Chapter 5

Liability

Tracy D. Hester

To actually sway the behavior of sovereign states and individuals, a climate engineering legal regime will need to set out clear and practical rules that impose liability for damages. Such rules should be adopted in advance of any large-scale deployment; it is far better for states to consider liability rules in the abstract than to try to craft them after an actual dispute has arisen. Yet climate engineering will inevitably pose difficult challenges to the typical legal approaches used to assign liability for violations or injury. For example, if the degree of liability should proportionately reflect the seriousness of an offense's threatened harm or gravity, courts may be forced to weigh charges or assessments for climate engineering projects that arguably could have unpredictable global consequences. National courts or international tribunals may also have to decide whether to impose liability for allegedly illegal climate engineering activities when the failure to take action itself may risk even graver consequences from unmitigated climate change effects.

This chapter explores possible approaches to liability that might apply to climate engineering field research or deployment. Given the early state of climate engineering research, the field of climate intervention law and liability is unsurprisingly also unshaped. As noted in earlier chapters, very few international entities or domestic governments have yet proposed or implemented new laws or regulations to explicitly regulate climate engineering projects. The lack of a binding and explicit governance framework has led governments and advocates to jury-rig regulation of climate engineering projects by adapting existing international instruments and domestic laws crafted for other purposes. As a result, the degree of liability arising from climate engineering legal violations will heavily depend on the nature of the attempted engineering project, the type and extent of damage that it allegedly can cause, and the specific law or statute triggered by the nature of the project and its attendant damages. Despite the early and unclear nature of climate engineering law, we can still forecast some possible general principles of liability that this field might adopt under current domestic, international and transnational laws.

To explore those issues, this chapter will focus on legal liability and compensation obligations to redress alleged damages or injuries caused by climate engineering efforts. To the extent that research and early limited field tests pose differing possible risks and damages than a broader deployment of climate engineering technologies, this analysis will parse out separate liability concepts that apply solely at the research stage. In the same vein, this chapter will assess possible injunctive remedies when they seek restitution or imposition of potentially costly corrective actions, to compel future regulatory actions, or to spur government implementation of climate engineering efforts.

As a result, this chapter will not explore other possible sources of legal obligation and responsibility. In particular, it will not focus on legal efforts by citizens (i) to impose obligations on entities charged as trustees to protect natural resources (unless such actions result in monetary or financial obligations), (ii) to challenge perceived violations of explicit or implied constitutional guarantees to environmental protection,[1] or (iii) to pursue disclosure obligations related to financial securities or liabilities arising from false statements to governmental officials.

I. Aspects of Possible Climate Engineering Techniques that Might Affect Future Liability

As earlier chapters made clear, sizable climate engineering field experiments or deployments theoretically could result in significant and unpredictable damages. The types of damages that could result will likely turn on the particular type of climate engineering that the projects used, and the variety of damages that each type can respectively cause.

Solar Radiation Management (SRM). Solar radiation management technologies would reduce the amount of sunlight that reaches the Earth's surface as a method to reduce mean global temperatures. Some techniques, as noted in earlier chapters, would use either the dispersal of particulates at stratospheric levels to scatter incoming solar radiation, the brightening of marine clouds, or the direct deflection of sunlight by space-based satellites. Some researchers fear that SRM, if deployed on a broad or global scale, could potentially cause an array of unexpected global and regional weather consequences such as diminished monsoons or redistributed precipitation. In addition, alteration of solar radiation influx could possibly reduce agricultural productivity in some regions (and increase it in others), impair ecosystems that rely on existing levels of light and radiation, and deplete stratospheric ozone levels through the use of chemicals that could scavenge existing ambient ozone.

Beyond risks posed by SRM even when it is deployed flawlessly, this strategy would not help prevent other damaging aspects of climate change such as continued or increased ocean acidification or accelerated deposition of possible byproducts of SRM chemicals that eventually migrate to the Earth's surface. More controversially, some modeling of proposed SRM approaches suggest that it could cause whitening of daytime skies and reduce the efficiency of solar power plants. SRM allegedly could also have unpredictable impacts on ecosystems and biodiversity as a whole, or at least on protected species that might prove sensitive to changes in solar radiation levels or climate engineering materials and practices. Last, even if SRM works perfectly, it poses the risk of accumulated climate momentum: if SRM deployment occurred on a broad and long-term scale, a sudden halt in its use could lead to a sudden and accelerated burst of warming and climate change effects due to a possible build-up of greenhouse gases (GHG) that would act without a counterbalance.

Direct Carbon Dioxide Removal. When compared to SRM, carbon dioxide removal (CDR) technologies[2] pose a different and much less imminent set of risks and environmental hazards. The direct removal of carbon dioxide (CO_2) from the ambient atmosphere generally should neither directly damage the local environment nor disrupt regional climatic conditions.[3] Depending on the specific type of method used to remove the CO_2, however, the technologies may yield unwanted residues, side effects, and local land use disruption. For example, some promising industrial CDR approaches would rely on direct absorption of CO_2 by passing ambient air over screens impregnated with an amine solution.[4] While this approach would reuse the amine solutions through a wash cycle that removes CO_2 from a saturated amine screen, the amines ultimately would become contaminated and require replacement. Managing the large volumes of spent materials and byproducts of globally-deployed CDR would therefore likely pose a significant waste management challenge. In addition to waste products from the CDR process, the captured CO_2 itself would require either its reuse as a commercial product, use as a replacement for other feedstocks and commercial chemical products, or – most likely – sequestration and disposal. The volumes of CO_2 requiring management and/or disposal generated by large-scale CDR needed to affect global temperatures would be staggering. By rough calculations, capturing enough CO_2 to reduce atmospheric levels by 1 ppm would generate 7.8 gigatons of CO_2 – over 31 times the amount of all municipal solid waste disposed in the United States in 2014.[5]

Until a dominant method of CDR emerges from research and market competition, we cannot identify likely environmental impacts and consequences with confidence. Some possibilities, however, do suggest themselves. For example, some CDR methods may require substantial amounts of energy for operation.[6] Unless that power comes from renewable sources, GHG emissions generated by CDR's power demands may therefore offset some of its benefits or pose collateral pollution risks.[7] The final choice of technology may also affect the amount of water that it will demand. For example, certain versions of CDR will require water to release CO_2 from spent amine screens.[8] While preliminary descriptions of these technologies emphasize that they will re-use water as much as possible, deployment of CDR in arid regions in amounts sufficient to affect global CO_2 concentrations might impose significant demands on local water supplies.

