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Direct Air Capture of Greenhouse Gases

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[Summary: Given the U.S. economy's ongoing reliance on fossil fuel energy sources and current high levels of anthropogenic greenhouse gases in the atmosphere, a full deep decarbonization pathway assessment should examine strategies using the direct air capture (DAC) of ambient carbon dioxide. DAC includes any industrialized and scalable method to remove greenhouse gases from the ambient atmosphere and either store or reuse those gases in a way that does not allow them to escape back into the atmosphere. While still nascent, these technologies include a wide array of approaches such as biomass energy with carbon capture and sequestration, enhanced weathering of minerals, and the direct mechanical capture of ambient CO_2 through filters and chemicals. Although the Deep Decarbonization Pathways Project does not discuss the viability and impact of DAC sequestration strategies because it believed that the feasibility and sustainability of large-scale negative emissions technologies remained too uncertain, a preliminary assessment shows

that broad use of DAC will face significant legal and policy barriers depending on the type of negative emission technology chosen. These barriers could include the potential impact of DAC on local land use, potential disruption of biological diversity and protected species, management of energy demands and wastes generated by DAC processes, concerns about potential liability for damages from DAC operations, and – most challenging -- assuring safe and effective permanent sequestration of the captured CO_2. Effective policies and legal reforms to address these obstacles could include direct public support and investment in the development of DAC technologies, expediting environmental assessments and permitting of DAC projects which require environmental impact statements or reviews, potential legislative caps or limits on liability, and providing incentives for the use of DAC to remove CO_2 from the atmosphere (e.g., through tradable credits or designation as an acceptable method to comply with air permit requirements).]

Deep decarbonization will require a fundamental transformation of U.S. energy and manufacturing industries, but those sweeping changes likely won't suffice. Anthropogenic emissions since the start of the Industrial Revolution have already resulted in concentrations of carbon dioxide (CO_2) in the ambient atmosphere that will lead to significant average global surface temperature increases before the end of this century. Simply put, even if current anthropogenic emissions drop to zero, the levels of CO_2 already present in the atmosphere will have locked us into rapid and intractable warming.[1] Deep decarbonization of future emissions also will not sufficiently offset or respond to disruptive physical transitions caused by ongoing climate change that could cause substantial new greenhouse gas emissions, such as melting permafrost, reduced arctic albedo and carbon releases from forest fires.[2]

To address these prior CO_2 concentrations already stockpiled in the atmosphere, deep decarbonization will likely require additional steps. One potential option under active investigation is the direct air capture (DAC) of atmospheric CO_2 or other greenhouse gases to sequester them in an inaccessible or inert form or convert them into a commercial product or good. Given the enormous difficulties facing efforts to reduce GHG emissions, climate change forecasts and strategies have begun to devote growing attention to DAC as a complement to broad emissions mitigation. For example, the United Nations' Intergovernmental Panel on Climate Change's latest Integrated Assessment Models suite of 900 scenarios found only a small set of 76 pathways that could attain the Paris Agreement's target of limiting temperature increases to 2˚C or less, and the vast majority of those models relied on negative emissions technologies.[3] In particular, the models assume that the world community will broadly adopt the technology of generating power through burning biomass energy with carbon capture and sequestration (BECCS).[4]

While most of this book focuses on approaches to remove carbon from the production of energy and economic goods, this chapter assesses the legal and policy challenges of decarbonizing the atmosphere itself through direct air capture of ambient carbon dioxide. The Deep Decarbonization Pathways Project's (DDPP's) analysis does not discuss the viability and impact of this potential approach because it concluded that the feasibility and sustainability of large-scale negative emissions technologies, including direct air capture, remained too uncertain to include in country-level Deep Decarbonization Pathways.[5] For example, in its 2014 Interim Report the DDPP Project excluded from its pathway assessments any significant reductions achieved by negative emissions technologies. According to the Project, "[t]he sustainability of the large-scale deployment of some net negative emissions technologies, such as Bio-Energy with Carbon Capture and Sequestratation (BECCS), raises issues still under debate, in part due to the competition in land uses for energy and food purposes."[6] The Project's final report eschewed any reliance on DAC or other negative emissions technologies for similar reasons.[7]

Yet despite its current technological uncertainty, the potential broad use of DAC could offer significant benefits to the Deep Decarbonization initiative. As the Project's authors note, the availability of net negative emissions technologies such as DAC would enable a gentler transition to reduced carbon emissions because they would allow for a higher carbon dioxide budget in the first half of the 21st century to the extent that those negative emissions technologies become widely available in the second half of the century.[8] More importantly, the widespread use of DAC could help reduce the historical accumulations of atmospheric greenhouse gases that currently would result in potentially disruptive climate change even if ongoing emissions dropped to zero. While we now have only an initial sense of the technological efficiency and economic viability of DAC technologies, some early assessments foresee that the wide use of DAC in the United States alone could lead to a removal of approximately 13 gigatons of CO_2 per year with a cumulative removal of approximately 1,100 gigatons of CO_2 by the year 2100.[9] In the United Kingdom, land-based negative emissions technologies could potentially remove 12 to 49 Mt C annually, or about eight to 32 percent of current emissions.[10] By comparison, the overall rate of CO_2e emissions from fossil fuel production, cement production and deforestation during the years 2002 through 2011 averaged approximately 33.7 gigatons per year.[11] A clearer legal framework that removes potential regulatory and liability barriers, as well as policies that foster and support the actual implementation of DAC, could encourage a broader deployment of DAC at scale in a speedier time frame.

The widespread deployment of DAC would face significant legal barriers, and the broad use of DAC strategies to achieve deep decarbonization would need to resolve several hurdles. Given the potential important role that fully-developed DAC could play in attaining deep decarbonization of the ambient atmosphere, the removal of these legal obstacles to DAC's deployment at an early stage could play an important role in improving the odds for its availability as a policy option. For clarity, this chapter groups the legal challenges into three categories: construction and infrastructure legal issues, legal consequences of operational impacts, and legal requirements for management of process wastes.

Construction and Infrastructure Legal Issues. These challenges would arise from the disruptions and effects of locating, constructing, and provisioning DAC operations and facilities. Some of these barriers might include the assessment and disclosure of the environmental impacts of the siting; construction and operation of industrial-scale DAC units dispersed throughout wide geographic regions; or the acquisition of rights to use potentially broad swaths of land or marine surfaces needed by some DAC technologies such as accelerated weathering. These hurdles might warrant the possible use of condemnation powers to obtain those property rights.

Legal Consequences from Impacts from Normal DAC Operations. Other obstacles may arise from the anticipated impacts that routine large-scale DAC operations might have on adjoining properties and neighbors. For example, broadly dispersed DAC operations may affect fragile ecological resources or protected species and their habitat. The operators of DAC systems may also face potential tort liability if they create conditions that either negligently injure other persons and resources or create nuisances and trespasses.[12]

Legal Issues Arising from the Management of DAC Process Wastes. In addition to legal questions raised by DAC siting, infrastructure and operations, some of these facilities will also likely generate substantial gas product streams and wastes. Such materials will evoke traditional environmental regulatory issues, such as the management and sequestration of potentially vast quantities of captured CO_2 (unless the gas is reused for some purpose) and the disposition of wastes generated by the CO_2 capture and removal process itself (e.g., spent chemicals or other process residues).

These legal obstacles to the full deployment of DAC center on the environmental side-effects and externalities of the expected operations. A more remote legal issue, however, may arise from the success (or failure) of attempts at large-scale DAC. If a nation or person successfully deploys significant DAC facilities that materially reduce ambient concentrations of CO_2 or other GHGs, those reductions may have substantial negative economic effects on current "climate change winners." For example, a government or corporation that has invested heavily in the expectation of expanded shipping across the newly opened Northwest Passage may argue that the DAC operations have seriously damaged its property and operational expectations.[13] Alternatively, the inept or incompetent implementation of DAC may create its own separate set of damages and legal concerns. To the extent that these speculative legal liabilities arise from the successful mitigation of anthropogenic disruption of the atmosphere, however, the prospects of such claims appear minimal and will not be further considered in this analysis.[14]

The legal options and pathways to resolve these issues will turn largely on the actual DAC technology selected and the location and manner in which it is used. But the bulk of legal barriers to the widespread deployment of DAC could likely be resolved through the creative use of legal tools that federal agencies have already provided for the capture and sequestration of CO_2 from power generation facilities as well as the policy options already developed for the use of CO_2 in enhanced oil and gas recovery. The broad use of programmatic environmental impact statements, presumptive model permits and condemnation powers could remove many of the remaining legal barriers as well.

This chapter will begin by briefly overviewing in Section I the suite of potential technologies that could help directly capture greenhouse gases at a scale that would significantly reduce their concentrations in the ambient atmosphere. Section II will outline the potential legal requirements under current U.S. environmental laws that might impede the full development and implementation of DAC technologies as well as possible bases for legal liabilities that might discourage their development. Last, Section III offers several potential avenues to minimize these legal hurdles in a way that could help the development of DAC strategies without unduly increasing environmental risks or weakening necessary environmental governance obligations.

I. Negative Emissions Technologies and Direct Air Capture.

As noted above, DAC technologies offer a possible strategy to help reduce ambient global CO_2 levels while the United States and other nations adopt comprehensive mitigation and adaptation strategies. This section will provide a brief description of the fast-growing portfolio of possible DAC technologies currently under development. It will then assess some of the relative strengths and weaknesses of the varied approaches.

As an initial step, it is worth clarifying the scope of the term “direct air capture” for purposes of this chapter. We will define DAC to include any industrialized and scalable method to remove greenhouse gases from the ambient atmosphere and either store or reuse those gases in a way that does not allow them to escape back into the atmosphere. As a result, this definition does not include various other technologies that attempt to directly offset the effects of anthropogenic climate change without removing atmospheric carbon stocks, such as solar radiation management (SRM), carbon capture and sequestration (CCS) from fossil fuel combustion streams (discussed in Chapter 28 of this book), enhanced agricultural or silvicultural carbon uptakes (including afforestation, reforestation, and REDD+) (discussed in Chapters 30 and 31),[15] and carbon-neutral fuels (Chapter 25).

Within the scope of this definition, DAC technologies fall into four general categories: mechanical direct air capture of CO_2 from the ambient atmosphere; enhancement of CO_2 removal through the manipulation of marine water chemistry and biota; removal of CO_2 through enhanced weathering of minerals (including the accelerated calcination through passage of CO_2 over basalt to generate carbonate minerals suitable for permanent sequestration); and direct soil aggregation and management (particularly through the use of biochar) to promote CO_2 uptake. These latter techniques, in particular, have seen some notable recent successes.[16]

This overview of DAC technologies bears a major caveat. While the general principles and processes of ambient CO_2 capture have been widely known for decades, the field is undergoing a burst of activity and research spurred, in part, by the increasingly prominent role of CO_2 removal technologies to attain the Paris Agreement's 2° C target. In its 2015 report on carbon dioxide removal and sequestration technologies, the National Academy of Sciences endorsed an active research program to develop a broad array of carbon dioxide removal technologies,[17] and it has created an ad hoc committee to develop a research agenda for carbon dioxide removal and reliable sequestration. The committee has begun a series of meetings and workshops to draw up research needs for Blue Carbon projects to enhance the ability of oceanic waters to absorb atmospheric CO_2, Blue Carbon oceanic capture, geological sequestration, direct air capture of atmospheric CO_2 (including through burning biomass for electricity and then capturing its emissions), and terrestrial biosphere sequestration.[18] In addition, the United Kingdom's Natural Environment Research Council and several other agencies have dedicated £8.6 million to Greenhouse Gas Removal Research Programme grants to evaluate the feasibility and impacts of various technologies.[19]

In the private sector, the NRG/Cosia Carbon XPrize Competition has offered a $20 million prize to the technology that absorbs the most CO_2 and converts it into one or more products with the highest net value. It received 47 entries from seven countries by the July 26, 2016 deadline[20] and chose 27 semifinalists on October 15, 2016. These semifinalists proposed the use of technologies to convert CO_2 emitted by coal and natural gas power production into several useful products. For example, these products might include fuels such as methanol, biofuels, or synthetic fuels created by combining hydrogen with carbon recaptured from the CO_2 emissions, biofuels. Alternatively, other proposals would use the CO2 to create carbon nanofibers (i.e., carbon fibers with a functional dimension smaller than 10 billionths of a meter).[21] The Competition will select its final winners in March 2020 after the development of pilot plants and demonstration scale competition.[22] A similar ferment has seized the rest of the DAC research field, and the technologies and approaches listed below will likely undergo substantial refinement and improvement in the near future.

Mechanical Direct Air Capture

The best-known DAC technologies adopt a similar approach: the capture of CO_2 by passing ambient air over a membrane or screen that contains chemicals which absorb the gas.[23] Under the most basic approach, a mechanical DAC unit would draw in ambient air either through passively relying on wind or breezes or by incorporating an active fan or blower. The ambient air would move through screens or other filtration steps if needed to remove contaminants or debris, and then it would flow over a tank, membrane or screen that would put the air in contact with a chemical to absorb the CO_2.

Most current DAC technologies take two different approaches to chemically remove the CO2 from the ambient air: liquid sorbents, or solid adsorbents. Liquid sorbents typically use an alkaline solution to capture the acidic CO_2 gas from the air that streams through them, and then precipitates out the CO_2 as a calcium carbonate residue. The system then heats that residue to release the CO_2, and the system captures the gaseous CO_2 before it escapes. It then returns the separated calcium back to the liquid sorption solution, and the cycle repeats itself. By contrast, solid adsorbent systems capture ambient CO_2 in a resin, soak the saturated resin in water to release the captured CO_2, and then reuse the recharged resin to capture more CO_2.

Under either of these approaches, once the chemical becomes saturated or spent the operator would remove it from the unit and either dispose of the spent chemical or take steps to release the CO_2 from the spent chemical. This step may often involve the use of either heat or other chemicals. The emitted CO_2 is captured and then either devoted to commercial use or sequestered at a permanent disposal site. In theory, while the amount of CO_2 removed by an individual unit would be relatively small, operators can scale up the process by building a large number of mechanical DAC units subject only to constraints of supplies, available locations, and processing requirements for power and chemicals.

