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Removing Methane via Atmospheric Oxidation Enhancement: The Legal Framework

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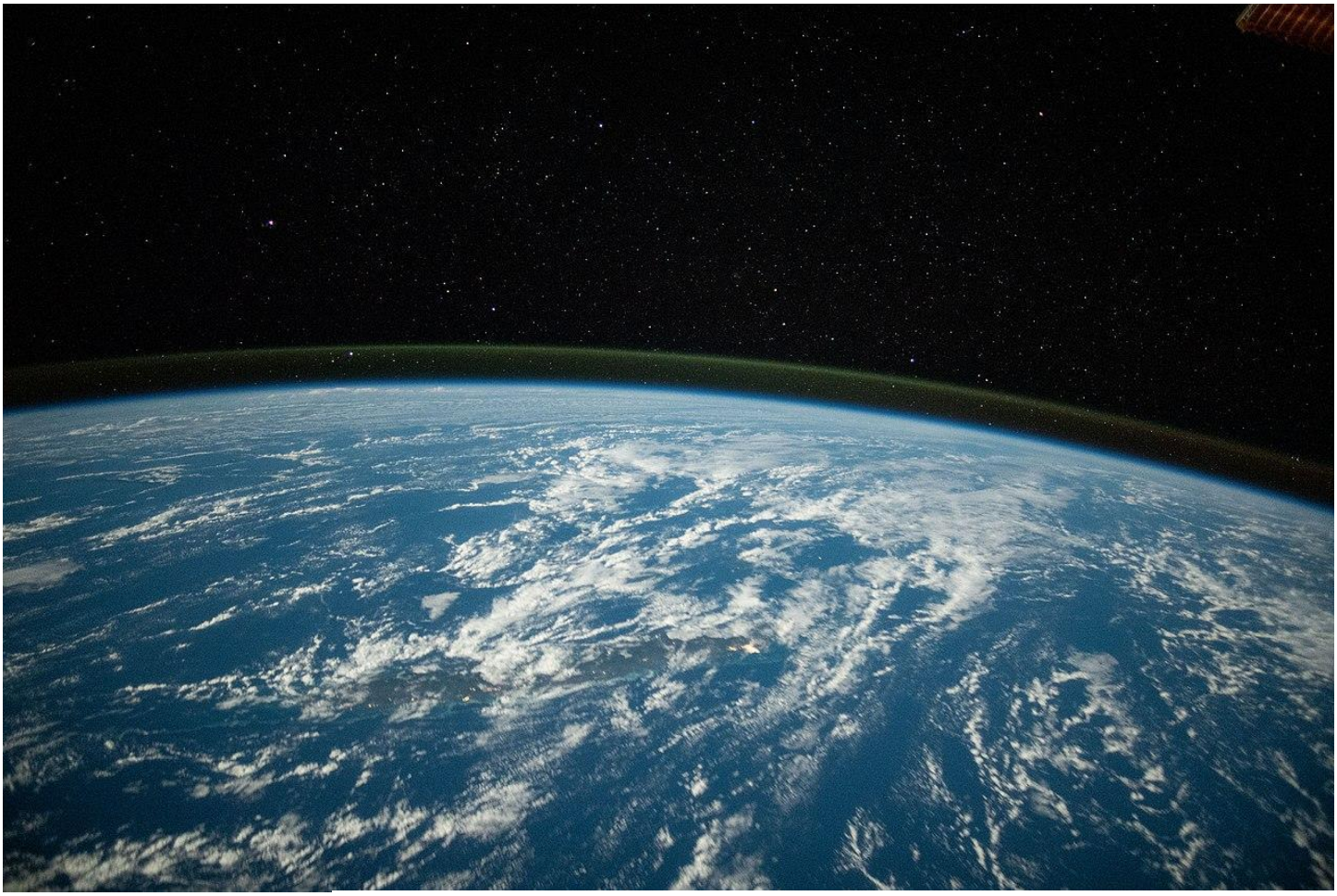

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EXECUTIVE SUMMARY

To achieve the Paris Agreement's goal of limiting the increase in global average temperatures to "well below 2 degrees Celsius," and ideally 1.5 degrees Celsius, above pre-industrial levels, global greenhouse gas ("GHG") emissions must reach net zero in the second half of the century. The global community is not currently on track to achieve net zero emissions. In fact, with the exception of a slight dip during the Covid-19 pandemic, emissions have risen steadily in recent years. This, together with the increasingly visible impacts of climate change, has prompted growing interest in the possibility of removing GHGs directly from the atmosphere. While GHG removal cannot substitute for rapid and deep emissions cuts, it could help to offset residual emissions from hard-to-abate sectors and potentially even reduce the total atmospheric GHG load by delivering net negative emissions.