If we consider broad-scale reforestation as a form of CDR,[9] it too might pose environmental risks and costs. Some estimates of the amount of acreage requiring reforestation to significantly offset global ambient CO_2 concentrations would exceed 500 million hectares (i.e., over half the land area of Australia).[10] Aside from the potential disruption of converting large swaths of land from its current use to this type of sequestration, the selection of the type of trees used for the reforestation could have sizable impacts on local biodiversity and the potential vulnerability of forest ecosystems to invasive species or other biological threats that prey on the vulnerabilities of monoculture ecosystems. For example, some models project that broad BECCS deployment would lead to species losses equivalent, at least, to a 2.8 degrees C temperature rise.[11] While current international agreements recognize some of these risks and attempt to balance the climatic benefits of reforestation with strategies to reduce biodiversity loss and distortions caused by large-scale monoculture methods,[12] their effectiveness remains to be seen.

Ocean Iron Fertilization (OIF). This technology, as described in Chapter 2, would rely on the dispersal of significant amounts of iron oxide onto the surface of anoxic[13] ocean waters to spur the growth of algal blooms.[14] These blooms, like any other plant growth, would capture ambient CO_2 and incorporate it into the plants' mass. When the algae deplete the supplemental iron and then ultimately die, they theoretically would sink into lower ocean depths and effectively sequester the CO_2 outside of the atmospheric carbon cycle.[15]

Because this technology directly alters the local ocean ecosystem and spurs atypical growth of large algal blooms, it has already triggered the most vociferous objections and strongest legal opposition.[16] Some of the feared environmental damages from OIF deployed on a global scale include the risk of significant ocean eutrophication and creation of local hypoxic areas, the stimulation of toxic algal blooms that could injure or kill local marine life, the skewing of distribution of species that feed on plankton and might be vulnerable to large fluctuations in their food supplies, and the potential disruption of plankton ecosystems and mix of plankton species that support the base levels of oceanic food chains and ecosystem webs.[17]

Other varieties of climate engineering. While SRM, CDR and OIF have received most of the initial focus, other new climate engineering technologies are emerging and may pose yet another set of risks for different types of damages. For example, some scientists have proposed a modified form of SRM that would increase the albedo of local marine clouds ("marine cloud brightening"). Other proposed techniques would thin the density of cirrus clouds in a way that would allow greater amounts of infrared radiation to escape from the Earth's surface into space ("cirrus cloud thinning").[18] Both marine cloud brightening and cirrus cloud thinning remain relatively new proposed approaches, and as a result most assessments have not focused on how they might pose a risk of damages that differs from other SRM approaches. The environmental assessment of other possibly promising new approaches to climate engineering – including broad deployment of biochar, enhanced weathering of olivine or calcine minerals, or aggressive modification of surface albedo through ground coverings or reflective surfaces – remains relatively unexplored. To the extent that the following discussion identifies general principles of liability that apply to SRM, CDR and OIF, those principles will also likely apply to environmental damages or side-effects of all climate engineering technologies.

Climate engineering, if it matures into a viable strategy to respond to climate change effects, would likely evolve from initial local field tests and research into increasingly broader deployments and, ultimately, global implementation.[19] As it expands the scale of its possible impact, climate engineering will likely face different sources of liability as it becomes subject to three possible fields of law: international, transnational, and domestic law. Each of these fields will now be addressed in turn.

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II. Climate Engineering Liability Under Domestic Law

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1. Liability for Tortious Conduct Under Domestic Law

In addition to any statutory authorities that potentially apply to climate engineering projects, tort law likely offers another vehicle for attempts to impose liability on climate engineering efforts that result in damages to other persons or nations. In fact, in 2016 an advocacy group filed in Canada the first class action lawsuit to challenge alleged clandestine climate engineering activities through chemical contrails from jets (known as "chemtrails") and they have announced plans to file a parallel lawsuit in the United States.[94] While many national legal systems rely on tort actions and concepts to provide redress to injured parties, this chapter will focus on U.S. federal and state tort laws and how they may apply to proposed climate engineering approaches.

While the legal challenge to alleged chemtrails may constitute the first tort challenge to alleged field deployment of a putative climate engineering technology, this lawsuit should be viewed in context of the larger chemtrail movement. Chemtrail adherents energetically contend that the United States and other nations have engaged in a vast clandestine program to test and deploy chemicals to control the climate through surreptitiously impregnating them into commercial and military jet fuels. To date, no independent credible investigation has uncovered any evidence of such a global or national conspiracy, or indeed of any such practice at all. Absent evidence of such secret climate engineering efforts, the pending lawsuit may face a dismissal in the Canadian courts.

While U.S. federal and state common law both provide for tort liability, the vast majority of tort actions arise under state law and proceed within state court systems.[95] If climate engineering research activities or projects result in harm to the other persons or their property, those damages could spark the filing of common law tort actions under the theories of private or public nuisance, trespass, negligence, failure to warn, and strict liability for ultrahazardous activities. Claimants alleging damages from general climate change effects have brought actions under each of these theories against public and private institutions seeking both injunctive relief and legal damages. Notably, to date, each effort to recover climate change damages under a tort claim has failed,[96] and those actions will continue to face daunting hurdles to satisfy standing requirements, prove causation and redressability of injuries, and overcome objections based on political question doctrines. They would also have to navigate likely equitable defenses such as laches, contributory negligence and allocation of responsibility among a vast array of potential co-defendants.