Even at this basic level, this approach faces several large and immediate challenges. Most importantly, the process would have to capture extremely dilute concentrations of CO_2 from ambient air. Because ambient air now contains only approximately 400 ppm of CO_2, most experts assume that the process would need to concentrate the CO_2 before it can be economically recovered and managed.[24] This low concentration makes any direct physical separation impractical, and as a result virtually all DAC systems rely on either carbonate absorptives or catalytic chemicals to remove the CO_2. In addition, the resulting CO_2 or products presumably would need to have sufficient economic value – for example, through a price on carbon via a tax or emissions cap -- to offset the cost of collecting, processing and managing the ambient air streams and CO_2. This combination of constraints led early evaluations of DAC to conclude that the technology would require enormous amounts of energy, large swaths of land, and management of vast amounts of waste materials and captured CO_2.[25] For example, the National Academy of Science's assessment of climate engineering technologies in 2015 concluded that removing significant amounts of CO_2 with DAC could require up to 100,000,000 acres in the Southeast United States.[26] This figure assumes, however, that the DAC units would use solar power sources that would demand large amounts of land.[27] A more refined calculation based on assumptions that DAC could use natural gas or coal power sources (and then capture those emissions during its operations) allows a much more compact demand for land that compares favorably with wind or solar energy facilities.[28]

As research into DAC has progressed, the range of potential removal strategies has expanded to make the technologies more effective and economical.[29] For example, a Canadian company based in Squamish, British Columbia is developing DAC systems that use the alkaline solution approach to capture CO_2 and concentrate it to high levels of purity. As a result, Carbon Engineering's DAC technology would output a commercial-grade CO_2 stream for reuse or sale. The purity of its CO_2 stream would also reduce its volume and makes its sequestration more viable.[30] This process, however, requires substantial energy, and its consumption of chemicals and waste production will need verification in field trials and test deployments.

By contrast, the Center for Negative Carbon Emissions at Arizona State University is developing systems that rely on the second DAC approach of using resins to capture air moisture and ambient air movement to power the removal of CO_2. Under this approach, the direct air capture unit wets a long strip of resin cloth and then exposes it to air; after the cloth becomes saturated with CO_2 as it dries, the unit collapses the cloth into a sealed chamber where the resin cloth releases its CO_2 upon exposure to water. As a result, this system uses much less energy than competing high-intensity alkaline solution DAC systems, but it removes comparatively less CO_2 from the ambient air input stream. This approach also does not generate a pure CO_2 stream that can be sold or managed as a commercial product. Instead it produces a stream of CO_2 –enriched air that can be used for other purposes, including enhancement of plant growth.[31]

While cost estimates are changing rapidly as research progresses, current projects based on available absorption technologies that use the alkaline chemical solutions strategy would likely capture CO_2 at costs ranging from \$250 to \$1,000 per ton.[32] Notably, the developers of DAC systems estimate that the cost per ton for captured CO_2 is much lower than academic estimates (generally, from \$20-\$30 per ton of CO_2 up to \$167 per ton).[33] If mechanical DAC technologies are widely deployed, those costs theoretically could drop to as low as \$30 per ton. By comparison, some studies expect the cost per ton of CO_2 captured and sequestered at fossil-fueled power plants to approach \$50 to \$100 if the U.S. energy sector fully implemented CO_2 reduction mandates under EPA's New Source Performance Standards for fossil-fueled power plants.[34] The federal government has estimated the social cost of carbon at roughly \$40 per ton for use when calculating the costs and benefits of federal regulations that affects CO_2 emissions.[35]

Carbon Removal Via Ocean Manipulation

Rather than seeking to remove dilute CO_2 from ambient air, other approaches have focused on enhancing the oceans' ability to remove CO_2 from the atmosphere. This strategy would essentially boost the key role already played by marine waters in capturing and sequestering CO_2 either through photosynthesis or direct chemical absorption. This natural process currently removes over half of all annual anthropogenic emissions, and the marine waters can offer an easier physical medium for the removal and management of CO_2 at higher concentrations than ambient air.[36] The vital role that oceans have already played so far in removing CO_2, however, has caused growing concerns over the increasing acidification of marine waters, the accelerating loss of marine biodiversity and extinction of aquatic species, and reduced efficiency in marine uptake of CO_2 due to the thermal warming of the ocean's surface layers.[37]

The most well-known DAC marine strategy is ocean iron fertilization (OIF). This proposed technology would add iron to certain mineral-poor ocean waters to spur the growth of marine phytoplankton. The plankton bloom would absorb CO_2, and then sequester the gas as the plankton died and sank to the deep ocean floor. The effectiveness of this approach lies in the extraordinary effectiveness of adding relatively small amounts of iron to large volumes of seawater. According to some estimates, the addition of very small amounts of dilute iron solution to an iron-poor marine body (such as the Southern Ocean or upper Pacific) would result in phytoplankton blooms that would uptake large quantities of CO_2.[38] This high uptake ratio led a famous biogeochemist to quip "give me half a tanker of iron, and I'll give you another ice age."[39]

As opposed to mechanical DAC, ocean iron fertilization has already undergone numerous field experiments.[40] These studies often focused on other scientific concerns rather than potential climate engineering applications, but the experiments have yielded useful data on the duration, size and effectiveness of phytoplankton blooms as a tool to absorb CO_2.[41] Some of the experiments that explicitly sought to demonstrate the climate engineering applications of OIF have proven controversial. An attempt by Planktos, a now-defunct entrepreneurial corporation that sought to obtain marketable carbon credits from OIF, to release solute iron in 2007 near the coastal waters off the Galapagos Islands led the U.S. Environmental Protection Agency (EPA) to attempt to halt the project.[42] An experiment to release iron in the Southern Ocean in 2009 caused the German federal government to order the researchers to halt their work until it could conduct further environmental reviews and assessment.[43] A similar release of 120 tons of iron sulfate in 2012 by the Haida Salmon Corporation off the coasts of British Columbia led to a civil investigation by the Canadian government into whether the deployment violated Canadian or international law.[44] Despite the controversy and legal difficulties triggered by these earlier attempts, the Oceanus Marine Research Foundation announced in 2017 that it intends to obtain permits from the Chilean government for a release up to ten tons of iron off the Chilean coast in 2018. While this release purportedly would seek to enhance Chile's fisheries, the experiment has already triggered strong objections because of its shared characteristics with earlier OIF releases tied to climate engineering research.[45]

Beyond attempts by domestic governments to halt or regulate OIF projects in their jurisdictional waters, the prospect of field testing of OIF on the high seas has already spurred action under international agreements to protect marine waters. For example, some of the parties to the London Convention, the primary international agreement to restrict disposal of pollution into international waters,[46] have entered into a supplemental protocol to impose additional restrictions on marine dumping. In particular, in 2013 the Contracting Parties to the London Protocol adopted Resolution LP.4(8), which defines "marine geoengineering" broadly to include any deliberate intervention in the marine environment to manipulate natural processes, including to counteract anthropogenic climate change and/or its impacts, and that have the potential to result in deleterious effects…."[47] The resolution essentially sets out criteria for adding marine geoengineering activities under a new Annex 4 pursuant to a "positive listing approach" that would not allow marine geoengineering activities listed in Annex 4 to take place.[48] As a result, the London Protocol parties' declaration effectively restricts listed marine geoengineering activities to legitimate scientific experiments under controlled circumstances after a thorough risk review.[49] Similarly, the parties to the Convention on Biological Diversity (CBD) have also sought to ban OIF (as well as other climate engineering activities, including SRM) as a threat to ecosystem resources and species protected under the CBD.[50]

In addition to OIF, DAC technologies can use marine waters to remove ambient CO_2 through other means. For example, CO_2 removal may take place more readily from marine waters because sea water contains CO_2 in concentrations over

100 times the levels in ambient air. As a result, this approach might yield substantial cost efficiencies.[51] It also promises to reduce ocean acidification, which other deep decarbonization techniques leave largely unaddressed (other than slow re-equalization after decarbonizing current emissions). Once the treated low-CO_2 waters are returned to the ocean, they theoretically could absorb additional CO_2; those returned waters could then be withdrawn again for repeated treatment in a cycle of continuous CO_2 removal. In general, however, seawater capture research is at a much earlier stage than direct air capture from land-based facilities.[52] It might also raise concerns about its effect on the chemical composition of seawater as well as its impact on marine biochemistry and ecosystems (especially if the system is deployed on a large scale), and its actual cost-effectiveness remains unknown.[53]

Accelerated Weathering and Enhanced Mineral Uptake

In addition to direct mechanical removal of CO_2 from ambient air and marine waters, researchers are exploring the option of removing CO_2 from ambient air indirectly through enhancement of the natural process of weathering minerals. For example, the accelerated weathering of olivine – a common mineral easily accessible in the Earth's crust -- can lead to substantial uptakes of CO_2 from ambient air for relatively low cost within a short time frame. This approach would require the spreading of ground olivine mineral in a thin layer on land, water or an intertidal area, and then maximizing the particle surface's exposure to ambient air or seawater. As the olivine or mineral matrix interact with the CO_2-laden medium, they absorb the CO_2 and release low amounts of heat. The resulting mineral matrix sequesters the CO_2 in an inert form that can be effectively managed, stored or disposed. Once sequestered in this mineral form, the captured CO_2 is not released back into the atmosphere except on a geological time scale.[54]

This technology promises to cheaply and effectively store large amounts of CO_2 with off-the-shelf tools and techniques. It poses several difficult concerns, however. The proposed use of enhanced weathering usually requires the dispersal of a finely ground particulate minerals over a large surface area, and the best results will likely occur if the particles are agitated to increase the exposure of the particles to ambient air or seawater. As a result, this approach would likely demand large areas of land, or the direct addition of particulate minerals to marine tidal waters. Both of these requirements would raise questions about the impact of broad dispersal of minerals on local ecosystems, and the energy required to grind the minerals to particles may generate CO_2 emissions in amounts that significantly offset the CO_2 that the weathering would sequester.[55] It should be noted, however, that recent attempts to sequester concentrated streams of CO_2 by injecting them into in situ basalt formations (rather than grinding the basalt for accelerated weathering) has seen notable success.[56]

Biomass Energy with Carbon Capture and Sequestration (BECCS).

The use of biological materials – usually crops or other plants – as an energy source has long held an important role in the energy economy.[57] For example, as discussed in Chapters 25 (Bioenergy Feedstock) and 27 (Production and Delivery of Bioenergy Fuels), the production of biomass energy in the United States has included ethanol and methanol produced from agricultural crops as a source of liquid fuels for transportation. The production of biomass energy also encompasses the burning of wood and other silvicultural products to produce energy from large power plants that might otherwise use fossil fuels.[58] Experts remain deeply divided on whether the use of biomass to produce fuels or energy feedstocks actually reduces total GHG releases over the entire life cycle of the fuel's production.[59]

The combination of biomass with carbon capture and sequestration, however, has emerged as a leading potential technology to produce carbon-neutral energy or net negative emissions power. Under this approach, a power plant operator collects plants or other biomass materials and either converts them into hydrogen or burns them directly to generate energy. The power plant then captures the GHG emissions from the burning process and permanently sequesters them, typically by injecting them in a nearby geological formation or including them in a carbon-based product (e.g., cement).[60] Because current mitigation efforts have yielded insufficient GHG reductions to meet the Paris Agreement's global temperature target of 2 degrees C (much less its aspirational goal of 1.5 degrees C), almost all of the Intergovernmental Panel on Climate Change (IPCC) model runs that show a high likelihood of attaining those targets by extensive use of BECCS as a net negative emissions energy technology.[61]

The growing focus on BECCS has raised concerns that this technology could have unexpected and damaging side-effects. The increasing reliance on BECCS in strategies to achieve the Paris Agreement's temperature goals has spurred warnings that the broad deployment of BECCS could disrupt or damage agriculture, water supplies, ecosystems, and fertilizer supplies. In particular, the use of BECCS to remove 600 gigatons of CO_2 by 2100 (a median estimate) would likely require the dedication of 430 million to 580 hectares of land to crops solely for CO_2 removal – nearly one-half the land area of the United States, or one-third of the current total arable land on Earth.[62] This enormous commitment of land surface to BECCS would create conflicts with agricultural needs for a growing global human population,[63] biodiversity protection,[64] albedo modification,[65] and sustainable land use. For example, the heavy use of BECCS in conjunction with current global land use patterns for agriculture would require the elimination of the majority of natural ecosystems.[66] It would also demand vastly increased use of nitrogen fertilizers which, in combination with existing agricultural fertilizer use, would add to the current exceedance (by a factor of two) of the suggested planetary boundary for nitrogen.[67] This use of nitrogen fertilizer would, ironically, also lead to substantial additional emissions of non-CO_2 greenhouse gases.[68]

The other concerns raised about BECCS center on its readiness for broad use. To date, only one demonstration BECCS plant is in operation in the United States,[69] and several researchers have publicly warned against heavy reliance of such an unproven technology as a policy to reach the Paris Agreement's 2° C goal.[70] The economic side-effects of broad cultivation of biomass for energy production may also produce unexpected market disruptions and distortions in biomass supply and demand.[71]

In sum, all of these negative emissions technologies are still struggling to get out of the laboratory. Initial feasibility studies have yet to verify that these techniques can work reliably and safely at a bench scale, and researchers will then have to meet the much larger challenges of broad scalability before we can assess their potential for mass deployment and their economic efficiency. Nonetheless, the general physical processes and likely technological pathways for each of these approaches seem well understood, and we can begin to forecast how current laws and environmental policies might aid, or impede, DAC's development and deployment.

II. Legal Reforms Needed to Maximize Use of Direct Air Capture for Deep Decarbonization by 2050.

The deployment of DAC on a scale large enough to significantly affect anthropogenic climate change will likely face numerous legal barriers and constraints. The exact nature of each challenge, however, will depend heavily on the specific aspects of the technology itself. The analysis offered below focuses more broadly on general aspects of DAC that each individual approach will share, but specific projects will likely require a closer examination to identify the unique and individual legal problems and options that each of them will create.