To date, efforts to advance GHG removal have primarily focused on developing carbon dioxide removal ("CDR") techniques, but another GHG removal approach—atmospheric methane removal ("AMR")—is now also beginning to receive attention. One AMR technique is atmospheric oxidation enhancement ("AOE"), which aims to accelerate the natural oxidation process whereby hydroxyl and chlorine radicals react with atmospheric methane, converting it into carbon dioxide and other by-products. This process could deliver significant climate benefits because methane is a particularly potent GHG, trapping 86 times more heat in the Earth's atmosphere than carbon dioxide in the first 20 years after it is released and 34 times more heat than carbon dioxide over 100 years (on a ton-for-ton basis). However, AOE is still in the very early stages of development, and significantly more research is required to fully evaluate its efficacy and impacts (both positive and negative).

This paper, *Atmospheric Oxidation Enhancement: The Legal Framework*, and the two accompanying case studies, explore the international and domestic (U.S.) laws governing methane removal via AOE. Parts 1 and 2 introduce the concept of AOE, explain proposed AOE techniques, and discuss the climate and non-climate benefits and risks that AOE may present. Part 3 then discusses key factors that will influence how AOE projects are regulated, both at the international level and domestically in the United States. With respect to the latter, Part 3 examines circumstances under which the United States may assert jurisdiction over AOE projects and introduces the different bodies of U.S. law—arising at the federal, tribal, state, and local levels—that might apply to such projects. The remainder of the paper then assesses the laws and regulations that might govern AOE projects: Part 4 identifies international agreements and rules of customary international law that might affect whether, when, where, and how AOE projects are conducted, and Part 5 explores applicable U.S. law that might apply to such projects, with a particular focus on federal environmental law.

The paper is accompanied by two case studies that highlight permitting, reporting, and other legal requirements that could impact two hypothetical AOE projects: one involving the dispersal of AOE aerosol from onshore towers located in coastal areas, and another conducted by adding iron-bearing additives to marine fuels used in ocean-going vessels.

The goal of this paper is to provide a detailed analysis of the key legal regimes that might have implications for the conduct of AOE projects. The paper does not assert any policy positions, argue for the adoption of specific

laws, or otherwise make specific legal recommendations. Nevertheless, several clear conclusions can be drawn from the analysis contained in this paper:

1. **AOE law is underdeveloped, but it is already complex.** The analysis in this paper shows that the legal framework for AOE activities is highly complex, and highly uncertain. There are currently no international or domestic (U.S.) legal frameworks designed specifically for AOE. Nevertheless, a large number of international and domestic laws might have implications for AOE projects (e.g., because those projects involve activities or have impacts that the laws were intended to regulate). There is often significant uncertainty as to when and how different laws will be applied in practice and whether they will ensure safe, responsible, and just AOE development.

2. **AOE projects will likely implicate several international agreements and rules of customary international law.** Several international agreements, including the Convention on Biological Diversity and the London Convention and London Protocol, address "geoengineering" —a term generally used to refer to activities involving deliberate, large-scale intervention in the Earth's natural systems or processes, including to counteract climate change. Since AOE aims to accelerate the natural methane oxidation process—i.e., the process by which methane in the atmosphere is converted into carbon dioxide–it might be viewed as a form of geoengineering under international legal instruments. Other agreements—e.g., addressing marine research, transboundary air pollution, and other environmental issues—may similarly apply to AOE projects depending on where and how they are conducted.

3. **Many AOE techniques implicate and will be governed by traditional environmental law.** Some AOE techniques, by design, affect either or both of the atmosphere and the hydrosphere. The two case studies that accompany this paper emphasize the extent to which AOE projects using such techniques will be governed by generally applicable environmental laws like the Clean Air Act, Clean Water Act, Endangered Species Act, and Marine Protection, Research, and Sanctuaries Act, among others. To assess the full extent to which these laws might constrain large-scale AOE deployment, it is important to research the full impacts of AOE processes on the environment, including any non-climate impacts on human, plant, and animal life.

4. **Different AOE techniques will be governed by significantly different laws.** While some frameworks, like those designed to protect endangered species, will be applied uniformly to AOE projects within the United States, other legal frameworks are tied to specific locations or AOE techniques. As the two case studies attached to this paper show, these differences may shape early AOE research. For example, some legal frameworks, such as those governing marine fuel additives and maritime air pollution, have existing processes that may allow environmental regulators to permit and oversee small-scale research projects.