2. Public and Private Nuisance Actions

Under state common law private nuisance actions, property owners can seek compensation if another person's actions have unreasonably interfered with their use and enjoyment of their real property. These lawsuits tend to focus on whether the alleged substantial and unreasonable interference rises to a level that outweighs the social utility of the defendant's activities. In addition to private nuisance actions, a governmental plaintiff (or a private party suffering harms beyond those shared by the general public) can bring a public nuisance action against persons who interfere with the enjoyment of a right held in common by the general public. For example, states have used public nuisance actions to halt, or obtain damages for, a wide variety of activities that injure public interests such as blocking public roads or waterways, maintaining a public bawdy house, or – most relevant – polluting or damaging an environmental resource (such as a waterway) held in common by the public. Other public nuisance claims have challenged activities that caused odors or noise which impaired the public's ability to quiet enjoyment of public resources.[97]

Given the large uncertainties surrounding their effects and operational consequences, climate engineering research and projects may create unanticipated damages that could lead to public and private nuisance claims. For example, SRM techniques will likely rely on the dispersal of aerosolized sulfates that could affect rainfall distribution and amounts, precipitate back to the ground after spending several months in the stratosphere, or materially reduce solar insolation to ground-level facilities that rely on constant solar influx (e.g., solar power facilities and large-scale open-air agriculture). Alternatively, OIF projects that disperse large amounts of iron onto marine bodies could allegedly cause water pollution, ecosystem damage, algae blooms that lead to hypoxic conditions, and other chemical imbalances in ambient water conditions. Private claimants whose use of their real property suffers because of these side effects could bring a private nuisance action that seeks damages or injunctive relief because the climate engineering has substantially and unreasonably interfered with their property enjoyment. Alternatively, other claimants could bring a public nuisance tort action to allege that these unintended consequences interfered with the use and enjoyment of a right held in common by the public to a healthy and stable climate and environment. To do so, private plaintiffs contesting a public nuisance would also have to demonstrate that they had suffered a special injury beyond the general damage suffered by the public at large[98] – a requirement which may pose considerable difficulties for many members of the public who want to challenge climate engineering projects.

3. Trespass

Trespass occurs when a person intentionally and tangibly interferes with a property owner's exclusive possession and use of their land. As opposed to nuisance and negligence, which require some demonstration of harm, a trespass occurs with the invasion or interference itself without proof of any additional injury. Common law trespass actions would typically arise when one person made a tangible entry upon the other party's land. In modern cases, some state and federal courts have found viable trespass claims based on the physical intrusion of smoke, particulate matter or vibration and seismic waves, especially if that trespass had resulted in substantial physical damage to the property.

Some climate engineering technologies might create an opportunity for actions that could constitute a trespass. For example, some SRM methods might disseminate sulfate particulate matter that eventually precipitates onto the claimant's land. Some CDR approaches might also require machinery and supplies that create smoke, dust, vibrations and particulate matter that crosses onto adjoining properties. Trespass might also occur if a climate engineering project resulted in the creation of clouds or enhanced precipitation that then physically passed onto the plaintiff's property.[99] But the ultimate application of trespass doctrine to climate engineering, however, seems limited because the leading proposed technologies for SRM and CDR require either overflights at an altitude that typically would not create a trespass, intrusions at depths below thresholds that have historically constituted trespass, or do not require any impact or access to adjoining properties at all (except for potentially altering the composition of the ambient atmosphere over that land area).

4. Negligence

Persons who perform climate engineering may face liability if they act in a way that creates an unreasonable risk of harm to others.[100] In general, a claimant alleging negligence must demonstrate that the defendant's conduct breached a duty of care that the defendant owed to the plaintiff, and that the breach proximately caused harm to the plaintiff. Because negligence focuses on a broad duty of responsible care that can apply flexibly to numerous situations, claimants often allege negligence claims first when faced with novel or unfamiliar technologies or risks. To the extent that persons who conduct climate engineering projects owe a duty of care to others who might suffer injury if the project goes awry, negligence claims would provide an attractive legal vehicle for persons who wish to challenge climate engineering activities. This argument would require the plaintiffs to demonstrate that persons who conduct climate engineering owe a duty to them to conduct it in a reasonable and safe manner that meets a level of care reasonably expected from anyone who undertakes this action. If the climate engineering project arguably fails to comply with any statutory or regulatory standard, plaintiffs could bolster their claims by arguing that those violations render the climate engineering project negligent per se.

5. Strict Liability

A person can incur strict liability for damages caused by their conduct if they engage in an abnormally dangerous action. If so, plaintiffs could recover damages without needing to identify any fault by the defendant. While the common law does not set out a bright-line standard to identify abnormally dangerous conduct, courts have imposed strict liability if the activity poses a high degree of risk, that risk cannot be eliminated through reasonable care, the activity is relatively uncommon, the activity takes place in an inappropriate location, and the risks posed by the activity outweigh its value to the community. While some states have imposed liability on persons who conduct weather modification efforts that cause damage, the caselaw remains divided and relatively old.[101] Climate engineering activities, by contrast, pose a relatively novel technology that raises a risk of unpredictable harm to other persons. In this context, a court might be more likely to subject climate engineering to strict liability to assure that injured parties can successfully obtain compensation.