Before this chapter details the potential legal hurdles for wide-scale implementation of DAC, it is important to note several important features of DAC that will likely make it less legally controversial than other forms of climate engineering that do not rely on deep decarbonization or direct air capture (such as solar radiation management or marine cloud brightening). First, the large-scale removal of CO_2 from the atmosphere would result in a comparatively slow reduction in the current pace of increases in ambient CO_2 levels because a noticeable reduction in the rise of global surface temperatures theoretically would need the removal of enormous amounts of CO_2.[72] Even preliminary estimates predict that full-scale removal of CO_2 using DAC would not result in measureable reductions in expected surface temperatures or the predicted rate of warming for several decades, although such removals could play a key role in conjunction with GHG emission reductions as part of a larger mitigation strategy.[73] Second, the broad implementation of DAC is, at heart, a reversible process. If the use of DAC sparked significant concerns or objections, the termination of DAC would not result in immediate or accelerated climate change effects. By contrast, halting solar radiation management could cause catastrophically accelerated climate change impacts. Because solar radiation management only offsets the warming effects of heightened CO2 levels without addressing their root cause, it theoretically could allow ambient greenhouse gas levels to rise if humanity continued to emit them at high rates while under a stratospheric (or even orbital) sunscreen. Like driving with one foot on the brake and another on the accelerator, suddenly lifting the brake – here, by halting solar radiation management that had offset a period of untrammeled greenhouse gas emissions – would produce a jolt of climate change effects at a rate double or triple the current pace.[74] If society commits to DAC and then suspends the effort, the effects of climate change would simply resume at their expected pace.

Third, DAC would rely on reassuringly familiar physical infrastructure and technologies for its deployment. This is in contrast to solar radiation management, marine cloud brightening or other novel technological options to offset climate change effects. For example, the installation of a DAC unit or array would use the same type of capital machinery deployment, land acquisition, site development, and utility and power infrastructure that we would expect for a pipeline or modest power production facility.[75] While the use of these construction and infrastructure approaches could raise significant and important concerns (e.g., the impact of DAC deployment within a protected species' critical habitat), those risks would be fundamentally familiar and amenable to conventional environmental assessment and permitting procedures.

Last, the full deployment of DAC would likely result in only a diffuse impact on the local ambient atmosphere surrounding the DAC facilities. Given the low concentrations of CO_2 under ambient atmospheric conditions and the long residence time of emissions, CO_2 becomes well mixed under normal conditions and quickly reaches a stable concentration level on a global basis. Given these constraints, even a large-scale DAC operation likely would not uptake CO_2 at a rate substantially higher than the rate at which CO_2 from other regions would flow in to replace it.[76]

While these general features suggest that DAC technologies will not pose some of the heightened concerns of other climate engineering methods, they will nonetheless face significant legal barriers to their full deployment. These barriers in turn may prevent or at least greatly impair DAC from assisting in the deep decarbonization of the U.S. economy needed to attain the Paris Agreement temperature targets. The legal issues will likely arise in two categories: (i) getting the necessary permission and approvals needed to construct, operate, and terminate DAC operations, and (ii) identifying and minimizing any environmental or physical damages arising from DAC that could cause legal liability. This chapter discusses each category in turn.

A. *Permissions and Authorizations for DAC Operations*.

As with any other significant industrial or commercial operation that might affect the environment, certain types of DAC may trigger requirements to obtain environmental permits or authorizations. Until the precise physical parameters of a large-scale DAC operation come into focus, it is difficult to predict what environmental authorizations or permits they will need. For example, if a DAC unit will use compression equipment that emits significant amounts of conventional air pollutants, the operator may need to obtain a preconstruction permit for emissions regulated under the federal Clean Air Act's programs for Prevention of Significant Deterioration (PSD) or non-attainment New Source Review (NSR). It is unclear, however, whether DAC technologies will require the use of ancillary equipment that will constitute a major source under either the PSD, NSR or analogous state air quality programs.[77]

Until the precise aspects of a DAC facility are established, a wide range of possible environmental authorization and permitting obligations may apply to the unit's construction, start-up, authorization, shut-down and decommissioning. Notably, almost all of these requirements will be the typical environmental, health and safety regulatory approvals needed for any large capital construction project with potentially significant environmental effects. Some aspects of particular types of DAC operations, however, may trigger unusual environmental permitting obligations that would apply uniquely to DAC production and operation.

As an initial step, an agency would need to address the fundamental conundrum of regulating an activity that *removes* a pollutant from the ambient atmosphere. The federal Clean Air Act only prohibits the emission of pollutants without authorization, and the removal of gases from the ambient atmosphere would normally not trigger regulatory concern unless another person suffered an environmental impact or had an ownership claim in the removed gas. Industrial gas producers who collect, condense and liquefy ambient atmospheric gases have historically not needed an environmental permit to authorize the removal of gases.[78] Under these precedents, the core feature of DAC – removal of GHGs from the atmosphere – will almost certainly fall outside permitting requirements under federal or state Clean Air Acts.[79]

Beyond the core action of removing GHGs from the atmosphere, DAC operations may require supporting industrial activities that could trigger other environmental obligations. Some of the most notable could include:

Environmental authorization for commercial products or fuels generated by DAC operations, including captured CO_2 *streams.* Some proposed DAC technologies would create a pure CO_2 stream that can serve as a commercial feedstock or product itself. Carbon Engineering, for example, is testing approaches that would generate a pure CO_2 stream for use in synthetic fuels production.[80] The Center for Negative

Carbon Emissions at Arizona State University is also exploring technology that would convert its comparatively dilute captured CO_2 stream into a marketable fuel. This process would essentially run a fuel cell in reverse: rather than splitting water into hydrogen and oxygen through a catalytic membrane to produce energy, this process would use low-carbon or carbon-free energy to combine hydrogen and carbon from ambient CO2 to generate hydrocarbon fuels.[81] If this type of synthetic fuel eventually was marketed in the United States for use in light duty automobiles or other mobile sources, that fuel would have to satisfy regulatory requirements under Title II of the federal Clean Air Act. These requirements include stringent limits on the volatility, oxygen content, sulfur concentrations, viscosity and other qualities and components of fuels commercially marketed to be burned for energy.[82] (As discussed in Chapter 14, the DDPP scenarios all assume that by 2050, light duty vehicles will no longer use liquid fuels.)

Integration into GHG permitting and trading. DAC operations, by definition, will almost certainly not emit sufficient CO_2 to trigger requirements to obtain a permit for GHG emissions under the federal Clean Air Act's Prevention of Significant Deterioration (PSD) program. This legal framework requires major emitters of air pollutants to obtain permits that limit their emissions to amounts that would keep the ambient air from growing significantly worse or failing to meet national ambient air quality standards.[83] First, the legal basis for requiring PSD permits for sources that emit only CO2 is highly suspect after the U.S. Supreme Court rejected EPA's regulations to control CO2-only sources and President Trump's subsequent executive order to direct EPA to reconsider and withdraw its regulations to control greenhouse gas emissions from new and existing fossil-fueled power plants.[84] Even if the compression equipment, power supplies or other ancillary operations associated with DAC units emit enough other conventional pollutants to require issuance of a PSD or non-attainment New Source Review permit and consequently would assess possible GHG reductions as part of their selection of control technologies, the use of netting or offsets due to the GHGs removed by the DAC[85] would almost certainly exempt the facility from the need to consider GHG controls associated with its operation.

DAC's removal of GHGs from the atmosphere may also create tradable emission reduction credits for use in PSD or NSR programs for other industrial sectors, in state GHG control programs, or internationally tradable credits authorized under other nations' GHG programs. If so, DAC may become integrated into federal and state Clean Air Act permitting as a tool to allow GHG emitters to come into compliance with emission limits through the purchase of offsets or emissions reduction credits. To date, however, EPA and state environmental agencies have not addressed whether GHGs removed through DAC would create emission reductions that can be banked, traded or used for offsets or netting.[86]

Some states, and ultimately the federal government, may choose to control GHG emissions through use of a carbon tax.[87] To the extent that DAC results in the large-scale removal of CO_2 or other GHGs, federal taxation laws and regulations may need to address whether persons who generate negative emissions can qualify for a tax credit or rebate. In analogous circumstances, the federal government generally has not allowed the taxation of an activity as a form of regulation or discouragement (e.g., "sin taxes" on liquor and cigarettes) to automatically enable the payment of tax credits or rebates to persons who actively remove those undesirable goods or activities from the market.[88] While EPA and delegated states likely would have the regulatory authority to authorize tradable credits or tax rebates for GHGs removed directly from the atmosphere, that step would almost certainly require legislation or rulemaking.

Environmental Impact Assessments. The National Environmental Policy Act[89] and its regulations[90] require an environmental review of any major federal agency action that may affect the environment. This review can take the form of an abbreviated environmental assessment, a finding of no significant impact, a programmatic environmental impact statement, or a full-blown environmental impact statement that examines the effects in detail of a particular project. This review must include an assessment of the indirect and cumulative effects of the project.

NEPA may apply to DAC if the operations either use significant federal funding or require certain federal governmental authorization or participation.[91] If so, the person proposing a DAC project would need to conduct an environmental assessment (EA) or environmental impact statement (EIS) review. While the federal Council on Environmental Quality has previously stated that projects with a significant impact on climate change can require an environmental review under NEPA, its assessment largely focused on projects that emit GHGs into the atmosphere.[92] It remains unclear whether the removal of significant amounts of GHGs would require a similar assessment,[93] although NEPA and CEQ's implementing regulations also provide for an environmental review if a project can spark significant public interest or controversy, or if it will involve a novel or precedent-setting action.[94] Alternatively, the responsible federal agency conducting the environmental review may choose from several tools to minimize the delay or disruption that a full environmental impact statement may cause for a DAC project. Some of these tools could include a categorical exception for certain types of DAC projects that fall within certain parameters or size limits, a programmatic EIS that would prospectively approve most aspects of DAC projects that fall within the program, or a finding of no significance (FONSI) that would remove the need to prepare a full EIS for a particular DAC project or group of DAC activities.[95]

Some states have their own environmental review statutes, and these can apply to more activities than the federal NEPA program, or mandate greater investigation or review by the project proponent. For example, New York and California have mini-NEPAs that have significantly broader reach, and each state has acted more aggressively than many federal agencies to require an environmental impact assessment for the climate change impacts of particular projects.[96] Even if a federal agency determines that a specific DAC project does not require an environmental impact statement, a state agency might nonetheless choose to require one for a DAC project within the state's jurisdiction.[97]

Land Acquisition and Use Authorization. Depending on its precise configuration and process, the broad deployment of DAC may require the acquisition or use of broad swaths of land or marine surface. Under one early estimate, for example, some projections of land use by terrestrial DAC could require the dedication of up to 100,000,000 acres of Bureau of Land Management (BLM) territory in the southwestern United States to generate clean solar energy that would power the DAC process.[98] This acreage would equal nearly 42% of the all public lands under tbe BLM's control. If DAC relies on the use of dispersed olivine grains onto land or coastal surfaces, it could also occupy a very large surface area.

As a result, early assessments of DAC strategies frequently raised concerns that this technology would require the acquisition of fee simple title, leasehold, or other type of access permission or authorization to enter and use surface properties.[99] The potential dedication of large surface land area to DAC also led to criticisms that DAC could have unforeseen effects on vulnerable species that relied on critical habitat and jeopardize valuable alternative uses of those lands (e.g., agricultural food production).

These concerns persist, and they may lead to legal constraints that would impede the broad implementation of DAC. But subsequent development of potential DAC technologies promise to alleviate some of these legal objections. For example, at least one of the DAC technologies under development would use relatively small modular units that co-located or stacked vertically.[100] This arrangement promises much greater operational efficiency and reduced demands for surface land space. In addition, as discussed in Chapter 18 (Utility-Scale Renewable Generating Capacity), these types of land use demands also hover over other large-scale renewable energy technologies or decarbonization strategies (in particular, techniques that rely on BECCS). To the extent DAC faces these challenges, they differ only in degree rather than quality. Moreover, some DAC technologies under development rely on natural wind rather than fans for air flow, and thus have low electricity demands.

In addition to surface land area, many versions of DAC will likely require the acquisition and use of subsurface strata or geologic formations to sequester captured CO_2. To some extent, these challenges to DAC will mirror the same legal hurdles that will face the deployment of CCS in large-scale industrial operations and power production. Many of the same legal steps and strategic approaches that promote the use of captured CO_2 for secondary hydrocarbon production (such as state legislation to clarify the ownership status of pore space in mineral estates, or regulatory determinations on the status of sequestered CO_2 as a potentially hazardous waste under federal and state waste management statutes) could also be used for CO_2 captured by DAC for permanent sequestration. These issues are discussed in greater detail in Chapter 28 (carbon capture and sequestration) and in the following section.

B. Identifying and Minimizing Possible Environmental Damages.

As with most industrial processes, the broad-scale implementation of DAC will likely result in the generation of by-products, wastes, and unwanted environmental consequences. Numerous legal restrictions and permitting obligations may be triggered by these secondary emissions or impacts, and those legal mandates may constrain the broadest possible implementation of DAC to achieve deep decarbonization. The benefits of these legal protections for responsible management of environmental harms arising from wastes or byproducts, however, will need to be preserved even if DAC receives its broadest possible authorization.

This section assesses some of the most likely legal mandates that will arise from environmental impacts and secondary materials generated by broad-scale DAC operations.