There is a need for further research into these issues and, more generally, into the laws governing different AMR techniques. Future papers by the authors will delve into these questions.

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ABBREVIATIONS AND DEFINED TERMS

ACE	Army Corps of Engineers
AMR	Atmospheric Methane Removal
AOE	Atmospheric Oxidation Enhancement
APPS	Act to Prevent Pollution from Ships
Aarhus Convention	Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters
Basel Convention	Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal
BLM	U.S. Department of the Interior's Bureau of Land Management
BOEM	U.S. Department of the Interior's Bureau of Ocean Energy Management
CAA	U.S. Clean Air Act
CARB	California Air Resources Board
CBD	Convention on Biological Diversity
CDR	Carbon Dioxide Removal
CE	Categorical Exclusion
CEQA	California Environmental Quality Act
CFCs	Chlorofluorocarbons
Colorado WMA	Colorado Weather Modification Act
COP	Conference of the Parties [to a convention, treaty, etc.]
CWA	Federal Water Pollution Control Act (commonly known as the Clean Water Act)
CZMA	Coastal Zone Management Act
DCEPA	District of Columbia Environmental Policy Act
DOE	U.S. Department of Energy
EA	Environmental Assessment
EEZ	Exclusive Economic Zone
EIA	Environmental impact assessment
EIS	"Environmental impact statement
ENMOD Convention	Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques

EPA	U.S. Environmental Protection Agency
ESA	U.S. Endangered Species Act
Escazú Agreement	Regional Agreement on Access to Information, Public Participation and Justice in Environmental Matters in Latin America and the Caribbean
FAA	Federal Aviation Administration
FLPMA	Federal Land Policy and Management Act
FWS	U.S. Fish and Wildlife Service
GHG	Greenhouse gas
Gothenburg Protocol	Protocol to the 1979 Convention on Long-Range Transboundary Air Pollution to Abate Acidification, Eutrophication and Ground-level Ozone, adopted Nov. 30, 1999
GWP	Global Warming Potential
HCFCs	Hydrochlorofluorocarbons
HFCs	Hydrofluorocarbons
ICJ	International Court of Justice
IPCC	Intergovernmental Panel on Climate Change
Kigali Amendment	Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer, adopted Oct. 15, 2016
London Convention	1972 Convention on the Prevention of Marine Pollution by Dumping of Waste and Other Matter
London Protocol	1996 Protocol to the London Convention
LRTAP	Convention on Long-range Transboundary Air Pollution
MACT	Maximum achievable control technology
MARPOL	International Convention on the Prevention of Pollution from Ships
Montreal Protocol	Montreal Protocol on Substances that Deplete the Ozone Layer
MPRSA	Marine Protection, Research, and Sanctuaries Act
MSR	Marine Scientific Research
NAAQS	National Ambient Air Quality Standards
NEPA	U.S. National Environmental Policy Act
NESHAP	National Emissions Standards for Hazardous Air Pollutants
NFMA	U.S. National Forest Management Act
NMFS	U.S. National Marine Fisheries Service
NOAA	U.S. National Oceanic and Atmospheric Administration

NPDES	National Pollutant Discharge Elimination System
NSR	"New Source Review" permitting process
nvPM	Non-Volatile Particulate Matter
OCS	U.S. Outer Continental Shelf
OCSLA	U.S. Outer Continental Shelf Lands Act
OSPAR Convention	Convention on the Protection of the Marine Environment of the North-East Atlantic
PM	Particulate Matter
PM2.5	PM consisting of ultrafine inhalable particles, measuring 2.5 micrometers or less in diameter
PM10	PM consisting of fine inhalable particles, measuring 10 micrometers or less in diameter
PSD	"Prevention of Serious Deterioration" standards
RCRA	U.S. Resource Conservation and Recovery Act
RHA	Rivers and Harbors Act
RMP	Resource Management Plan
SIP	State Implementation Plan
SRM	Solar Radiation Management
UNCLOS	United Nations Convention on the Law of the Sea
Vienna Convention	Vienna Convention for the Protection of the Ozone Layer
VOC	Volatile Organic Compounds
WMRA	U.S. Weather Modification Reporting Act