6. Possible Obstacles to Climate Engineering Liability Actions

While several tort theories could arguably apply to climate engineering activities that allegedly injure other persons, those tort claims will face a daunting list of jurisdictional and procedural obstacles in federal and state courts in the United States. For example, federal common law tort lawsuits seeking damages or injunctive relief against persons who had allegedly contributed to climate change have faced dismissal on multiple fronts, including political question, sovereign immunity, laches, statutes of limitation, standing, and justiciability.[102] For tort actions filed under federal common law, the U.S. Supreme Court has ruled that all such climate change claims were displaced by Congress' grant of power to EPA to regulate greenhouse gas emissions.[103] Beyond these jurisdictional threshold challenges, common law tort actions seeking to impose liability on climate engineering project operators would also have to prove causation (i.e., that the climate engineering project directly and proximately caused their injury). Attempts to prove similar causation claims for climate nuisance tort actions have faced great judicial skepticism, but climate engineering projects notably would overtly seek to produce detectable changes to the climate that could be attributed to the project. In addition, at least one state has created an affirmative defense against nuisance and trespass actions premised on greenhouse gas emissions from permitted sources, and other states have considered similar legislation.[104] The language of those laws may also limit the availability of tort actions against climate engineering projects.

Beyond the displacement defense to federal common law tort actions, claimants bringing tort or damage actions under the domestic laws of their respective nations will likely face numerous jurisdictional and procedural hurdles. For example, the plaintiffs will have to navigate varying legal standards of responsibility and liability among different nations, inconsistent transnational standards for enforcement of foreign judgments, and harmonizing potentially inconsistent liability verdicts by multiple national courts for the same action. This patchwork puzzle also may raise the risk of paralyzing any significant climate engineering research or deployment simply because of the open-ended risk of possible liability from overlapping and inconsistent jurisdictions of differing national courts and laws.

The key jurisdictional challenges will likely begin with the ability of claimants to find a court system that can exercise personal jurisdiction over the defendants.[105] As discussed previously, lawsuits against sovereigns will need to find a forum where the responsible state parties have given consent to the International Court of Justice, an international arbitral tribunal or other international decisional body. Litigation against private defendants similarly will need to identify judicial fora where the allegedly responsible parties have sufficient contacts (or have consented) to permit that forum's judiciary to exercise jurisdiction over the defendants. U.S. climate change tort actions under federal common law squarely faced this constraint because they typically targeted a large number of defendants,[106] but domestic litigation challenging climate engineering activities will likely need to target only a small number of defendants who participated in the climate engineering project themselves.

In addition to demonstrating personal jurisdiction over the defendants, climate engineering litigants will also face steep challenges to their subject matter jurisdiction over projects where no domestic laws (as yet) explicitly impose duties on climate engineering activities. They will also have to demonstrate that their damages were caused by the climate engineering research or deployment under either a strict liability regime under public international law or, more problematically, a proximate causation standard under most domestic tort or statutory environmental laws. These difficulties, however, may be offset by the facts that climate engineering projects will include a dramatically smaller pool of defendants, focus on activities that expressly intend to produce a discernable effect on climate systems which can be attributed to the engineering project, and can point to data and statements by the defendants about the results of their work as an admission against interests.[107]

Similar challenges await climate engineering litigants against private defendants in the United States federal court system. As an initial step, claimants would have to prove that they can sue the climate engineering operator in the first place. U.S. federal courts require, for example, that plaintiffs demonstrate that they have standing to pursue their specific claims in federal court. Absent a showing that they have suffered a concrete, particularized injury-in-fact that can be fairly traced to conduct of the defendants which the courts can redress, climate engineering plaintiffs would not satisfy the irreducible requirements mandated by the U.S. Constitution to bring a claim before federal courts (although redressability obviously is less problematic if the plaintiffs simply seek monetary damages or specific injunctive relief to halt ongoing activity).[108] Even if they prove that they have standing to bring their claim, climate change litigants in U.S. federal courts would still have to navigate objections to their claims based on prudential justiciability doctrines such as the political question doctrine,[109] ripeness (if the alleged damages from the climate engineering action have not yet fully manifested themselves), and deference to decisions that affect the conduct of foreign affairs by the U.S. President or other executive officials.[110]

For a nuisance or negligence claim, the plaintiffs would also have to show that the climate engineering project was conducted in an unreasonable way – a daunting proposition if domestic environmental laws do not require an operator to obtain a permit or authorization for certain types of climate engineering.[111] To the extent that a climate engineering project requires an environmental permit, that permit (once issued) might also act as a shield to potential tort or statutory liability if the operator complies with its terms. Finally, after they have surmounted all of these barriers, climate engineering litigants in U.S. federal court would have to answer challenges that Congress has already displaced any possible federal common law tort claims arising from climate change effects.[112]

In addition to identifying which individual parties can bring actions to impose liability for damages from climate engineering projects, courts will also have to designate which defendants can be sued. For example, plaintiffs may seek damages for a governmental agency's failure to anticipate foreseeable damages caused by a climate engineering project that the agency undertakes or approves. This type of action would parallel arguments that federal governmental agencies potentially bear responsibility if they build public facilities that either fail to account for likely climate change effects such as increased rainfall and flooding or higher peak surface temperatures. To do so, the plaintiffs would also have to prove that the governmental defendants had not waived their sovereign immunity against such a lawsuit. Despite these challenges, at least one case in the United States has already successfully held at least one federal agencies liable for failing to plan for increased flooding, structural damage and water disruption from climate change.[113]

Last, even if a plaintiff successfully navigates a claim past all of these shoals, the final burden of causation will likely loom. Admittedly, a lawsuit seeking to impose liability on a climate engineering project likely will not face the notorious difficulties of proof of causation that challenge tort lawsuits against historical and current emitters of greenhouse gases. Climate engineering plaintiffs, however, will still need to demonstrate that the events that damaged them arose from a climate engineering action rather than the typical variability of weather (even severe weather) and natural climate systems. While climate engineering activities will often inherently seek to produce exactly that type of discernable effect or "fingerprint" which can support causation, a plaintiff may face difficult evidentiary challenges in linking an unexpected and undesired side effect to the underlying climate engineering action.