Managing and Disposing of Captured CO_2*.* A necessary by-product of DAC is, of course, captured CO_2. While CO_2 is frequently sold and managed as a commercial chemical product or feedstock, the quantities of CO_2 that DAC would have to remove from the ambient atmosphere would likely dwarf any conceivable market for commercial-grade CO_2 for industrial uses.[101] Some proposed DAC processes would potentially convert the CO_2 into fuels for transportation or other uses.[102] Other processes would permanently lock the CO_2 in mineral basalt formations either in situ in geologic formations or by placement into disposal sites.[103] At least one test project has directed captured CO_2 to large adjoining algae ponds to photosynthesize the CO_2 into biofuel stock.[104] But the most common proposed ultimate disposition of captured CO_2 is most likely disposal in either deep geologic strata or deep marine waters.

As noted above, the disposal of CO_2 into deep geologic strata or marine waters would raise similar issues to proposals to sequester CO_2 from CCS operations with industrial processes and power plants. The aggressive use of DAC, however, would face constraints if the legal framework used for CCS were applied uncritically to captured CO_2 from the ambient atmosphere. First, the volume of CO_2 from DAC would dwarf the amounts of CO_2 from industrial CCS. If attainment of the Paris Agreement's less ambitious 2° C goal would require the capture of 1,800 gigatons of ambient CO_2, even a portion of that amount would exceed the potential CO_2

captured from U.S. power plants alone by several orders of magnitude.[105] Second, the current U.S. legal framework for management of CO_2 from CCS provides a conditional exemption from hazardous waste regulations under the federal Resource Conservation and Recovery Act (RCRA)[106] and clean-up obligations under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA).[107] To qualify for these conditional exemptions, the operator must satisfy numerous regulatory requirements for the disposal of the CO_2 via an injection well. If it does so, the operator could then manage the sequestered CO_2 as only a special waste under Subtitle D of RCRA prior to injection into the well and not comply with the full panoply of regulatory requirements for hazardous waste treatment, storage or disposal facilities.[108] For example, the operator would need to obtain a permit under the Safe Drinking Water Act's regulatory standards for underground injection wells, and that permit would require a demonstration that CO_2 placed into a sequestration well would permanently contain the gas.[109] It is unclear whether an operator could readily satisfy this standard for geologic formations that receive significantly larger volumes of CO_2 from DAC operations.[110] Notably, the SDWA Underground Injection Control framework for protecting groundwater drinking supplies would not apply to wells that dedicate the CO_2 to productive reuse in secondary oil recovery or other uses.[111]

In addition to its ultimate disposal or disposition, the captured CO_2 may require interim storage or management prior to injection or disposal offsite. An operator can choose from multiple technologies to manage captured CO_2 on an interim basis, potentially including cryogenic liquefaction, massive tank storage of compressed CO_2, or temporary underground storage in constructed or native geologic formations.[112] All of these storage methods will require their own environmental and safety permitting, and they may also entail the generation and management of their own waste streams, emissions and byproducts.

Management and storage of captured CO_2 would also pose other risks. For example, high-pressure CO_2 vessels might pose an explosion or catastrophic release risk if improperly managed, and cryogenic CO_2 releases could theoretically create pockets of dangerous CO_2 concentrations in depressed landscapes or contained areas. While these risks might occur on a larger scale, they do not differ in nature from the risks posed by industrial management of CO_2 or other industrial gases in contemporary chemical production processes. The risk of slow leaks or releases, of course, could undermine the effectiveness of the DAC process if the captured CO_2 simply escaped back into the atmosphere.

Finally, the U.S. legal requirements for storage of CO_2 in tanks or other containment vessels may differ dramatically between CO_2 destined for disposal or permanent sequestration instead of CO_2 intended for use as an industrial product. Under routine circumstances, federal and state environmental laws and regulations impose different obligations on tanks that store commercial chemical products or materials and tanks that store wastewaters or solid wastes. For example, federal regulations requiring site operators to comply with Process Safety Management requirements under the Occupational Safety and Health Act[113] and the federal Clean Air Act require operators to assess and manage their tank systems to minimize the risks of catastrophic releases or explosions.[114] By contrast, a tank dedicated to the storage of hazardous waste needs to satisfy different federal regulatory requirements under RCRA and analogous state laws and regulations. Under those rules, any "solid waste" – which can include containerized gases such as CO2 kept in tanks or storage vessels – is considered "hazardous waste" if it either displays a hazardous characteristic or is listed by EPA as a hazardous waste. While it remains uncertain whether supercritical CO2 would (or could) display a hazardous characteristic such as corrosivity, containerized CO_2 that displays a hazardous characteristic (or which is mixed with other hazardous waste streams) would likely need to be stored a tank or storage vessel that satisfied RCRA hazardous waste standards if the containerized CO_2 were subsequently discarded as a RCRA "solid waste" (and did not meet the requirements for the conditional exemption). If that same CO_2 was stored in a tank for ultimate use as a commercial chemical product or feedstock, it might not need to satisfy RCRA requirements unless the proposed use constituted a form of disposal via recycling or reuse.[115] While these two scenarios would trigger significantly different management requirements, the environmental risks posed by the storage and disposition of captured CO_2 are the same for each. EPA could address these legal concerns by exempting captured CO_2 from RCRA, provided necessary precautions were taken.

Managing and disposing of residues and emissions from the DAC process itself. Like any other industrial process, large-scale DAC will likely generate its own process wastes and emissions (apart from the CO_2 that it captures). Some iterations of DAC will likely require substantial power generation, compression equipment and processes, and the use of substantial quantities of absorbent chemicals or catalysts. For example, some proposed DAC technologies would use catalytic surfaces to capture ambient CO_2 and then release it via a water wash or acid release. Spent chemicals from this process might require regeneration, on-site management, or disposal by the DAC operator or at substantial tolling operations (where third-party contractors process or treat the spent materials and then return the restored chemicals to the customer).[116] Other DAC methods may generate large amounts of materials that might qualify as solid or hazardous wastes because they are placed onto the ground in a manner that might constitute disposal (e.g., dispersal of milled olivine over large land surface areas to promote accelerated weathering). As a result, some DAC processes will almost certainly generate air and water emissions as well as solid or hazardous wastes that will require environmental permitting or authorization.

These challenges, however, are not qualitatively different than the permitting and environmental management requirements for any large industrial operation with significant emissions or discharges (although they likely would ultimately involve much larger quantities of CO_2 than amounts generated even by large industrial operations). Given that some centralized DAC operations may generate a large quantity of wastes or emissions, they may face substantial delays and permitting requirements that smaller or modular DAC operations would not incur. These permitting requirements may discourage potentially larger centralized and more efficient DAC systems and technologies.[117]

Potential tort liability for damages proximately caused by DAC. If a DAC facility operates in a fashion that purportedly injures particular individuals or the public at large, the persons responsible for the DAC operation may face private and public tort actions. For example, if a DAC facility withdraws enough CO_2 at a fast enough rate to arguably affect local environmental conditions or ecosystems,[118] landowners who reside near the DAC facility may claim that the operators have created either a public or private nuisance or have acted negligently in their operation of the plant.[119] Admittedly, this prospect appears extremely unlikely given the removal rates promised by current technologies and the fast mixing rates of ambient CO_2. But the scales of DAC required to approach a significant impact on existing CO_2 stockpiles in the atmosphere theoretically may spur development of future technologies that might raise this concern in future permitting or approval deliberations. Alternatively, emissions from other associated equipment or water and waste discharges may interfere with the ability of nearby landowners to enjoy the use of their property in a fashion that gives rise to a private nuisance claim, but these types of tort claims for ancillary emissions are common features to any industrial operation and are not distinct to DAC technologies.

More powerfully, DAC operations that purportedly interfere with a right held by the public in general – for example, preventing damage to public resources such as public waterways or ambient air – can spark a public nuisance action. While such actions might typically be brought by the governmental authority with responsibility for the public resource or right imperiled by the DAC operation, private parties could also bring a public nuisance action if they can prove that they suffered a special injury distinct from the general public.[120] Such claimants, however, will face difficult challenges in proving that DAC reductions of CO_2 have directly and proximately caused their special injuries. The facility operator could also respond that the DAC operation serves larger public interests that outweigh the special injury underlying the alleged public nuisance.[121]

III. New Public Law Approaches to Expedite Deployment of DAC for Deep Decarbonization.[122]

As shown by the prior discussion, large-scale deployment of DAC at levels that could appreciably alter the global ambient atmosphere within a time frame contemplated by the Paris Agreement would need to navigate several legal hurdles and overcome initial economic and policy disincentives. Some possible policy options that might make DAC more feasible as an option to aid decarbonization efforts in the United States could include the following strategies.

Provide public support and investment for basic research into the feasibility and cost-effectiveness of DAC. While DAC has attracted growing attention from researchers who wish to explore foundational concepts and economics of DAC in the laboratory or field tests, the United States has not provided large-scale funding of DAC research or tests. In part, the lack of public support may arise from persistent objections and concerns about the climate engineering concept in general (including solar radiation management). Critics contend that climate engineering, including DAC, could detract from needed initiatives to reduce current GHG emissions into the atmosphere, and the risks of planetary-scale projects to alter the climate poses extraordinarily thorny liability, governance and implementation challenges. While

DAC probably offers the climate engineering strategy that raises the fewest of these concerns, it nonetheless has suffered from the broader disinterest that climate engineering in general has drawn from U.S. policymakers.[123] Prior federal funding remained modest and focused on basic research concepts (such as modeling of stratospheric releases), and the number of projects is small despite calls by some groups for expanded support under a coordinated research strategy.[124]

Despite that distaste, scientists and policy-makers have begun to discuss the need for climate engineering research in public fora. The National Research Council, for example, expressly included DAC in its 2015 recommendation that the United States should provide significantly more funding for climate engineering research to assess its viability and desirability.[125] U.S. federal agencies have also suggested that climate engineering research (at least at the proof-of-concept stage) merits additional research support and financing.[126] To achieve CO_2 removal at the necessary scale within a relevant time frame, Congress and relevant state legislatures would likely need to significantly boost the funding available to support climate engineering research proposals.

Environmental Permits, Reviews and Authorizations. U.S. policymakers and regulators can take several steps to help reduce barriers to widespread DAC that might arise from legal requirements to obtain environmental permits or environmental impact reviews. These steps, of course, should be taken with a firm expectation that any such reduction of legal barriers will not expose the public or the environment to unwarranted environmental risks that the permitting process or environmental impact review would identify and forestall. To some extent, these strategies are familiar and have already been discussed in Chapter 18.

At the least, U.S. regulatory agencies and policymakers, especially EPA and state agencies with delegated authority to issue environmental permits, can explore whether they should reduce any permitting barriers or environmental review disincentives for laboratory research or limited field testing of DAC technologies. For example, as noted earlier, EPA could extend its current conditional RCRA and CERCLA exemption for CO2 captured from industrial operations for geologic storage to also include CO2 captured from the ambient atmosphere by DAC operations. For broader deployment or implementation, EPA and state environmental agencies can also reduce barriers to deep decarbonization efforts with DAC by adopting (i) standardized approval and review procedures for DAC technologies that use common procedures or similar physical designs, and (ii) general permits for DAC technologies that will likely have either a small or predictable and controlled impacts to the environment. The President could also issue an executive order directing expedited federal review of DAC projects and activities. Presidential administrations have ordered expedited review and approval of key pipelines and other major energy infrastructure projects.[127] In addition, Congress could adopt legislation to provide favorable waivers or reduced environmental reviews of DAC projects similar to the limited federal waiver from state permitting requirements on the same model used by CERCLA.[128]

More controversially, Congress and state legislatures can reduce barriers to DAC posed by land acquisition or authorization requirements by utilizing their power to authorize condemnation of property needed for these projects (akin to pipelines, rail corridors, municipal water districts and flood control projects). Congress or state legislatures could extent that condemnation power to private parties who engage in industrial-scale DAC operations authorized by state or federal permit or certificates of convenience (again, similar to private condemnation authority provided to private rail operations, pipeline construction and power line corridors). Given the controversial nature of climate engineering and the intense opposition that private condemnation efforts and governmental takings can provoke, however, federal or state governmental authorities should probably exercise this condemnation authority initially. If they should extend this power to private parties, they should do so with great caution.[129] And, most importantly, the staggering amounts of land demanded by some DAC approaches (in particular, BECCS) would make it difficult to acquire the required space through heavy reliance on condemnation powers without triggering political and financial backlash.

Damages and Liability. Congress has adopted a broad range of tactics to keep liability and damages concerns from stifling desirable emerging technologies. Many of these strategies could apply readily to DAC.

For example, the United States has shielded the domestic nuclear energy industry through the adoption of liability caps that prevent a nuclear plant operator's liability for an incident from exceeding statutorily designated caps. These caps, which are imposed under the Price Anderson Act, also include limitations on the judicial fora that could hear damages claims and preclude certain state law tort actions.[130] A few other federal statutes have included liability limitations or restrictions on judicial review as a means to promote the initial growth of important technologies.[131] Congress or federal agencies could explore the possibility of offering certain liability protections for DAC operators who meet size, operational and safety requirements. To some extent the U.S. EPA has already explored some of these strategies in a related context by providing conditional waivers from hazardous waste regulations and CERCLA liability for persons who capture and sequester CO_2 through injection wells into subsurface strata.[132] Congress and EPA should craft a similar combination of legislative and regulatory options to allow DAC research and limited deployment to occur without significant delays from permitting disputes or environmental impact reviews.

Incentives. Given DAC's nascent state, current environmental regulations unsurprisingly do not provide any express regulatory or financial incentives for persons to undertake DAC research, testing or deployment. As a result, any comprehensive and rational system to spur DAC investigations will likely require legislative or regulatory action. Within that framework, the federal (and state) government can offer several possible benefits and rewards.