1. Introduction

2023 was the warmest year on record with global average temperatures reaching at least 1.4 degrees Celsius above pre-industrial levels.[1] Without concerted action, the world will soon surpass the temperature limits set in the Paris Agreement, with devastating consequences for human and natural systems. The Intergovernmental Panel on Climate Change ("IPCC") has long warned that to achieve the Paris Agreement's goal of limiting warming to "well below" 2 degrees Celsius, and ideally to 1.5 degrees Celsius, above pre-industrial levels, global greenhouse gas ("GHG") emissions must reach net-zero in the second half of this century and potentially go net negative shortly thereafter.[2] The global community is not currently on track to achieve that goal.[3]

To date, efforts to mitigate climate change have primarily targeted carbon dioxide. Recognizing that carbon dioxide is the most commonly emitted GHG and thus makes the largest contribution to climate change, governments around the world are pushing to decarbonize their energy systems and take other steps to reduce additional releases of carbon dioxide into the atmosphere. Some governments are also exploring so-called "carbon dioxide removal" ("CDR") techniques that are designed to pull carbon dioxide out of the atmosphere and durably store it. According to the IPCC, both rapid carbon dioxide emissions reductions and significantly expanded use of CDR will be necessary to get to net zero, and thus limit future warming. They will not be sufficient by themselves, however. As the IPCC has recognized, action must also be taken to address other, non-carbon dioxide GHGs.

One such GHG is methane. Compared to carbon dioxide, methane is emitted in smaller quantities, and has a shorter atmospheric life, but it has a much higher global warming potential ("GWP"). The GWP of a GHG reflects the amount of energy one ton of the gas absorbs over a given time period relative to the amount of energy absorbed by one ton of carbon dioxide over the same period.[4] Methane has a 20-year GWP of 86 and a 100-year GWP of 34.[5] In effect, then, methane traps 86 times more heat in the Earth's atmosphere than carbon dioxide in the first 20 years after it is released and 34 times more heat than carbon dioxide over 100 years. As a

[1] Press Release, World Meteorological Organization, 2023 Shatters Climate Records, With Major Impacts (Nov. 30, 2023), https://wmo.int/news/media-centre/2023-shatters-climate-records-major-impacts (last visited May 28, 2024).

[2] Intergovernmental Panel on Climate Change, *Summary for Policymakers*, *in* CLIMATE CHANGE 2022: MITIGATION OF CLIMATE CHANGE. CONTRIBUTION OF WORKING GROUP III TO THE SIXTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (Shukla P.R. et al., eds) (Cambridge, UK and New York, USA: Cambridge University Press).

[3] UNITED NATIONS ENVIRONMENT PROGRAMME, EMISSIONS GAP REPORT 2023: BROKEN RECORD – TEMPERATURES HIT NEW HIGHS, YET WORLD FAILS TO CUT EMISSIONS (AGAIN) (2023), https://www.unep.org/resources/emissions-gap-report-2023.

[4] *Greenhouse Gas Emissions: Understanding Global Warming Potentials*, EPA (Mar. 27, 2024), https://www.epa.gov/ghgemissions/understanding-global-warming-potentials (last visited May 28, 2024).

[5] Peter B.R. Nisbet-Jones et al., *Is the Destruction or Removal of Atmospheric Methane a Worthwhile Option?*, 380 PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY 2215 (Jan. 2022), https://royalsocietypublishing.org/doi/10.1098/rsta.2021.0108.

result, according to the International Energy Agency, "[m]ethane is responsible for around 30% of the rise in global temperatures since the industrial revolution, and rapid and sustained reductions in methane emissions are key to limit near-term warming."[6]

Globally, about 60 percent of methane emissions are from anthropogenic sources, and about 40 percent are attributed to natural emissions.[7] The agricultural sector is a major source of anthropogenic emissions, both globally and in the U.S.[8] The raising of livestock, in particular, results in significant methane emissions. Cows, sheep, and other livestock naturally produce methane in their digestive tracts when breaking down food (a process known as "enteric fermentation").[9] Additional methane is also produced during the decomposition of livestock manure.[10] The decomposition of other organic materials (e.g., food waste and sewage) similarly produces methane, making landfills and wastewater treatment plants large sources of emissions.[11] Significant amounts of methane are also emitted during fossil fuel production, as methane is the primary component of natural gas and is frequently released through gas venting, flaring, and leaks during production.[12] There are also several natural sources of methane, including wetlands, permafrost, inland waters, geological processes, the ocean, termites, wild animals, and vegetation.[13]

Reducing methane emissions has proved challenging for a number of reasons.[14] Many emissions sources, particularly in the agricultural sector and natural sources, are highly dispersed and thus technically difficult and costly to control. Partly for this reason, there is growing interest in the possibility of removing methane directly from the atmosphere. Atmospheric methane removal ("AMR") could help to compensate for continued emissions from hard-to-abate sectors, as well as natural releases (e.g., from wetlands and permafrost melt) which are expected to increase in coming years due to climate change.