Presumably a successful climate engineering lawsuit would accept the typical methods to satisfy a liability judgment. For example, plaintiffs could likely seek monetary damages to compensate them for their injuries, injunctions against continuation of those activities,[114] revocation or remand of any governmental permits or approvals for the climate engineering action, and restitution for their diminished assets or non-monetary losses. They could also seek a declaratory judgment that would lay out clear principles of liability to guide future climate engineering activities that involve the same parties.[115]

While a court system would have the panoply of traditional remedies to assess against climate engineering actions that violate rights or obligations to third parties, courts would still face novel and difficult issues when they apply those familiar tools to climate engineering. They would first have to parse damages from climate engineering from damages caused by underlying climate change itself. To the extent that overall climate change continues as a backdrop to climate engineering efforts, it may drown out the signal of causation normally attributable to climate engineering actions. In addition, the climate engineering action itself may also generate benefits that arguably should offset the damages due to any litigant that the engineering may have aided.[116]

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III. Future Directions

Given its potentially sweeping role in responding to climate change disruption, the prospect of climate engineering has understandably generated a buzz of commentary and analysis on its governance. Many initial comments have centered on the challenge of regulating global SRM, which raises the largest concerns about potentially harmful side-effects, equity concerns, and allocation of risks onto objecting states and parties. As a result, much of this initial analysis has sought to define a clear and forceful set of rules that would govern most types of climate engineering in a flexible, fair and effective fashion. Given the complex interactions that SRM liability would raise between domestic and international law as well as the challenge of prospectively regulating a complex emerging technology, the range of suggested approaches has spanned a complete ban on all climate engineering[140] to establishment of a de minimis liability threshold that would protect researchers and small-scale field deployments of SRM from liability.[141]

Despite its nascent state, the liability principles described in this chapter offer some initial directions for further consideration. First, liability for climate engineering will depend heavily on the type of technology at issue. The risks and benefits posed by SRM are so vastly different from the concerns evoked by direct air capture CDR or marine cloud brightening that it is probably misleading and unproductive to define a single liability framework that treats all climate engineering technologies in the same way.[142]

That said, some initial possible distinctions may point to differing liability approaches for each technology. For example, the deployment of SRM on a global scale to regulate planetary surface temperatures would likely mandate the participation and resources of national governments or international organizations. As a result, a liability framework crafted for state actors conducting global SRM would make the most sense.

The absolute liability standard and dispute resolution approaches set out by the Space Liability Convention could provide a useful starting point for analysis. While initial attempts to spur discussions about regulation of ocean iron fertilization under the London Convention and Protocol or the Convention of Biological Diversity have had limited success, they highlight a possible approach that could seek the development of either a new Protocol under the UNFCCC or a new multilateral convention. This approach, however, will likely require an enormous amount of diplomatic effort, time and financial resources to reach a resolution acceptable to the world community.

If the world community seeks to craft a liability standard to govern SRM, it could draw on other existing principles from current international agreements. First, international law now relies almost exclusively on strict liability as a tool to impose liability under either state actor or civil liability approaches. This burden of proof would allow claimants to focus on factual causation and damage quantification issues without wrestling with nettlesome questions of fault and equity. Second, states should be required to assure that persons or organizations within its jurisdiction comply with fundamental norms that would prevent untrammeled deployment without careful consideration and research into potential side effects. This approach would likely rely on existing international norms incorporating the precautionary principle as well as an escalating scale of deployment that allows investigation into SRM's effects and consequences on an interim basis before full deployment.[143] And last, given the potentially vast scale of unintentional damages caused by side effects from SRM,[144] a SRM governance framework should also incorporate steps to assure that adequate funds will be in place to compensate aggrieved parties for demonstrable damages. This need could potentially be met with mandatory taxation on activities that generate GHG emissions or a broad carbon tax.

By contrast, the hazards posed by direct air capture or CDR are vastly different from SRM's risks. CDR will likely require local land use decisions, minimal impact on global surface temperatures from any single CDR or direct air capture project, and great challenges in discerning any causation between particular CDR efforts and unexpected climate side effects or disruptions. CDR could have local land use or environmental impacts, but those are well suited for domestic resolution. As a result, reliance on domestic laws and liability principles could effectively regulate the environmental consequences of CDR until it reaches a stage where collective CDR actions potentially disrupt climate systems or large-scale land use.[145]

In truth, liability for climate engineering will likely need to reflect the broad array of potential climate engineering technologies, their disparate scales of deployment, and their varying degrees of development and readiness. The field remains new, and it is highly likely that variations of SRM, CDR, accelerated weathering, biochar deployment, BECCS, cirrus cloud stripping, and other new approaches will emerge from ongoing research initiatives. For example, some investigators have proposed that lower-altitude tropospheric dispersion of sulfate particles can moderate solar radiation on a regional scale instead of a global effect. As a result, this targeted variety of SRM could address immediate climate disruption concerns on a local scale such as severe heat waves or disrupted precipitation cycles. If this approach proves viable, it would allow smaller nations, state governments, local governmental authorities or even private parties to undertake short-term regional climate engineering. Any governance system that dictates liability solely on the assumption that SRM must take place on a global scale and be performed by sovereign states would likely fail to reach or properly regulate the benefits and risks of this emerging technology.

As a result, the most fruitful approach to crafting liability standards for climate engineering will likely be a careful delineation of multiple standards that would apply to the different risks and challenges of the growing suite of climate engineering technologies. By tailoring liability rules to better fit the risk and promise of different technologies, emerging approaches that pose lesser risk or greater benefit could proceed without cumbersome governance requirements or chilling liability requirements that larger and more risky approaches would demand. Although automobiles, motorcycles, trucks, ships and aircraft all provide the basic service of transportation, they each operate under very different liability regimes that reflect their global and local impacts, risks and benefits, and societal demands. As climate engineering evolves, we may see a similar proliferation of liability and governance approaches to fit the growing variety of climate technologies.

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[11] Many nations now recognize a constitutional right to a clean environment either through express constitutional terms or through implied rights provided by a broader right to life or liberty. *See* E. Daly and J. May, GLOBAL ENVIRONMENTAL CONSTITUTIONALISM at 13, 55-84 (Cambridge Univ. Press 2016). Citizens of other nations may attempt to use those constitutional provisions as a basis to force or stop climate engineering projects. That analysis, however, lies outside the scope of this chapter.