Drawing on prior federal efforts to incentivize research or early deployment of emerging technologies, some effective and common tools would include the Congressional provision of tax credits, favorable depreciation and federal loan guarantees to investors in desirable new technologies[133] or outright research grants from EPA, the U.S. Department of Energy, the National Science Foundation, or other federal agencies to spark research that offers limited immediate financial return but immense long-term public benefits.[134]

But the most powerful concept that could accelerate private sector DAC research and deployment would be the imposition of a carbon tax or other pricing mechanism that would expressly allow DAC operators to obtain a financial return on the CO_2 they capture from the atmosphere. (Carbon pricing is discussed in detail in Chapter 3.) This approach would allow private enterprise capital markets, entrepreneurs and investors to develop DAC technologies without mandatory governmental control, approval or disbursement, and free markets could theoretically help allocate resources in an efficient fashion to the most effective methods and technologies. The use of DAC projects to generate tradable carbon credits, however, would likely prove controversial in light of concerns over verifying the validity of the traded credits and unexpected side-effects created by prior CO2 trading systems,[135] and a large number of credits generated by commercial DAC ventures might swamp other policy, ethical and social goals.[136] The verification of CO_2 captured by certain DAC methods (such as OIF) may also be difficult, and the value of such credits may fail to reflect the corollary environmental harms created by the DAC process itself.

In the short term, EPA and state environmental agencies could promote the investigation and deployment of DAC through incorporating it into GHG control permit requirements and emission control standards. These strategies might include, for example, the use of CO_2 captured through DAC as a tradable offset for compliance with state emission limits from existing fossil-fueled power plants or from future industrial sectors that may be subject to existing source performance standards.[137] EPA or delegated states (states with authority to run their own regulatory programs under the Clean Air Act) could also consider the use of DAC removal of CO_2 as an alternative control strategy to consider during their selections of Best Available Control Technologies for Prevention of Significant Deterioration (PSD) permits to control emissions of other regulated pollutants.[138] Given the quick dispersion of CO_2 emissions on a national (and global) basis, EPA or a delegated state might also make the defensible decision to let a facility offset its CO_2 emissions from one of its facilities through that operator's use of DAC at a different location within the United States. The inclusion of such offsets or netting, however, might provoke some public controversy and opposition, and as a result affected persons could perhaps challenge DAC through administrative petitions or judicial action involving the underlying permit (or non-major source determination).[139]

Beyond these regulatory incentives and exemptions, federal and state environmental agencies could remove barriers to DAC on other fronts. For example, EPA and state environmental agencies could promote the reuse of captured CO_2 as a feedstock or commercial product by issuing guidance or a regulatory determination that CO_2 captured through DAC would not constitute a pollutant under the Clean Water Act or Clean Air Act or a discarded hazardous waste or substance under RCRA or CERCLA.[140] The conditions (if any) accompanying this determination should protect the public or ecosystems from any anticipated risks from DAC, but the agency would need to navigate the exemption with care because non-discarded products or feedstocks typically fall outside EPA's jurisdiction under RCRA and the Clean Water Act.[141] The re-use of captured CO_2 to generate carbon-based fuels for transportation or energy production would obviously pose extremely difficult regulatory concerns[142] and arguably would not promote the eventual ultimate goal of reducing CO_2 accumulations in the ambient atmosphere (unless they displace fossil fuels that would otherwise be burned).

Farther in the future, EPA might also choose to encourage the development of certain types of DAC – in particular, olivine dispersal and direct mechanical removal of CO_2 from coastal waters -- by designating them as possible treatment technologies to address ocean acidification. Several water bodies in the United States have already become sufficiently acidic from air deposition that they do not meet the use designation or water quality standard set out for them, and as a result state environmental agencies (or EPA) will need to consider possible mitigation strategies to reduce their acidity.[143] EPA has resisted citizen suit actions and administrative petitions to force it to update its ocean acidity water standards and to reject state water quality plans that did not directly mitigate ocean acidity.[144] Its settlement of a citizen suit in 2010 led EPA to promulgate a guidance memorandum that will make any regulatory obligation to address ocean acidity unlikely for the near future.[145] But if a DAC project wished to either release CO_2 entrained in ocean waters to increase the coastal or ocean water's uptake capacity for additional CO_2 absorption, or to disperse finely ground olivine in coastal waters to accelerate enhanced weathering in a way that also reduced coastal or marine acidification, those technological options might constitute an acceptable control strategy for a state to propose to satisfy a waste load allocation or Total Maximum Daily Load action plan. The environmental implications of directly manipulating ocean waters to reduce their CO_2 uptake, however, will raise troubling issues about potential effects on marine ecosystems and protected marine organisms, and any regulatory consideration of these options will have to carefully address these possibly severe damages to ocean environments. All of these techniques are at such early stages of development that it is difficult to foresee their environmental impacts, and the regulatory tools that will be needed to deal with them.

IV. Conclusion.

Even if DAC meets the technical and logistical challenges to its adoption, it will still need to surmount legal uncertainties. Certain features of the technology will make it less controversial than other proposed techniques for climate engineering, but some types of DAC could still trigger burdensome obligations to obtain permits based on land use, emissions from associated equipment, and management or disposal of captured GHGs. These technologies could also face unsettled risks from the difficulty of assessing their environmental impacts for NEPA.

These legal impediments can be proactively addressed with some of the strategies discussed above. If so, legislators and regulators should assure that possible solutions provide adequate governance oversight; all stakeholders receive opportunities to participate in decisions on risk and management; and help DAC operators identify and manage unexpected or otherwise uninsurable risks.

Other important issues could include how DAC and negative emissions technologies complement CCS and agricultural sequestration techniques, but they may compete with mitigation approaches. For example, large-scale production of captured CO_2 might swamp carbon credit markets with large-volume CO_2e removal credits for DAC. There is also the risk of moral hazard from wide-scale DAC because it might be politically and economically less painful to withdraw CO_2 from the ambient atmosphere than to restrict or minimize the emissions from industries or power generators.[146]

Last, efforts to use DAC to enhance the deep decarbonization of the U.S. economy will likely also have to examine issues outside strictly legal or policy concerns. For example, DAC may raise difficult issues related to the social benefits and costs that broadly implemented DAC may impose. If DAC requires significant use of lands, for example, the placement and operation of DAC facilities may face the same environmental justice scrutiny that other industrial facilities may trigger (especially if the DAC facilities are located in environmental justice communities or Native American tribal territory). The allocation of any credits or other financial benefits designed to spur DAC research and development, like any trading system that relies on an initial allocation of tradable credits, may create large transfers of wealth and expose certain communities to greater risks or benefits.[147]

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[1] Intergovernmental Panel on Climate Change, CLIMATE CHANGE 2014 SYNTHESIS REPORT at § 2.4, p. 63 (2014) ("[w]arming caused by CO_2 emissions is effectively irreversible over multi-century timescales unless measures are taken to remove CO_2 from the atmosphere").

[2] *Id.* at § 2.2.4, p. 62.

[3] K. Anderson and G. Peters, *The trouble with negative emissions,* 354 SCIENCE 182 (Oct. 14, 2016) ("[i]t is not well understood by policy-makers, or indeed many academics, that [integrated assessment models showed attainment of the Paris Agreement's 2° C goal] assume such a massive deployment of negative-emission technologies", including assumptions that negative emissions technologies will bring global emissions to at least net zero in the second half of the 21st century); J. Horton, D. Keith and M. Honegger, Harvard Project on Climate Agreements, *Implications of the Paris Agreement for Carbon Dioxide Removal and Solar Geoengineering* at 3 (July 2016). *See also* M. Gerrard, Columbia/SIP Center on Global Energy Policy, *What the Paris Agreement Means Legally for Fossil Fuels* at 2 (Dec. 18, 2015) (concluding that the Paris Agreement will require capture of carbon emissions before they enter the air, create new sinks, and "[d]evise, and deploy on a massive scale, technologies to remove the carbon from the air, and sequester it").

[4] Anderson and Peters, *supra* n.3, at 183.

[5] Sustainable Solutions Development Network and the Institute for Sustainable Development and International Relations, PATHWAYS TO DEEP DECARBONIZATION: 2014 REPORT at 8-9 (2014) ("Pathways Report")("We have therefore made an assumption in the DDPP that large-scale net negative emissions are still too uncertain to build into our country-level Deep Decarbonization Pathways (DDPs), even though we strongly support research programs that could make net negative emissions a future reality"); *id.* at 19 ("[a] disadvantage is that the process of isolating and removing the CO_2 from air at low ambient concentrations is technically challenging, currently expensive, and unproven at scale.")

[6] Sustainable Solutions Development Network and the Institute for Sustainable Development and International Relations, *Pathways to Deep Decarbonization Interim Report* at p. 2 (July 8, 2014), at http://www.iddri.org/Publications/Rapports-and-briefing-papers/DDPP%20Executive%20SummaryEN.pdf .

[7] PATHWAYS REPORT, *supra* n.5, at 8-9, 19.

[8] *Id.* at 18-19.

[9] National Research Council of the National Academies, CLIMATE INTERVENTION: CARBON DIOXIDE REMOVAL AND RELIABLE SEQUESTRATION at 62 (2015) ("NAS Report").

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[10] P. Smith, R. Haszeldine and S. Smith, *Preliminary assessment of the potential for, and limitations to, terrestrial negative emissions technologies in the UK,* 18 ENVIRON. SCI.: PROCESSES IMPACTS 1400 (2016), doi: 10.1039/c6em00386a.

[11] *Climate Change 2013: The Physical Science Basis* at p. __. Contribution of Working Group I to the FIFTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press (2013).

[12] While several states have Good Samaritan laws to provide protection against tort liability for parties who provide assistance to threatened individuals, those laws typically restrict their coverage to medical personnel or specialists who intervene in emergency situations. They also typically require (i) the rendering of emergency care, (ii) gratuitously, and (iii) in good faith (with an exception for grossly negligent, wanton, or willful misconduct. RESTATEMENT (THIRD) OF TORTS: PHYS. & EMOTIONAL HARM § 42 (2012); D. Waisman, *Negligence, Responsibility, and the Clumsy Samaritan: Is There A Fairness Rationale for the Good Samaritan Immunity?*, 29 GA. ST. U. L. REV. 609 (2013) ("all fifty states have adopted the [Good Samaritan] immunity [doctrine] in one form or another, and it shows no sign of disappearing any time soon"). These laws appear unlikely to protect DAC operators who negligently cause harm during their operations.

[13] J.B. Ruhl, *The Political Economy of Climate Change Winners,* 97 MINN. L. REV. 206, 272 (2012) (arguing that climate change winners should not receive legally protected property rights from climate change effects).

[14] These potential types of liability may also arise within the larger field of climate engineering, and they could potentially apply to atmospheric manipulation techniques that do not rely on removal of ambient CO_2 (e.g., solar radiation management and albedo enhancement from marine cloud brightening). *See, e.g.,* M. Gerrard and T. Hester, eds., CLIMATE ENGINEERING AND THE LAW: REGULATION AND LIABILITY FOR SOLAR RADIATION MANAGEMENT AND CARBON DIOXIDE REMOVAL at chap. 6 (Cambridge U. Press, forthcoming 2018) (discussions of potential theories of legal liability for climate engineering activities).

[15] UN-REDD Programme, *What is REDD+?,* http://www.unredd.net/about/what-is-redd-plus.html (last verified Sept. 15, 2016) *(*"[r]educing emissions from deforestation and forest degradation (REDD+) is a mechanism developed by Parties to the United Nations Framework Convention on Climate Change (UNFCCC). It creates a financial value for the carbon stored in forests by offering incentives for developing countries to reduce emissions from forested lands and invest in low-carbon paths to sustainable development. Developing countries would receive results-based payments for results-based actions. REDD+ goes beyond simply deforestation and forest degradation, and includes the role of conservation, sustainable management of forests and enhancement of forest carbon stocks").

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[16] *See* discussion *infra* at __.

[17] NAS Report, *supra* n. 9, at 5-7.

[18] National Academy of Sciences, *Project Information: Developing a Research Agenda for Carbon Dioxide Removal and Reliable Sequestration,* DELS-BASCPR-16-01 (2017), available at http://www8.nationalacademies.org/cp/projectview.aspx?key=49862 .

[19] Natural Environmental Research Council, *Greenhouse Gas Removal from the Atmosphere,* at http://www.nerc.ac.uk/research/funded/programmes/ggr/ (2017).

[20] P. Bunje and M. Extavour, *Teams Around the World Take On the Carbon XPrize* at p. 1, http://carbon.xprize.org/news/blog/teams-around-world-take-carbon-xprize (verified Sept. 7, 2016).

[21] NRG | Cosia Carbon XPrize, *27 Teams Advancing in $20 Million NRG Cosia Carbon X Prize,* http://carbon.xprize.org/press-release/27-teams-advancing-20m-nrg-cosia-carbon-xprize (verified Nov. 8, 2016).

[22] *Id.* at http://carbon.xprize.org/about/schedule .

[23] This brief overview does not provide a comprehensive overview of emerging DAC technologies, but only provides a summary to allow comparisons of approaches and costs. For a comprehensive review of these technologies and their costs, *see* E. Sanz-Pérez, C. Murdock, S. Didas and C. Jones, *Direct Capture of CO_2 from Ambient Air,* 116 CHEMICAL REVIEWS 11840, 11876 (2016);M. Broehm, J. Strefler, and N. Bauer, *Techno-Economic Review of Direct Air Capture Systems for Large Scale Mitigation of Atmospheric CO_2 at https://ssrn.com/abstract=2665702* (2015).

[24] *See, e.g.,* Royal Society, GEOENGINEERING THE CLIMATE: SCIENCE, GOVERNANCE, AND UNCERTAINTY at 15 (2009); J. Fleming, FIXING THE SKY at p. 251 (Columbia U. Press, 2010).

[25] *See, e.g.,* Government Accountability Office, GAO, *Technology Assessment: Climate Engineering: Technical Status, Future Directions, and Potential Responses* at p. 21 (2011) (projecting that the energy required for DAC to capture one ton of ambient CO_2 would itself release a ton of CO_2, thereby nullifying the capture). *See also* P. Smith et al., *Biophysical and economic limits to negative CO_2 emissions,* NATURE CLIMATE CHANGE (Dec. 7, 2015), DOI:10.1038/NCLIMATE2870 (investment in BECCS sufficient to meet temperature goals would require $123 to $138 billion per year by 2050, which would equal nearly five percent of projected total global energy infrastructure investments by 2050).

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[26] NAS Report, *supra* n.9, at 58, 62 (this projection assumes that the DAC technology would rely on solar power rather than non-renewable energy sources that might cause carbon emissions of their own).

