts of CO_2 for concentration into a pure stream for industrial use. The Center for Negative Carbon Emissions at Arizona State University under Dr. Klaus Lackner also is pioneering a moisture-swing sorbent technology that captures comparatively less concentrated CO_2 streams by using ambient air movement with much lower energy demand. Numerous other commercial ventures, including Global Thermostat's use of low-temperature waste heat from power plants to drive a unit that captures CO_2 from the ambient atmosphere using amine chemicals, are nearing field demonstrations as well, and the entire negative emissions technology field (and direct air capture in particular) likely will see increasing research testing outside the laboratory over the next two or three years.

By contrast, field research into SRM has remained much more contentious and has been slower to progress. While Harvard University may sponsor an initial field test of basic principles underlying SRM in Arizona in the near future, the technology remains mired in considerable controversy and governance challenges. In particular, because SRM is relatively cheap, comparatively fast-acting, and highly risky, it is possible for a small group of nations (or one) to undertake SRM without the consent or participation of other nations. Given concerns that SRM also might unpredictably affect rain and snowfall patterns vital for global water supplies and agriculture (including the subcontinental Indian monsoons), damage the stratospheric ozone layer, and pose a risk of climate weaponization, the lack of governance and absence of any effective legal framework to impose liability for errant SRM actions have spurred calls for a moratorium on deployment and field research. These frictions likely will slow SRM's initial outdoor testing and deployment at any significant scale for the foreseeable future.

Emerging Legal Challenges for Climate Engineering Research and Deployment

The growing prominence of negative emissions technologies, including BECCS, in national climate strategies are likely to provoke challenges and potential legal hurdles. For example, if affected persons wish to attack a climate engineering project or research demonstration, they may allege either that the project lacks governmental approvals or permits or that it will inflict harm on them in a way that creates an actionable tort claim. Because no federal or state environmental program in the United States requires permits or authorizations explicitly for negative emissions technologies or SRM, this line of attack must find an aspect of a climate engineering project that creates an environmental side effect that could trigger regulation or permitting (e.g., discharges of water or air pollutants or injury to an endangered species). Absent that sort of environmental impact, objections to climate engineering projects instead may seek injunctive relief premised on tort claims such as nuisance, public nuisance, or negligence. Michael B. Gerrard and Tracy Hester (eds.), *Climate Engineering and the Law: Regulation and Liability for Solar Management and Carbon Dioxide Removal* (Cambridge U. Press, forthcoming 2018); Tracy Hester, *Remaking the World to Save It: Applying U.S. Environmental Laws to Climate Engineering Projects,* 38 Ecology L. Q. 851 (2011).

Some of the regulatory groundwork for climate engineering already has been created on behalf of other technologies. Negative emissions technologies and direct air capture have benefitted from research and support for "clean" coal technology carbon capture and sequestration (CCS) initiatives, but they have important differences. CCS has focused on capturing CO_2 from the flue stacks of fossil-fueled power plants, whose exhaust already contains highly concentrated CO_2. While advocates for coal-fired power continue to advocate CCS as the best technology to allow broad use of fossil fuels, recent demonstration plants have failed economically. For example, Southern Company announced in June 2017 that it would cancel construction of the CCS portion of its power plant in Kemper, Mississippi, after the CCS project ballooned $4 billion over budget and fell over three years behind schedule. Katie Fehrenbacher, *Carbon Capture Suffers a Huge Setback as Kemper Plant Suspends Work*, Greentech Media, June 29, 2017, www.greentechmedia.com/articles/read/carbon-capture-suffers-a-huge-setback-as-kemper-plant-suspends-work. Some economic difficulties facing CCS are because electricity generated by coal with CCS is much more expensive than power from natural gas, wind, or solar. By contrast, negative emissions technologies and direct air capture need not satisfy a similar cost metric (although they still face the more fundamental challenge of how they can be paid for without government funding, a price on carbon, or a regulatory mandate).

CCS and negative emissions technologies do, however, share an important hurdle: the legal obligations and liabilities arising from the need to safely manage and dispose of the captured CO_2. If successful, these technologies could generate vast quantities of captured CO_2 that would require safe storage, permanent sequestration, or reuse. Today, most of the proposals to reuse or manage captured CO_2 focus on commercial uses that either result in a future release of the gas (e.g., to produce carbonated beverages or pharmaceuticals) or in the generation of other products that themselves increase the production of fossil fuels (e.g., for enhanced recovery of petroleum). Although these proposals improve the economics of CCS and negative emissions technologies, they work at cross-purposes with the larger objective of reducing ambient atmospheric CO_2 concentrations and forestalling climate change effects. To find potential alternatives to these questionable uses, a great deal of research now centers on productive reuse of captured CO_2 in items such as carbon-neutral (or negative) liquid fuels, cement formulation, plastics feedstock, or as agricultural fertilizer (at low concentrations). In addition, some sequestration methods may permanently mineralize and immobilize the CO_2 in a mineral matrix to remove any significant future risk of release or exposure. Some of this recent research, for example, demonstrated that CO_2 injected into basalt formations in Iceland was incorporated into the minerals at an unexpectedly high speed, and more studies of this process are planned on the U.S. Atlantic and Pacific coasts in subsea formations.