[2] E. Kinitsch, *supra* at p. __ (Part II: Carbon Dioxide Removal).

[3] The current state of CDR technologies would remove CO_2 at a relatively steady and comparatively low rate that would not exceed local atmospheric mixing conditions for CO_2 in ambient conditions. As a result, the prospect of accelerated CO_2 removal resulting in a local "pocket" of ambient air with disruptively low greenhouse gas levels appears exceedingly unlikely in the near future. *See* Intergovernmental Panel on Climate Change, *Changes in Atmospheric Constituents and in Radiative Forcing*, in CLIMATE CHANGE 2007: THE PHYSICAL SCIENCE BASIS at 138-39 (Susan Solomon et al. eds., 2007) (discussing CO_2 mixing and radiative forcing rates); R. Lazarus, *Super Wicked Problems and Climate Change: Restraining the Present to Liberate the Future*, 94 CORNELL L. R. 1153, 1163-64 (2009) (global warming effect of CO_2 emissions not dependent on location of emission because of fast mixing rates).

[4] *See, e.g.,* T. Hester, *Direct Air Capture of Greenhouse Gases* in LEGAL PATHWAYS FOR DEEP DECARBONIZATION IN THE UNITED STATES (Michael B. Gerrard & John Dernbach, eds.)

(Environmental Law Institute, forthcoming 2018) (describing various direct air capture technologies and strategies).

[5] According to the Carbon Dioxide Information Analysis Center at the Oak Ridge National Laboratory, the removal of 1 ppm by volume CO_2 of from the ambient atmosphere would generate 2.13 gigatons (Gt) of carbon, or 7.8 Gt of CO_2. *See* F. O'Hara, Jr (ed.), Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, *Carbon Dioxide and Climate*, ORNL/CDIAC-39 (3d ed. 1990). Removing sufficient CO_2 to reduce ambient levels from 400 ppm to 350 ppm would therefore generate approximately 390 Gt of CO_2 that would require either sequestration or reuse. By comparison, all anthropogenic GHG emissions in 2010 totaled 49 Gt of CO_2e (±4.5 Gt). *See* Intergovernmental Panel on Climate Change, SUMMARY FOR POLICYMAKERS; in *Climate Change 2014: Mitigation of Climate Change, Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* at p. 6 (Cambridge Univ. Press 2014). For comparison, the total amount of all solid waste generated in the United States in 2014 was only 249 million tons – a vanishingly small fraction of the weight of such potentially captured CO_2. *See* U.S. Environmental Protection Agency, *Advancing Sustainable Materials Management: Facts and Figures,* https://www.epa.gov/smm/advancing-sustainable-materials-management-facts-and-figures (last verified March 24, 2017).

[6] *See, e.g.,* P. Smith, R Hazeldine and S Smith, *Preliminary assessment of the potential for, and limitations to, terrestrial negative emission technologies in the UK,* 18 ENVIRON. SCI.: PROCESSES IMPACTS 1400, 1403 (2016) (along main technical limitations of negative emissions technologies are "high cost and energy requirements for DAC"). The energy demands will vary substantially according to the technology involved. *See* K. House, *Economic and energetic analysis of capturing CO_2 from ambient air*, 108 PNAS 20428, 20428-29 (Dec. 11, 2011), at www.pnas.org/cgi/doi/10.1073/pnas.1012253108; L. Joos, *Cutting the cost of carbon capture: a case for carbon capture and utilization*, 192 FARADAY DISCUSS. 391, 391-93 (Dec. 20, 2011). The high cost of post-combustion carbon capture has long been noted. *See, e.g.,* L. Joos, J. Huck, V. Speybroeck and B. Smit, *Cutting the cost of carbon capture: a case for carbon capture and utilization,* FARADY DICUSS. 192, 391 (2016).

[7] American Physical Society, Panel on Public Affairs, *Direct Air Capture of CO_2 with Chemicals: A Technology Assessment for the APS Panel on Public Affairs* at iv, 72-73 (June 1, 2011) (concluding that high-carbon energy sources are not viable options to power DAC systems because their emissions may exceed the amount of CO2 captured by the DAC; further, using low-carbon energy sources to power DAC would divert the more logical use of those energy sources to directly displace high-emitting centralized carbon sources).

[8] *See* Kinish, *supra* note 2 at __.

[9] While the editors of this text have excluded afforestation and reforestation from its definition of climate engineering, the development of biological energy carbon capture and storage (BECCS) as a negative emissions technology would likely spur a large increase in the amount of land devoted to forests and crops as a fuel source to the biogenic energy facility. *See* K. Tokimatsu, R. Yasuoka, M. Nishio, *Global zero emissions scenarios: The role of biomass energy with carbon capture and storage by forested land use*, APPLIED ENERGY 185, 1899 (2017) ("[o]ne of the key requirements of BECCS is land for biomass production, with 200 Exa Joule (EJ) per year (EJ/yr) of bioenergy estimated to require approximately 500 Mha of land, corresponding to one-third of global crop land"); M. Ranjan and H. Herzog, *Feasibility of Air Capture*, 4 ENERGY PROCEDIA 2869, 2873 (2011) ("[t]he land area required to capture and store 1 [gigaton] of CO_2 through this route is 203,125 square miles, which is a third more than the land area of California"), at doi:10.1016/j.egypro.2011.02.193; L.R. Boysen, W. Lucht, D. Gerten and V. Heck, *Impacts devalue the potential of large-scale terrestrial CO_2 removal through biomass plantations*, 11 ENVIRON. RES. LTRS 09510 (2016) (changes in land carbon uptake, albedo modification, and nitrogen fertilizer use would reduce the efficacy of BECCS and require disruptively large amounts of surface territory to achieve targets of 1.5, or even 2.0, degrees in the absence of aggressive emissions mitigation).