[27] *Id.*

[28] D. Keith, M. Ha-Duong, and J. Stolaroff, *Climate Strategy with CO_2 from the Air*, CLIMATIC CHANGE at (2005), DOI: 10.1007/s10584-005-9026-x, available at https://keith.seas.harvard.edu/files/tkg/files/51.keith_.2005.climatestratwithaircapture.e.pdf .

[29] For a good survey of current DAC commercialization projects (and their associated cost projections), *see* Y. Ishimoto, M. Sugiyama, E. Kato, R. Moriyama, K. Tsuzuki and A. Kurosawa, *Putting Costs of Direct Air Capture in Context*, Forum for Climate Engineering Assessment, Working Paper 002 (SSRN 2982422) at 7-9 (June 2017) (summarizing technology choices and unit costs for efforts by Carbon Engineering, the Center for Negative Emissions of Arizona State University, Global Thermostat, Climeworks, Carbon Sink, Coaway, and Skytree).

[30] *About CE* at http://carbonengineering.com/about-ce/ (verified on June 25, 2017).

[31] The Center for Negative Carbon Emissions, *Research* at https://engineering.asu.edu/cnce/research/ (verified on Sept. 16, 2016). *See also* T. Wang, K.S. Lackner, & A.B. Wright, *Moisture-swing sorption for carbon dioxide capture from ambient air: a thermodynamic analysis*, PHYSICAL CHEMISTRY CHEMICAL PHYSICS, (Nov. 5, 2012) (discussing basic thermodynamic chemistry of reaction).

[32] These cost assessments vary widely. For example, a cost calculation for CO_2 removal by DAC that assumed the use of sodium hydroxide to capture the CO_2 and a natural gas-fired kiln to release it for sequestration yielded a cost projection of $2,200 per ton of CO_2 annually. Notably, this cost did not include the additional expense of transporting and sequestering the CO_2 after capture. 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 ii (2011).

[33] Y. Ishimoto *et al., supra* n.29, at 7-9 (June 207) ("Cost Estimates by DAC Companies").

[34] These costs and estimates are discussed in greater detail in Chapter 28 (Carbon Capture and Sequestration) of this book, *supra*, at pp. .

[35] The federal government's most recent estimates of the social cost of carbon ranged from $12 to $62 per metric ton of CO_2 by the year 2020 based on a range of discount rates from 2.5% to 5%. The median average and cost, which is frequently cited, is $42. Interagency Working Group on the Social Cost of Carbon, TECHNICAL SUPPORT DOCUMENT: TECHNICAL UPDATE OF THE SOCIAL COST OF CARBON FOR REGULATORY

Impact Analysis Under Executive Order 12866 at p. 4 (August 2016). Notably, the Trump presidential administration disbanded the Interagency Working Group and withdrew this Technical Support Document. All future calculations of social costs of carbon used in federal governmental actions must use estimates "consistent with the guidance contained in OMB Circular A-4 of September 17, 2003". Executive Order, Section 5 (March 29, 2017), available at https://www.whitehouse.gov/the-press-office/2017/03/28/presidential-executive-order-promoting-energy-independence-and-economi-1 . It remains unclear how this executive order will affect future uses of social costs of carbon, or how agencies will calculate that cost. H. Hess, *OIRA Works Quietly on Updating the Social Cost of Carbon,* Greenwire (June 15, 2017) at item 3, available at https://www.eenews.net/greenwire/2017/06/15/stories/1060056112 (verified June 27, 2017).

[36] *See, e.g.,* H. Willauer, D. Hardy and F. Williams, *The Feasibility and Current Estimated Capital Costs of Producing Jet Fuel at Sea Using Carbon Dioxide and Hydrogen, Naval Research Laboratory*, NRL/MR/6180—10-9300 (2010); G. Rau, CO_2 *Mitigation Via Capture and Chemical Conversion in Seawater*, 45(3) Envt'l Sci. & Technology 1088 (2010).

[37] IPCC, *supra* n.1, at 45, 60-62. Recent surges in the rate of CO_2 increases in the ambient atmosphere have raised concerns that natural greenhouse gas sinks, such as the oceans, have begun to absorb smaller portions of anthropogenic greenhouse gas emissions. J. Gillis, *Rise in Carbon Defies Slowing of Emissions,* The New York Times at p. A1 (June 27, 2017).

[38] NAS Report, *supra* n.9, at 47-53. *See also* R. Abate, *Sowing Seeds Uncertain: Ocean Iron Fertilization, Climate Change, and the International Environmental Law Framework,* 27 Pace Envtl. L. Rev. 555, 560-572 (2010). Some of the initial enthusiasm for the concept of OIF arose from the combination of its proposed effectiveness at withdrawing large volumes of CO_2 (each ton of iron would effectively sequester up to 15,900 tons of carbon) at a very low cost (ranging from $2 to $5 per ton). P. Boyd, *Introduction and Synthesis,* 364 Marine Ecology Progress Series 213, 216-217 (2008).

[39] Fleming, *supra* n.24, at p. 247; K. Coale, *Preface* to 45 Deep Sea Research II at p. 915 (1998).

[40] J. Tollefson, *Plankton-boosting project in Chile sparks controversy,* 545 Nature 393, 394 (May 25, 2017) ("[r]esearchers worldwide have conducted 13 major iron-fertilization experiments in the open ocean since 1990").

[41] NAS Report, *supra* n.9, at 49-50.

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[42] The U.S. Environmental Protection Agency notified Planktos that its planned experiment would require a permit under the federal Clean Water Act for the discharge of a pollutant into U.S. marine waters, or that the U.S. flagged vessel would require authorization for the discharge. The company responded it would use a non-U.S. flagged vessel to conduct its experiment outside U.S. jurisdictional waters. T. Hester, *Remaking the World to Save It: Applying U.S. Environmental Laws to Climate Engineering Projects,* 38 Ecology L.Q. 851, 862 (2011).

[43] *Id.* at p. 863.

[44] H.J. Buck, *Village Science Meets Global Discourse: The Haida Salmon Restoration Corporation's Ocean Iron Fertilization Experiment,* Case Study (2014) at p. 4 in GEOENGINEERING OUR CLIMATE Working Paper and Opinion Article Series at: http://wp.me/p2zsRk-9M (last verified Sept. 16, 2016) (including the execution of a search warrant at the experimenter's offices).

[45] J. Tollefson, *supra* n.40, at 394. Because the proposed project would take place in Chilean waters and constitute a small-scale research project, Oceanus alleges that the release would satisfy the research framework set out under Annexes to the London Protocol. *Id; see also* discussion of London Protocol annexes *infra.*

[46] The London Convention is an international organization consisting of eighty-six member states, and it implements the London Convention of 1972. This Convention controls the discharge of pollutants into the high seas. In 1996, the parties to the Convention agreed to the London Protocol as a step to modernize the Convention and – ultimately – to replace it. The London Protocol takes a muscular stance by prohibiting all dumping into the high seas (except for potentially acceptable wastes on the so-called "reverse list"). The Protocol entered into force on March 24, 2006, and thirty-eight states have joined it. The United States, notably, has joined the London Convention, but it has not subscribed to the London Protocol. INTERNATIONAL MARITIME ORGANIZATION [IMO], THE LONDON CONVENTION AND PROTOCOL: THEIR ROLE AND CONTRIBUTION TO PROTECTION OF THE MARINE ENVIRONMENT (2008) *available at* http://www.imo.org/KnowledgeCentre/ShipsAndShippingFacts AndFigures/TheRoleandImportanceofInternationalShipping/IMO_Brochures/Documents/6%20page%20flyer%20London%20Convention.pdf.

[47] London Protocol, 6*bis.*

[48] London Protocol, 6*bis.* The prohibition on activities positively listed in Annex 4, however, may be lifted if the listing allows the activity to be authorized under a permit. *Id.* This permitting exception allows the performance of small-scale scientific research in certain coastal marine environments. International Marine Organization, *Assessment Framework for Scientific Research Involving Ocean Fertilization,* Resolution LC-LP.2 (2010).

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[49] *Id.*

[50] Conference of the Parties to the Convention on Biological Diversity, *Biodiversity and Climate Change Draft Decision Submitted by the Chair of Working Group I* (Oct. 29, 2010). The final text of Decision X/33 limits the prohibition to climate engineering projects that might affect biodiversity and that lack transparent and effective governance mechanisms. The final language also includes important exceptions for small-scale scientific research as well as a working definition of "geoengineering." *See also* Convention on Biological Diversity, *Update on Climate Geoengineering in Relation to the Convention on Biological Diversity: Potential Impacts and Regulatory Framework,* UNEP/CBD/SBSTTA/19/INF/2 (Oct. 5, 2015).

[51] *See, e.g.,* M. Eisaman, K. Parajuly, A. Tuganov, C. Eldershaw, N. Chang and K. Littau. *CO_2 extraction from seawater using bipolar membrane electrodialysis*, 5(6) ENERGY & ENVIRONMENTAL SCIENCE 7346, 7352 (2012). doi:10.1039/C2ee03393c.

[52] NAS Report, *supra* n.9, at 62, Box 3.3.

[53] *Id*.

[54] *See, e.g.,* G. Rau, S. Carroll, W. Bourcier, M. Singleton, M. Smith and R. Aines, *Direct electrolytic dissolution of silicate minerals for air CO_2 mitigation and carbon negative H2 production*, 2003 Proceedings of the National Academy of Sciences, DOI:10.1073/pnas.1222358110. *See also* NAS Report, *supra* n.9, at 40-47.

[55] NAS Report, *supra* n.9, at 46-47.

[56] D. Clark *et al.*, *Monitoring of CO_2/H2S gas mixture injection in basaltic rocks at Hellisheidi geothermal power plant, Iceland,* 18 GEOPHYSICAL RESEARCH ABSTRACTS EGU2016-14713-1 (2016) (rapid incorporation of CO_2 from geothermal power facility into basaltic formation).

[57] One form of biological capture of carbon for sequestration – biochar – will not be discussed in detail in this chapter. Biochar results from the combustion of biomass at a relatively low temperature (300-600° C) without oxygen to form charcoal. This form of organic carbon is relatively stable, and the conversion of biomass into biochar would slow the release of greenhouse gases to the atmosphere via decomposition. The biochar would be added to soil as a conditioner for agricultural purposes.

The classification of biochar as a negative emissions technology, however, raises difficulties. First, the production of biochar yields less net useable energy per unit of carbon emitted to the atmosphere than does combustion of the same material. Combusting the biomass to produce energy therefore would offset more fossil fuel

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and reduce greenhouse gas emissions more than using it as biochar feedstock. For these reasons, the National Academy of Sciences chose to exclude biochar from consideration as a negative emissions technology. NAS Report, *supra* n.9, at 39. Chapter 31 (Legal Pathways to Reducing Agricultural Greenhouse Gas Emissions in the United States) contains additional discussion of the use of biochar as a greenhouse gas reduction technique.

[58] In the United States, woody biomass is often used on-site by industrial operators who rely on pulp feedstocks (e.g., paper and furniture production) and for small scale power production in agricultural operations and rural communities. The use of biomass production in Europe occurs on a larger scale in part as a greenhouse gas mitigation strategy. J. Stolark, Environmental and Energy Study Institute, *Despite Biomass Provisions in Omnibus, Biomass Woes Far From Over* at p. 1 (May 12, 2017), at http://www.eesi.org/articles/view/despite-biomass-provisions-in-omnibus-biomass-woes-far-from-over . Congress recently directed federal agencies to treat biomass energy production as a carbon neutral source of power, but it remains unclear whether this exemption will materially benefit the industry in light of recent federal efforts to rescind greenhouse gas emission restrictions. *Id.*, *see also* Section 428 of P.L. No. 115-31 (May 4, 2017). Biomass power production is discussed in further detail in Chapter 25 (Bioenergy Feedstocks).

[59] The debate over the greenhouse gas benefits of corn-based ethanol fuels in the United States, for example, continues unabated. *Compare* U.S. Department of Agriculture, A Lifecycle Analysis of the Greenhouse Gas Emissions of Corn-Based Ethanol at 4-6 (Jan. 12, 2017) (greenhouse gas emissions from corn-based ethanol in the United States are 43 percent lower than gasoline when measured on an energy-equivalent basis) *with* J. DeCicco, D. Liu, J. Heo, R. Krishnan, A. Kurthen, and L. Want, *Carbon balance effects of U.S. biofuel production and use,* 138 Climatic Change 667 (Oct. 2016) (U.S. biofuel use resulted in net increase, rather than a decrease, in CO_2 emissions).

[60] D. Sanchez, J. Nelson, J. Johnston, A. Mileva and D. Kammen, *Biomass enables the transition to a carbon negative power system across western North America,* 5 Nature Climate Change 230, 231-234 (2015).

[61] K. Anderson and G. Peters, *supra* n.4, at 183 ("[a]lthough BECCS, like all negative-emission technologies, is subject to scientific and political uncertainties, it dominates the scenario landscape. Yet, as recognition of the ubiquitous role of BECC in mitigation scenarios has grown, so have concerns about its deployment.")

[62] P. Williamson, *Scrutinize CO_2 removal methods,* 530 Nature 153, 154 (2016).

[63] C. Field and K. Mach, *Rightsizing carbon dioxide removal,* 356 Science 706, 707 (May 19, 2017) (in its latest report, the IPCC identified 116 integrated assessment models that had a 66% of better chance of limiting global warming to 2° C by 2100,

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and over 101 used CDR – mostly BECCS – at levels with median commitment of 12 billion tons annually, which would require land use approaching 80% of total global cropland or up to 8% of the Earth's total land area).

[64] P. Williamson, *supra* n.62, at 154 (widespread reliance on BECCS to reach 2° C goal would cause a loss of terrestrial species by 2100 that would exceed losses from a temperature increase of 2.8° C above pre-industrial levels).