Some of these disposal and reuse methods might raise concerns by nearby residents or local governments about the potential risks and undesirable impacts that such activities would have on the environment or on land values or use. Other legal issues also would raise challenges to widespread use of geological or subsurface sequestration of CO_2, such as pore space management and liability for leakage. At the least, underground sequestration in the United States, either under the land or under the seabed, will require federal permits for the injection and state and federal permits for the pipelines to carry the gas to the reservoirs, which may be located a great distance away from the facilities at which CO_2 is captured. Romany M. Webb and Michael B. Gerrard, *Sequestering Carbon Dioxide Undersea in the Atlantic: Legal Problems and Solutions,* 36 UCLA J. L. & Pol'y 1 (2018).

The United States already has done a great deal to lay the regulatory groundwork on these issues as part of its efforts to promote CCS technologies. For example, the U.S. Environmental Protection Agency (EPA) has crafted a conditional exemption for sequestered CO_2 from regulatory coverage as hazardous waste under the Resource Conservation and Recovery Act (RCRA) and certain liabilities under the Comprehensive Environmental Response, Compensation, and Liability Act. EPA also promulgated regulations in 2010 to create a new class of underground injection wells that could accept CO_2 streams for sequestration in deep geologic formations. Federal Requirements Under the Underground Injection Control (UIC) Program for Carbon Dioxide (CO_2) Geologic Sequestration (GS) Wells, 75 Fed. Reg. 77,230 (Dec. 10, 2010). This regulatory work, which the Trump administration has not sought to reverse or modify, easily could be adapted to facilities that use direct air capture or other negative emissions technologies.

Looking Ahead

Given the current state of climate engineering technologies, what lies ahead for their immediate future governance? We see a combination of trends and realities that will shape the legal landscape for the next several years.

First, governments seeking to meet their Paris Agreement commitments will continue to rely heavily on negative emissions technologies in plans to attain the 2°C temperature goal. In doing so, however, they are effectively betting on technologies that will remain relatively unproven for many years and may have unacceptable side effects. As a result, some of these technologies (particularly wide-scale BECCS) will pose difficult risk assessments and thorny governance challenges.

This dependence on developing technologies highlights the second key feature of future climate engineering governance: in light of the technologies' fast-emerging status, the international community almost certainly will not have any comprehensive governance treaties or regulatory framework implemented in time for the first climate engineering research projects, initial test deployments of large-scale negative emissions technologies, or trials of SRM in the field. Instead, the first rampart for oversight of climate engineering, by default, will be existing national domestic laws and regulatory programs. Extending our existing environmental laws to these new climate engineering technologies will require considerable ingenuity and creativity. For example, as noted earlier, current RCRA exemptions from hazardous waste regulations for sequestered CO_2 cannot, as written, apply to CO_2 captured by negative emissions technologies such as BECCS or DAC.

Even when current environmental laws would not regulate a negative emissions technology directly, nations may need to revise their domestic laws to minimize unexpected regulatory side effects. For example, other than management of captured CO_2, individual DAC units (even if deployed at large scale) probably would not pose any particularly difficult or novel legal issues when considered in isolation. The DAC units can be manufactured by conventional processes and located virtually anywhere because the capture of ambient CO_2 by these processes likely will not affect local air quality, and the impact of capturing CO_2 will be felt globally regardless of where the capture occurs. But to the extent that they disrupt species habitat or require the disposal of large quantities of captured CO_2, governments could take steps using their domestic laws to facilitate the regulatory approvals for such storage as well as impose logical conditions (for example, requiring large-scale units be located close to the injection locations or disposal sites to minimize pipeline infrastructure and other support costs).

Despite these challenges, some researchers have begun to draft proposed codes to govern climate engineering experiments that might pose environmental risks. For example, Oxford University's Geoengineering Program has proposed a set of principles to govern conduct of climate engineering research, and the Carnegie Climate Geoengineering Governance Initiative is exploring similar approaches to provide transparency on emerging research as well as the extension of existing governance principles and laws to them. It should be noted, however, that these draft principles will remain strictly voluntary unless governments choose to enact them into their domestic laws.

As governments wrestle with how to investigate and deploy BECCS as indicated by their Paris commitments, research will continue—and accelerate—into a host of other exotic negative emissions technology options. As noted above, these additional technologies could cover a wide gamut of approaches that vary from simple approaches, such as crushing olivine rocks and exposing them to air so that they absorb CO_2 in a process called accelerated weathering, to development and deployment of technologically sophisticated solar updraft towers to absorb methane emitted from melting permafrost in arctic regions.