[10] Kinish, *supra* at __ (chap. 2) (citing 2015 National Research Council report).

[11] P. Williamson, 530 NATURE 153 (2016); K. Anderson, *The Trouble with Negative Emissions,* 354 SCIENCE 182, 183 (Oct. 14, 2016). *See also* T. Powell and T. Lenton, *Scenarios for future biodiversity loss due to multiple drivers reveal conflict between mitigation, climate change and preserving biodiversity,* 8 ENVIRON. RES. LETT. 8 (2013), doi:10.1088/1748-9326/8/2/025024 (withdrawal of

energy via BECCS has a "large negative effect on biodiversity" on agricultural systems under four scenario models to 2050).

[12] *See, e.g.*, T. Gardner et al., *A framework for integrating biodiversity concerns into national REDD+ programs*, 154 BIOLOGICAL CONSERVATION 61, 62 (2012).

[13] *Anoxic* waters lack dissolved oxygen and, as a result, cannot support species that respire oxygen from the water through surface filtration, diffusion or extraction (e.g., fish with gills). Waters can become anoxic through the process of *eutrophication*, where the decomposition of eukaryotic or prokaryotic organisms in the water consumes available oxygen. By contrast, waters that still contain some dissolved oxygen (even if at a low level that cannot support life) are *hypoxic.* The infamous zone of oxygen-depleted waters that recurs annually at the mouth of the Mississippi River, for example, is hypoxic*.*

[14] *See* Kinish *supra* at __ (chap. 2); Burger & Gundlach, *infra* at __ (chap. 6).

[15] In other words, the carbon contained in the algal bloom sinks below the thermocline and into deep ocean depths where circulation and refresh rates are measured in centuries. *Id.* at __.

[16] *See* discussion *supra* by Reynolds at __ (review of legal responses to ocean iron fertilization proposals under the London Convention, London Protocol and the Convention on Biological Diversity) and by Burger & Gundlach at __ (legal issues raised by research projects on open seas to examine iron fertilization effects).

[17] R. Abate and A. Greenlee, *Sowing Seeds Uncertain: Ocean Iron Fertilization, Climate Change, and the International Environmental Law Framework*, 27 PACE ENVT'L L. REV. 555, 566-572 (2010); C. Trick, B. Bill, W. Cochlan, M. Wells, V. Trainer and L. Pickell, *Iron enrichment stimulates toxic diatom production in high-nitrate, low-chlorophyll areas,* 107 PNAS 5887, 5891 (2010).

[18] *See* J. Latham et al, *Marine Cloud Brightening: regional applications,* 372 PHIL. TRANS. R. SOC. A 20140053 (2014); T. Storelvmo, W.R. Boos and N. Herger, *Cirrus cloud seeding: a climate engineering mechanism with reduced side effects?,* 372 PHIL. TRANS. R. SOC. A 20140116 (2014); A. Cirisan et al*, Microphysical and radiative changes in cirrus clouds by geoengineering the stratosphere,* AMERICAN GEOPHYSICAL UNION, doi:10.100/jgrd.50388 (2013).

[19] Some possibility of regional deployment, which could pose an entirely new set of legal questions and dictates. *See* T. Hester, *A Matter of Scale: Regional Climate Engineering and the Shortfalls of Multinational Governance,* 2013 CLIMATE CHANGE L. R. 168 (2013). Because the prospect of meso-scale climate engineering remains relatively undeveloped, this chapter will not directly assess liabilities related to these approaches, but many of the same general principles of legal liability identified for global climate engineering may also apply to regional initiatives.

[94] *See Pelletier v. Her Majesty, the Queen,* (filed March 10, 2016), T-431-16 (class action filed in Federal Court of Canada), *available at* http://www.geoengineeringwatch.org/documents/D%20Pelletier%20-%20Claim.pdf.

[95] It should be noted, however, that many tort law actions arising under state law proceed nonetheless in federal courts under either diversity jurisdiction or federal statutes that authorize state law claims (e.g., the Federal Tort Claim Act).

[96] T. Hester*, A New Front Blowing In State Law and the Future of Climate Change Public Nuisance Litigation*, 31 STAN. ENVTL. L. J. 101, 115-19 (2012).

[97] RESTATEMENT (SECOND) OF TORTS § 821B; W. Page Keeton *et al.,* PROSSER & KEETON ON THE LAW OF TORTS § 86, at 616 (5th ed. 1984); (discussion of historical context of public nuisance claims).

[98] D. Antolini, *Modernizing Public Nuisance: Solving the Paradox of the Special Injury Rule,* 28 ECOLOGY L.Q. 755 (2001).

[99] Historically, cloud seeding or other attempts to enhance rainfall have not triggered state law trespass complaints because, in part, many states have statutes that bar trespass, negligence or other tort damage claims for properly permitted rain enhancement projects. *See* Hester, *supra* note 78, at 860.

[100] Of course, a national government or agency that conducts a climate engineering research project or deployment would typically enjoy sovereign immunity against actions brought in its own courts or under its domestic laws (subject to any statutory waivers or other self-imposed restrictions). To the extent that an individual has received a permit from a national government to conduct a similar project, however, such authorizations do not typically provide a shield against tort liability claims unless provided by the underlying statute or by preemption or displacement of the underlying state