[65] L. Boysen, W. Lucht, D. Gerten, V. Heck, T. Lenton and H. Schellnhuber, *The limits to global-warming mitigation by terrestrial carbon removal,* EARTH'S FUTURE, 5, at p. 8, doi:10.1002/2016EF000469 (2017).

[66] *Id.* at 8.

[67] *Id.* at 7-8.

[68] *Id.* at 8.

[69] K. Anderson and G. Peters, *supra* n.4, at 183 ("[d]espite the prevalence of BECCS in emission scenarios at a level much higher than afforestation, only one large-scale demonstration plant exists today.")

[70] *See, e.g., id.*; L. Boysen *et al.*, *supra* n.65; P. Williamson, *supra* n.62; C. Field and K. Mach, *supra* n.63.

[71] *See generally* discussion of legal and market barriers to full deployment of bioenergy feedstocks in Chapter 25.

[72] 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 enough CO_2 to reduce ambient levels from 400 ppm to 350 ppm would therefore create 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). *See also* NAS Report, *supra* n.9, at 25 ("[r]educing CO_2 concentration by 1 ppm/yr would require removing and sequestering CO_2 at a rate of about 18 $GtCO_2$/yr; reducing CO_2 concentration by 100 ppm would require removing and sequestering a total of about 1800 $GtCO_2$ or roughly the same amount of CO_2 as was added to the atmosphere from 1750 to 2000.")

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[73] Royal Society, *supra* n.24, at 21 ("[CDR technologies] have a slow effect on the climate system due to the long residence time of CO_2 in the atmosphere and so do not present an option for rapid reduction of global temperatures"); NAS Report, *supra* n.9, at 3, 72-73 ("[CDR] may produce only modest climate effects within decades.")

[74] By some accounts, such a halting of SRM could cause climate change effects to take place at double or triple the pace expected if GHG emissions remain unabated during the temporary use of SRM. For this (and many other) reason, the use of SRM poses fundamentally different policy and legal challenges than the adoption of DAC. D. Keith, A CASE FOR CLIMATE ENGINEERING at xx – xxi (MIT 2013) ("[t]his divergence of costs and risks means that the challenges solar geoengineering and carbon removal raise for policy and governance are almost wholly different").

[75] This assumption relies on current models of DAC under development in research laboratories. A large-scale DAC process that uses novel or unexpected technological approaches, of course, might require the use of unanticipated methods and resources for its construction.

[76] U.S. Environmental Protection Agency, *Overview of Greenhouse Gases,* at https://www.epa.gov/ghgemissions/overview-greenhouse-gases (verified June 28, 2017) (discussing residence and mixing times of CO_2). If DAC processes reach unexpectedly effective and speedy removal rates, however, the local impact on CO_2 on the surrounding ambient airshed might require further assessment and legal consideration.

[77] Even if federal and state requirements applicable to major sources will not apply to certain DAC facilities, other state environmental laws and permitting requirements may still affect the DAC unit's operation. For example, many states maintain minor source permitting programs that could apply even to DAC units that emit only low levels of regulated air pollutants. *See, e.g.,* 30 TEX. ADMIN. CODE Chap. 117, Subchap. D (regulation of minor sources in ozone non-attainment areas).

[78] *See, e.g.,* Texas Commission on Environmental Quality, Site Operating Permit Revision Application Guidance at Attachment C, p. 10 (March 2017) (list of insignificant activities whose emissions do not require New Source Review or Title V permits includes "[a]ny air separation or other industrial gas production, storage, or packaging facility. Industrial gases, for purposes of this list, include only oxygen, nitrogen, helium, neon, argon, krypton, and xenon.") The United Kingdom has taken a similar position. Environment Agency, *Permitting of Air Separation Units,* Regulatory Position Statement 032 (Nov. 2015), available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/477544/LIT_9932.pdf. In general, atmospheric gases fall within the category of *res ferae* natural items that no person owns until they are captured or controlled.

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[79] Recent cases seeking to declare that the atmosphere and its constituent gases fall within the public trust doctrine, however, might alter this legal preconception if a court determines that the public has an undifferentiated right to the atmosphere under which governments have a fiduciary duty to protect. *See, e.g.,* M. Blumm and M. Wood, *"No Ordinary Lawsuit": Climate Change, Due Process, and the Public Trust Doctrine,* 67 Am. U. L. Rev. 1 (April 18, 2017).

[80] Carbon Engineering, Inc., *From Air to Fuels* (2017) at http://carbonengineering.com/about-a2f/ (verified on June 27, 2017); see also H. Brueck, *This Company Wants to Recycle Carbon Dioxide From the Atmosphere* (July 24, 2015), at https://www.forbes.com/sites/hilarybrueck/2015/07/24/this-company-wants-to-recycle-carbon-dioxide-from-the-atmosphere/#13db3f79212e (verified on June 28, 2017). The relatively purity of the CO_2 stream generated by this company's DAC process would presumably make it suitable for use in manufacturing, pharmaceuticals, food processing and enhanced oil recovery operations.

[81] *See* discussion *supra* at n.31.

[82] 42 U.S.C. §§ 7521-7590 (Title II of the federal Clean Air Act, setting out standards for fuels for on-road and off-road vehicels, aviation, motor emission specifications, clean vehicles requirements and renewable biofuels).

[83] A. Reitze, STATIONARY SOURCE AIR POLLUTION LAW at 174-180, 195-202 (Environmental Law Institute 2005) (general description of the Prevention of Significant Deterioration permitting program). *See also* National Research Council of the National Academy of Sciences, AIR QUALITY MANAGEMENT IN THE UNITED STATES at 177-186 (National Academies Press 2004) (same).

[84] *Utility Air Regulatory Group v. EPA,* 134 S. Ct. 2427 (2014); Executive Order, *supra* n.35, at Section 4 (directing review and, if warranted, withdrawal of Clean Power Plan).

[85] *See* Reitze, *supra* n.83, at 184 (general discussion of using bubbling, netting of internal emissions, and offsets from internal and external sources of emissions to keep a facility's emissions below a threshold that would trigger permitting requirements under Title I of the federal Clean Air Act).

[86] EPA proposed limits on GHG emissions for new fossil-fueled power plants that anticipate the use of carbon capture and sequestration by the power plant. To the extent that capturing CO_2 at the emission points of a power plant are analytically indistinguishable from CO_2 captured outside the plant's fenceline, EPA's acceptance of CCS for New Source Performance Standards might suggest that CO_2 captured by DAC could be used to demonstrate attainment or compliance with a performance standard (assuming the emission captures were reliable, verifiable, and quantifiable, and that DAC operations did not create other environmental harms or perverse

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incentives). Given the pending reconsideration and likely withdrawal of these rules as part of the Trump Administration's reconsideration of the Clean Power Plan, however, this option is now likely purely hypothetical.

[87] The Clean Power Plan had preserved the option for states to adopt a carbon tax as a strategy to demonstrate attainment of the emission reductions required by the rule. *But see* discussion *supra* at n.35 (reconsideration, and likely withdrawal, of Clean Power Plan). To date, no state has adopted a carbon tax as a method of greenhouse gas reduction or for regulatory compliance purposes. Y. Bauman and C. Komanoff, Opportunities for Carbon Taxes at the State Level, at 7-8 (Carbon Tax Center April 2017) available at https://www.carbontax.org/Opportunities_for_Carbon_Taxes_at_the_State_Level.pdf (verified June 24, 2017). If a state adopted a carbon tax, it is unclear whether the federal government would allow individuals or businesses to deduct their payment of state carbon taxes from their federal tax obligations (either as a business expense or as a state tax).

[88] A person who purchases tobacco or alcohol (or their precursors) to remove them from the market typically cannot seek credits or reimbursement of the taxes that a consumer of those goods would have ultimately paid if they had otherwise been sold and consumed. The U.S. Internal Revenue Code, for example, does not provide any exemption from cigarette excise taxes to persons who purchase cigarettes for non-consumptive use (other than transfers of title associated with bonding in warehouses). 26 U.S.C. § 5407 (2017).

[89] 42 U.S.C. §§ 4321 *et seq.* (2017) (The National Environmental Policy Act of 1969).

[90] 40 C.F.R. §§ 1500 *et seq.* (2017).

[91] While the issuance of permits pursuant to programs delegated to states under the federal Clean Air Act or the Resource Conservation Recovery Act typically have not required an environmental review under NEPA, decisions to grant a federal section 404 permit under the Clean Water Act can require an environmental impact assessment or other review. *See* 33 U.S.C. part 325, Appendix B (Army Corps of Engineers' regulations to implement NEPA environmental assessment requirements).

[92] C. Goldfuss, U.S. Council on Environmental Quality, *Final Guidance for Federal Department and Agencies on Consideration of Greenhouse Gas Emissions and the Effects of Climate Change in National Environmental Policy Act Reviews* at 18 (Aug. 1, 2016) (discussing mitigation options for GHG emissions). The Trump Administration has also ordered the withdrawal of this guidance as well, and it appears unlikely that federal agencies will need to include greenhouse gas emissions effects in future environmental assessments to satisfy CEQ regulatory guidance or standards. Executive Order of March 28, 2017, *supra* n.35, at Section 3(c). However,

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judicial decisions have caLLED for such analysis even in the absence of the CEQ guidance. E.g., Center for Biological Diversity v. National Highway Traffic Safety Administration, 538 F.3d 1172 (9th Cir. 2008).

[93] *See, e.g.,* S. Goho, *NEPA and the "Beneficial Impact" EIS*, 36 Wm. & Mary Envt'l L. & Policy Rev. 367 (2012) (contending that, despite apparently conflicting decisions, federal actions that yield only an environmental benefit without any disadvantages should not be require preparation of an environmental impact statement).

[94] CEQ's regulations that define whether a major federal action "significantly" affects the environment require an agency to consider both the context and intensity of the action. In particular, an action's "intensity" can include whether the effects are "highly controversial," "highly uncertain or involve unique or unknown risks," or the action "may establish a precedent for future actions with significant effects or represents a decision in principle about a future consideration." 40 C.F.R. § 1508.27(b)(4)-(6) (2017).

[95] U.S. Council on Environmental Quality, *Report on the National Environmental Policy Act Status and Progress for American Recovery and Reinvestment Act of 2009 Activities and Projects* (May 18, 2009).

[96] M. Gerrard, Greenhouse Gases: Emerging Standards for Impact Review, 241 New York Law Journal (58) at 1-2 (March 27, 2009), available at http://columbiaclimatelaw.com/files/2016/06/Gerrard-2009-03-Standards-for-GHG-Impact-Review.pdf .

[97] If a federal agency undertakes an environmental assessment and issues a finding of no significant impact from the project, some state laws would not require a further additional state environmental impact assessment. *Id.*

[98] NAS Report, *supra* n.9, at 75.

[99] NAS Report, *supra* n.9, at 68, 75; H. Buck, *Rapid Scale-Up of Negative Emissions Technologies: Social Barriers and Social Implications*, Climatic Change at 2.0, DOI 10.1007/s10584-016-1770-6 (2016).

[100] L. Krauss, *Cutting Carbon Dioxide Isn't Enough,* Slate (2013) at http://www.slate.com/articles/technology/future_tense/2013/05/direct_air_carbon_capture_technology_must_be_developed_to_help_fight_climate.html .

[101] This statement assumes that the DAC process would yield CO_2 of sufficient purity and quantity that it would be suitable for industrial use in the first place.

[102] *See* discussion *supra* at nn 80-81. To the extent that such DAC processes entrain the CO_2 in a fuel, the subsequent combustion of that fuel would ultimately release

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the CO_2 back into the ambient atmosphere. As a result, DAC used in this context is only carbon neutral rather than true CO_2 removal.

[103] *See* discussion *supra* at n.56.

[104] Power Plant CCS, *Arizona Public Service Company* – CO_2 *Algae Capture* (2010), at http://www.powerplantccs.com/ccs/cap/fut/alg/alg_proj_arizona_public.html.

[105] As noted earlier, the direct capture of enough CO_2 to reduce ambient atmospheric concentrations by 100 ppm would generate 1,800 $GtCO_2$. *See* discussion *supra* at n.72 (NAS Report estimate). By contrast, electrical power generated by fossil fuel combustion in the United States generated 1,900.7 $MtCO_2$ in 2015 – by comparison, only 0.1% of the global sequestration total generated by a 100 pm drawdown of ambient CO_2 levels. U.S. Environmental Protection Agency, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015, at pp. 3-2 (Table 3-1) (April 15, 2017), available at https://www.epa.gov/sites/production/files/2017-02/documents/2017_complete_report.pdf .

[106] 42 U.S.C. §§ 6901 *et seq.* (2017).

[107] 42 U.S.C. §§ 9601 *et seq.* (2017).

[108] 40 C.F.R. § 261.4(h) (conditional exclusion for CO_2 streams injected for geologic sequestration); 79 Fed. Reg. 350 (Jan. 3, 2014) (preamble and explanatory overview of final rule).

[109] In anticipation of the need to dispose substantial amounts of CO_2 emissions from energy production and other industrial activities that would use carbon capture and sequestration systems, EPA created a new class of injections wells to geologically sequester CO_2. These new Class VI wells under the Underground Injection Control program of the Safe Drinking Water Act require individual permits with extensive characterization of the site's geologic conditions to confirm that sequestered CO_2 would not migrate or affect potential drinking water sources. 40 C.F.R. § 144.6(f); 75 Fed. Reg. 77230, 77246 (Dec. 10, 2010).

[110] While the United States possesses an estimated capacity to geologically sequester CO_2 that exceeds 3,500 $GtCO_2$, the actual usable capacity will depend on site-specific technical and economic considerations. 75 Fed. Reg. 77234 (citing U.S. Department of Energy assessments).

[111] Injection wells that use CO_2 for enhanced recovery of petroleum and natural gas fall under regulatory requirements for Class II wells. EPA emphasized that the Class VI well requirements for geologic sequestration wells (as well as the conditional exemption of such CO_2 from the definition of hazardous waste under RCRA) would not apply such enhanced recovery wells. 79 Fed. Reg. 350, 355 (Jan. 3, 2014)

("…this conditional exclusion is not intended to affect the regulatory status of CO_2 streams that are injected into wells other than UIC Class VI wells.… [S]hould CO_2 be used for its intended purpose as it is injected into UIC Class II wells for the purpose of [enhanced oil recovery or enhanced gas recovery], it is EPA's expectation that such an injection process would not generally be a waste management activity.")