Some of these additional technologies will exacerbate the governance challenge. For example, some scientists have proposed fertilizing regions of the ocean with iron to spur blooms of phytoplankton that would absorb CO_2 from the atmosphere, and then sequester the carbon when the plankton dies and sinks to the marine floor. This research is highly controversial, and the international community has responded to early ocean iron fertilization experiments by creating a partial governance framework under the London Protocol and London Conventions against ocean dumping. The framework declares the placement of iron onto the ocean as a form of prohibited "dumping" unless it meets guidelines to assure its scientific validity and appropriate scope.

But even this halting initial step toward international governance highlights the challenge. For example, this prohibition likely will not apply to fundamental research on oceanic iron uptake and phytoplankton production. Some ocean iron fertilization projects, as well as many climate engineering research projects (at least in their early stages), easily could be recast as investigations into fundamental physical and chemical properties of the atmosphere or ocean. As a result, they could constitute a type of dual-purpose research that could pose a difficult challenge to governance frameworks. In addition, the London Protocol and London Convention restrictions are narrowly keyed to the specific technology of ocean iron fertilization. If researchers pursue other marine approaches to capture CO_2—such as direct removal of dissolved CO_2 from marine waters or other targeted manipulation of ocean chemistry to offset global acidification—those new pathways probably would remain outside the London Protocol's restrictions.

If governments wish to allow development of these technologies, the governance gaps and uncertainties may frustrate their research and development. Nations that want to investigate and test these technologies therefore would need to consider additional steps to guide and encourage scientific work. Some of these steps are matters of political commitment and policy rather than legal frameworks. For example, and most obviously, governments could commit to increasing their funding for climate engineering research and development, and those commitments would probably focus on technologies that likely will merit deployment in the near future (e.g., negative emissions technologies such as direct air capture or BECCS). While the UK has its Negative Emission Research Consortium, no similar governmental grant program to spur broad negative emissions research is underway in the United States or other nations.

Governments could expressly include negative emissions technologies in their portfolio of mitigation commitments. Current climate mitigation strategies often rely on multiple emission reduction options combined into an overall mix of strategies that collectively offer sufficient emissions reductions. These solution suites should be reexamined and expanded to include combined and complementary climate engineering strategies as a companion to solely mitigation approaches. *See, e.g.,* Steven J. Davis et al., *Rethinking Wedges*, 8 Environ Res. Lett. 011001(2013), *available at* http://iopscience.iop.org/article/10.1088/1748-9326/8/1/011001/pdf (including "phase-out" wedges and negative technologies); Peter Psarras et al., *Slicing the Pie: How Big Could Carbon Dioxide Removal Be?*, WIREs Energy, Sept./Oct. 2017, at 6:e253, http://wires.wiley.com/WileyCDA/WiresArticle/wisId-WENE253.html.

Last, nations could take an enormously important and effective step if they wish to develop negative emissions technologies by providing a monetary value for the carbon that they capture from the air. Any pricing system for carbon emissions (either cap-and-trade or taxation) should include the ability to reap a benefit or credit for CO_2 captured from ambient air by direct air capture or other directly measurable means. Without this, it is difficult to envision a way to finance the large-scale deployment of these technologies. Because providing a simple 1:1 ratio of one ton of credit for every ton of CO_2 removed would only achieve carbon neutrality, this system likely would need to adapt a larger ratio to drive negative emissions. This skewed offset ratio would parallel similar offset ratios established under the federal Clean Air Act for permitting of major sources under the nonattainment New Source Review program.

NETs and the Role of Environmental Law (and Lawyers)

Without fanfare or public debate, the large-scale removal of GHGs from the ambient air (particularly BECCS) has already assumed a central role in plans to meet the Paris Agreement's 2°C goal. That role will almost certainly grow as current GHG emissions continue at high levels, and as the stockpile of ambient CO_2 from historic emissions builds up in the atmosphere. These new technologies, however, pose a thorny governance gap for nations that lack any laws to address them and likely will not reach agreement on any international framework to govern them. The likely emergence of a menagerie of additional climate engineering technologies will only add to the confusion and uncertainty. Especially given SRM's potential for offering immediately effective responses to an unanticipated climate emergency or crises at a comparatively low cost (albeit at unknown high risks of unexpected side effects and harms), the legal challenges of overseeing these technologies will demand proactive and clear-eyed assessment and legal guidance by nations that want to allow this type of research to proceed.

All of this work is occurring in a near vacuum of explicit governance or regulation for climate engineering. As a result, environmental lawyers need to prepare for the inevitable battles over attempts to extrapolate existing federal and state environmental laws and regulations, as well as long-standing tort doctrines and injunctive remedies, to govern these wholly new, and potentially critical, technologies.