law. *See, e.g.*, *FPL Farming v. Envt'l Processing Systems, Inc.,* 351 S.W.3d 306, 310 (Tex. 2011) (a "permit is not a get out of tort free card").
[101] Hester, *supra* note 78, at footnotes 27-32.
[102] *See, e.g.,* J. May, *Climate Change, Constitutional Consignment, and the Political Question Doctrine,* 85 DENV. U. L. REV. 919 (2008); A. Thorpe, *Tort-Based Climate Change Litigation and the Political Question Doctrine,* 24 J. LAND USE & ENVTL. L. 79, 79 (Fall 2008).
[103] Notably, while the Court found that the Clean Air Act displaced federal common law nuisance actions for greenhouse gas emissions, the Court explicitly declined to rule on whether the Clean Air Act also pre-empted state tort actions for climate change. *See* Hester, *supra* note 78, at footnote 32.
[104] For example, Texas has barred nuisance and trespass actions based on the release of greenhouse gases if the facility operator is in substantial compliance with its environmental permits. *See* TEXAS WATER CODE § 7.257.
[105] The issue of jurisdiction pertains primarily to private individuals. The ability of a domestic court to order a foreign sovereign to take action is highly questionable, and that court's powers would require that government's waiver of its sovereign immunity either through its express consent or through actions within the forum nation that constitute waiver. For example, a government that engages in commercial activities within the United States that do not constitute state actions may subject itself to the jurisdiction of U.S. federal courts under the Federal Sovereign Immunities Act. This liability, of course, does not constitute a grant of power to the federal court to issue injunctions against the sovereign, but U.S. federal courts can issue contempt orders against sovereign defendants before them as well as order the attachment of a sovereign's assets under the court's jurisdiction that can satisfy a judgment.
[106] For example, both the *Kivalina* and the *Comer* lawsuits targeted numerous companies in the oil, gas, chemical, mining and refining sectors because of their aggregate emissions of greenhouse gases.
[107] Note, however, that climate change actions expressly seek to produce discernable effects in the environment, and consequently the statements of researchers or parties may unintentionally provide statements against interest that could support a lawsuit. *See* Hester*, supra* note 78, at 897.
[108] *See id.* at 895*.* The U.S. Supreme Court has indicated, however, that Congress may have a broader degree of power to define the concrete injury underlying constitutional standing than previously assumed. *See Spokeo, Inc. v. Robbins,* 578 S. Ct. --- (2016)*.*
[109] *See* Hester, *supra* note 78, at 892.
[110] *See id.*
[111] For example, the testing of direct air capture of carbon dioxide and other greenhouse gases will likely not require a permit under U.S. federal environmental statutes, although the operator might need to obtain permits for any impacts arising from the land use or corollary aspects of the direct air removal. For instance, a sizable direct air capture test or deployment might require an environmental impact statement, an authorization for any anticipated impacts on nearby protected species, or approvals to manage the captured CO_2 stream.
[112] *See American Electric Power v. Connecticut,* 564 U.S. 410 (2011).
[113] *See St. Bernard Parish v. United States,* 121 Fed. Cl. Ct. 687, 746 (2015) (holding U.S. Army Corps of Engineers liable for temporary takings caused by its failure to prevent flooding after Hurricane Katrina). State cases have sought to hold state and local governmental agencies accountable for similar failures to anticipate foreseeable environmental effects of actions that they undertake or approve, such as causing increased flooding in downstream neighborhoods by failing to require detention ponds and other preventive steps. *See, e.g., Harris County Flood Control Dist. v. Kerr*, 499 S.W.3d 793 (2016) (dismissing homeowners' claims that City's failure to halt untrammeled upstream development that allegedly caused downstream flooding).
[114] Such plaintiffs would have to show that they satisfy all of the prerequisites for the court to issue equitable relief of this nature. *See Weinberger v. Romero-Barcelo,* 456 U.S. 305 (1982)*.*
[115] *See* discussion *supra* at __.
[116] To successfully argue that a climate engineering project has generated benefits which offset a damage claim, the defendants would likely have to show that the benefit accrued in the same nation or area that suffered the damage. For example, if India seeks redress for damages from a climate engineering project that generated benefits in Canada, the benefits to Canada would likely not provide a valid basis to reduce or reject the claim for damages suffered in India. From a larger perspective, the imposition of liability for

damages to an individual for an action that benefits a larger portion of society as a whole raises fundamental issues about the allocation of tort liability and individual autonomy. In the United States, this debate frequently surfaces in judicial decisions to provide injunctive relief that protects an individual against trespass by pollutants or the designation of a nuisance for an activity that may benefit may other persons. The paradigmatic decision discussing this principle in the United States is *U.S. v. Boomer Cement*, 26 N.Y.2d 219, 257 N.E.2d 870 (1970).

[140] For example, an environmental non-governmental advocacy group in Canada has repeatedly and persistently urged that all research and deployment of climate engineering should be banned until a comprehensive treaty is in place to govern development of disruptive novel technologies (including nanoscale materials and genetically modified organisms). *See* The ETC Group, *ETC Group calls for a ban on all testing or deployment of geoengineering technologies, available at* http://www.etcgroup.org/content/etc-group-calls-ban-all-testing-or-deployment-geoengineering-technologies-and-supports-move.

[141] *See* J. Long, F. Loy and M.G. Morgan, *Start Research on Climate Engineering,* 518 NATURE 29 (Feb. 5, 2015) (calling for self-implementing threshold to allow small-scale field testing of climate engineering technologies).

[142] D. Keith, A CASE FOR CLIMATE ENGINEERING at __ (2013) (discussion of the fundamental differences between SRM versus CDR and the need to distinguish the issues and policy demands of each technology).

[143] The application of the precautionary principle has already spurred a large, and fast growing, body of academic literature. *See* discussion *supra* at Chapters__ and __. While the precautionary principle may challenge some deployments or tests of climate engineering technologies, its application is less clear when the risk of inaction is greater than the comparable (albeit uncertain) risk of acting. *See id.*

[144] Some researchers have preliminarily estimated that stratospheric aerosol injection could potentially cause damages equal to roughly one percent of gross domestic product. As a result, monetary damages incurred by particular states will vary according to the size of their economies (e.g., China could face damages of $100 billion, while Indonesia could incur damages up to $10 billion). *See* Horton et al, *supra* note 20, at 243.

[145] For example, the broad-scale deployment of BECCS could have significant biodiversity impacts arising from deforestation or accelerated species loss. *See* discussion *supra* at note 11.