[112] Such storage is common for the temporary retention or management of natural gas, volatile liquids and other compressed gases in salt dome formations or other geologic structures.

[113] 29 U.S.C. §§ 651 *et seq.* (2017).

[114] *See, e.g.,* 42 U.S.C. §§ 7612(r); 40 C.F.R. Part 68 (2017) (Risk Management Planning program and regulatory requirements under the federal Clean Air Act).

[115] Even if stored CO_2 did not trigger federal hazardous waste requirements, states may impose their own (and more stringent) tank storage requirements. In addition, RCRA Subtitle D also provides the federal government with authority to regulate certain non-hazardous solid wastes as "special wastes" upon a specific finding by the federal EPA. 79 Fed. Reg. at 354-356 (discussing regulatory consequences under RCRA of declaring sequestered CO_2 to be a discarded "solid waste" instead of a usable or stored product or resource).

[116] Full life-cycle assessments of direct air capture technologies are now beginning to take place as specific technologies begin to emerge. *See, e.g.,* J. Wilcox, P. Psarras, and S. Liguori, *Assessment of reasonable opportunities for direct air capture,* 12 Environ. Res. Lett. 065001 at 2 (May 23, 2017), available at https://doi.org/10.1088/1748-9326/aa6de5 (discussing life cycle analysis of direct air capture and enhanced oil recovery options, primarily from energy inputs and offsetting CO_2 process emissions).

A tolling operation is a commercial transaction where a customer conveys a batch of materials or product to a contractor who processes those materials and then returns the finished product to the customer. Typically a tolling operator never acquires any ownership interest in the processes materials, and the operator also assumes responsibility for any wastes or environmental consequences of the tolling operation. If the customer exercises broad oversight and control over the tolling operation, however, the customer may incur liability for environmental regulatory violations or cleanup obligations. *See, e.g., United States v. Aceto Agricultural Chemicals Corp.,* 872 F.2d 1373, 1381-82 (8th Cir. 1989) (discussing tolling operations and their potential basis for liability under the federal Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA)).

[117] *See* discussion *infra* at __ (potential standardized permitting or programmatic review approaches to streamline environmental approval of DAC technologies).

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[119] Interestingly, once a person begins a DAC operation, they may incur an ongoing duty to perform it competently even if they had no duty to originally undertake the DAC. Many states impose have "Good Samaritan" laws, however, that may shield an individual from potential negligence tort liability if they undertake action to save the life or property of another person. *See* discussion *supra* at n.12.

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

[121] One tort action frequently brought against environmental releases or disturbances – trespass -- will have a less likely role in challenges to DAC. Trespass actions require the intentional invasion of the real property interests of another party. Absent any direct intrusion onto an adjoining property, with DAC the action that might affect a nearby landowners would be the removal of CO_2 from the ambient atmosphere that might otherwise pass over the neighbor's land. From this perspective, the removal of such airborne gas might constitute a reverse trespass (taking of something that another person might expect to cross onto their property). *Cf.* J.B. Ruhl, *Making Nuisance Ecological,* 58 CASE WESTERN RESERVE L. REV. 753 (2008) (action on one's own property that indirectly results in degradation of ecosystem services on another person's property may constitute actionable tort). If they do not have a property right in the CO_2 captured on someone else's land, however, the adjoining neighbors probably do not have a trespass or wrongful taking tort action.

[122] Given the early stage of DAC development, most of the work has occurred in research settings or early start-up demonstration projects. As a result, almost all of the governance discussions to date have focused on public law or regulatory approaches. Private governance approaches or consensual codes of conduct, however, may play a growing and significant role in the future, especially within the research community. *See* M. Burger and J. Gundlach, *Research Governance,* in M. Gerrard and T. Hester, *supra* n.14, at chap. 6.

[123] O. Morton, THE PLANET REMADE: HOW GEOENGINEERING COULD CHANGE THE WORLD at 158-164 (2016) (discussing moral hazard framing and subsequent justifications for climate engineering); A. Lin, PROMETHEUS REVISITED at 124-128 (U. Mich. Press 2013); D. Jamieson, *Ethics and Intentional Climate Change*, 33 CLIMATIC CHANGE 323, 333 (1996).

[124] NAS Report, *supra* n.9, at 90-91 (recommending broader research program and funding for carbon dioxide removal technologies); Royal Society, *supra* n.24, at 61. *See also* U.S. Government Accountability Office, *supra* n.25, at 29 (as of 2011, only nine projects explicitly focusing on climate engineering had received federal research funding).

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[125] NAS Report, *supra* n.9, at 90-91.

[126] *See, e.g.,* B. Yirka, *CIA co-sponsoring geoengineering study to look at reversing global warming options,* (July 22, 2013), available at https://phys.org/news/2013-07-cia-co-sponsoring-geoengineering-reversing-global.html (National Academy of Sciences climate engineering project suggested for funding by the U.S. Central Intelligence Agency, the National Aeronaturics and Space Administration, and the National Oceanic and Atmospheric Administration); E. Kinitsch, *DARPA to Explore Geoengineering* at 1 (March 14, 2009), available at http://www.sciencemag.org/news/2009/03/darpa-explore-geoengineering (verified on June 29, 2017).. Our research has not identified any states that are sponsoring independent climate engineering research.

[127] Executive Order Expediting Approvals for High Priority Infrastructure Projects at §§ 2, 3 (Jan. 24, 2017); Executive Order 13604 on Improving Performance of Federal Permitting and Review of Infrastructure Projects (March 22, 2012).

[128] 42 U.S.C. § 9621(e)(1) ("[n]o Federal, State, or local permit shall be required for the portion of any removal or remedial action conducted entirely onsite, where such remedial action is selected and carried out in compliance with this section.") Notably, the ultimate remedial action selected must still account for all applicable or relevant and appropriate state and local standards.

[129] The Honorable Richard Epstein, *Kelo v. City of New London Ten Years Later,* at http://www.nationalreview.com/article/420144/kelo-v-city-new-london-ten-years-later-richard-epstein (June 23, 2015) (recounting strong reaction to U.S. Supreme Court decision allowing condemnation and acquisition of private property for public real estate development project that provided only indirect benefits to the public); I. Smolin, THE GRASPING HAND: *KELO V. CITY OF NEW LONDON* AND THE LIMITS OF EMINENT DOMAIN (U. Chicago Press 2015).

[130] 42 U.S.C. §§ 2210 *et seq. See also* Chapter 21 of this book.

[131] *See, e.g.*, 33 U.S.C. § 2704 (limitations on liability under the Oil Pollution Act for damages arising from spills of petroleum into navigable waters); D. Dana, *When Less Liability May Mean More Precaution: The Case of Nanotechnology,* Faculty Working Papers No. 194, at 29-32, available at http://scholarlycommons.law.northwestern.edu/facultyworkingpapers/194 (2009) (analyzing proposals to limit liability for damages arising from nanoscale materials in exchange for instituting a broad testing regime); A. Lin, *supra* n.123, at 95-96, 100-101 (role of tort liability and insurance as regulatory backstops for development of nanoscale materials).

[132] *See* discussion *supra* at nn.108 - 115

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[133] This strategy, however, has proven controversial when federal investments, loans or tax credits go to ventures that ultimately fail or go bankrupt. *See, e.g.,* E. Lipton and J. Broder, *In Rush to Assist a Solar Company, U.S. Missed Signs,* THE NEW YORK TIMES at p. A1 (Sept. 23, 2011).

[134] *See, e.g.,* J. Golden and H. Wiseman, *The Fracking Revolution: Shale Gas as a Case Study in Innovation Policy,* 64 EMORY L. J. 955, 983-999 (2015) (reviewing role of government support in development of hydraulic fracturing technology). *See also* L. Steffy, *How Much Did the Feds Really Help With Fracking?* (Oct. 31, 2013) available at https://www.forbes.com/sites/lorensteffy/2013/10/31/how-much-did-the-feds-really-help-with-fracking/#24fcd1c13edf ; M. Shellenberger and T. Nordhaus, *A boom in shale gas? Credit the feds,* (Dec. 16, 2011), available at https://www.washingtonpost.com/opinions/a-boom-in-shale-gas-credit-the-feds/2011/12/07/gIQAecFIzO_story.html?utm_term=.2d79e64926c4 (recounting federal support for early research in the natural gas potential of shale formations and innovative techniques to cost-effectively extract hydrocarbons from them).

[135] K. Bradsher, *Outsize Profits, and Questions, in Effort to Cut Warming Gases,* The New York Times at p. A1 (Dec. 21, 2006).

[136] A. Lin, *Geoengineering* in GLOBAL CLIMATE CHANGE AND U.S. LAW at 724 (ed. M. Gerrard and J. Freeman) (2d ed., American Bar Association 2014)

[137] While the federal Clean Power Plan and federal CO_2 emission limits on fossil fueled electrical generation facilities might have provided a fertile basis to explore permitting requirements that incorporated offsets from DAC or other negative emissions technologies, the federal government's recent moves to halt efforts to permit GHG emissions under the federal Clean Air Act's Prevention of Significant Deterioration program and its New Source Performance Standards likely foreclose that avenue for the foreseeable future. *See* discussion *supra* at n.35, at Section 4(b) (directing review and, if warranted, withdrawal of Clean Power Plan regulations to restrict greenhouse gas emissions from existing and new fossil-fueled power plants under Sections 111(b) and 111(d) of the federal Clean Air Act).

[138] DAC removal might also play a role in selection of Lowest Achievable Emission Rate technologies for sources located in areas that do not meet National Ambient Air Quality Standards for certain criteria pollutants. While EPA has not promulgated a NAAQS for CO_2 that would support the designation of non-attainment areas or selection of LAER for CO_2, EPA or delegated state agencies could choose a LAER technology to control that non-attained criteria pollutant while also offering additional desirable reductions in CO_2 as well. As noted earlier, the U.S. Supreme Court in *UARG v. EPA* upheld the ability of EPA (and, presumably, a state agency with delegated authority) to select BACT standards to control regulated pollutants which also limit CO_2 and other GHGs as co-pollutants. *See* discussion, *supra* at n.84, at --- U.S. ---, 134 S.Ct. at 2447-2449 (discussion of regulation of "BACT anyway" sources).

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[139] While the use of netting and offsets have become an accepted facet of routine PSD and NSR permitting under the federal Clean Air Act, the concepts have sparked controversy when used as compliance mechanisms or as a mechanism under state law to attain GHG reduction goals. *See, e.g.,* A. Ashton, *Is It a Fee or a Tax? California's Cap-and-Trade Faces Tough Questions* at 1 (Jan. 24, 2017), available at http://www.sacbee.com/news/politics-government/capitol-alert/article128494604.html (lawsuit challenging California's use of a cap-and-trade system to control greenhouse gas emissions under state law).

[140] For example, some proposals for DAC would use the captured CO_2 as a feedstock to manufacture hydrocarbon fuels. This type of reuse of captured CO_2, however, might be classified as a form of discarding through recycling for energy recovery that could lead to its classification as a solid waste under federal RCRA regulations. 40 C.F.R. § 241.2(c)(2)(i)(B) (materials are "solid waste" if they are recycled by being "used to produce a fuel or are otherwise contained in fuels (in which cases the fuel itself remains a solid waste).") The secondary use of solid wastes to manufacture fuels or to burn for energy recovery, however, is an extremely complex area of regulation under federal and state hazardous waste laws. *See, e.g.,* 40 C.F.R. §§ 261.38 (comparable fuels exclusions), Part 266 Subpart H (regulations for boiler and industrial furnaces that burn secondary materials for energy recovery).

[141] *See, e.g., American Mining Congress v. EPA,* 824 F.2d 1177 (D.C. Cir. 1987) (certain secondary materials reused in the primary mining production process are not "discarded," and therefore are not "solid wastes" that EPA can regulate under RCRA); Hester, *supra* at n.36, at 877 (jurisdictional issues regarding ability of EPA to rely on the federal Clean Air Act to regulate chemicals intentionally released into the air to achieve their designated purpose).

[142] *See* discussion *supra* at n.140 (solid and hazardous waste regulatory requirements triggered by burning of materials for energy recovery).

[143] Memorandum from Denise Keehner, Dir., Office of Wetlands, Oceans & Watersheds, U.S. EPA, to Water Div. Dirs., Regions 1–10 (Nov. 15, 2010), http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/upload/oa_memo_nov2010.pdf (outlining EPA strategy for assessing Total Maximum Daily Loads for oceanic acidification); R. Craig, *Dealing with Ocean Acidification: The Problem, the Clean Water Act, and State and Regional Approaches,* 6 WASH. J. OF ENVT'L L. & POL. 387, 426-28 (2016).

[144] In particular, the Center for Biological Diversity has aggressively pursued EPA to require affirmative action to address listings of coastal and oceanic waters as impaired for failing water quality standards for acidity. R. Craig, *supra* n.143, at 421-428.

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[145] *Id.* at 425-28. *See also* Center for Biological Diversity, *Legal Settlement Will Require EPA to Evaluate How to Regulate Ocean Acidification Under the Clean Water Act* at http://www.biologicaldiversity.org/news/press_releases/2010/ocean-acidification-03-11-2010.html (March 11, 2010).

[146] Royal Society, *supra* n.24, at 37-39 (assessing moral hazard objections to widescale deployment of CO_2 technologies); M. Ranjan and H. Herzog, *Feasibility of Air Capture,* 4 ENERGY PROCEDIA 2869, 2875-77 (2011) (noting moral hazard issues raised by current framings of direct air capture options).

[147] For example, residents near large DAC facilities may face environmental impacts from the facility's operations as well as the risk arising from the management, disposal or release of wastes or pollutants from the facility (aside from CO_2). *See* discussion *supra* at nn.11-14.