Scientists have proposed several atmospheric methane removal approaches, but all are in the very early stages of development and require further testing to fully evaluate their efficacy, benefits, and risks. Given the significant uncertainty regarding AMR's feasibility and safety, it should not be used as a reason for delaying near-

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[6] *Global Methane Tracker 2022: Methane and Climate Change*, INTERNATIONAL ENERGY AGENCY (n.d.), https://www.iea.org/reports/global-methane-tracker-2022/methane-and-climate-change (last visited May 28, 2024).

[7] Marielle Saunois et al., *The Global Methane Budget 2000–2017*, 12 EARTH SYSTEM SCIENCE DATA 1592 (2020), https://doi.org/10.5194/essd-12-1561-2020.

[8] *Global Methane Tracker 2022: Overview*, INTERNATIONAL ENERGY AGENCY (n.d.), https://www.iea.org/reports/global-methane-tracker-2022/overview (last visited May 28, 2024); *Overview of Greenhouse Gases*, EPA, https://www.epa.gov/ghgemissions/overview-greenhouse-gases#methane (last visited May 28, 2024).

[9] EPA, *supra* note 8.

[10] *Id*.

[11] *Id*.

[12] *Id*.

[13] Saunois et al., *supra* note 7, at 1594.

[14] *See generally* Romany M. Webb, *Non-CO2 Pollutants*, in GLOBAL CLIMATE CHANGE AND U.S. LAW (Michael B. Gerrard et al., eds, 2023).

term action to control methane emissions. At best, AMR may be a useful complement to emissions reductions, but cannot substitute for them.

The AMR approaches currently being explored are often divided into the following five categories:

- *Atmospheric oxidation enhancement* ("AOE"), which aims to accelerate natural processes whereby methane in the atmosphere reacts with hydroxyl and chlorine radicals and is destroyed. While the approach is still largely theoretical, scientists have proposed releasing iron salt aerosol, photocatalytic aerosol, and/or hydrogen peroxide to increase hydroxyl and chlorine radicals in the atmosphere. Scientists posit that the radicals would react with methane, converting it into carbon dioxide and water.

- *Surface treatments,* which involve the application of a catalytic species that enhance the destruction of methane at or near a surface. This could, in theory, be achieved by covering building walls, roofs, and/or other structures with photocatalytic paints which would react with methane in the air.

- *Ecosystem methane removal enhancement,* which involves an amendment or practice that augments methane removal by or within natural systems. One way to do this is by applying organic materials (e.g., biochar, compost, or sewage) or other soil amendments (e.g., copper or silicate dust) to agricultural lands. It might also be possible to engineer bacteria to more effectively oxidize methane in soils.

- *Atmospheric methane reactors*, which are physically bounded systems open to the flow of air that convert methane to a different chemical species (e.g., carbon dioxide, methanol, or polymeric substance).

- *Methane pre-concentrators*, which are materials or reactors that can separate or enrich methane with some degree of selectivity relative to other atmospheric components (e.g., polymeric substances that can separate methane from a dilute stream).

This paper explores the international and domestic (U.S.) laws governing methane removal via AOE. The legal framework applicable to other AMR techniques will be analyzed in future white papers.

The remainder of this paper is structured as follows: Part 2 introduces AOE, explaining how it would be performed, its climate mitigation and other potential benefits, and the risks it presents. Part 3 then discusses key factors that will influence how AOE projects are governed. As explained in Part 3, the governing laws will depend, in large part, on precisely where and how an AOE project is conducted. Part 3 explains when the United States may assert jurisdiction over AOE projects and introduces the different bodies of U.S. law—arising at the federal, tribal, state, and local levels—that might apply thereto. Part 4 then delves into the implications of international law for the conduct of AOE projects within or outside the United States. Relevant international agreements and rules of customary international law that might affect whether, when, where, and how AOE projects are conducted are discussed. The focus of Part 5 is on applicable U.S. law, especially federal environmental law, though state and local laws are also briefly discussed. Part 6 concludes.

2. Overview of Atmospheric Oxidation Enhancement

AMR encompasses a suite of approaches aimed at accelerating the breakdown of methane in the atmosphere, using either chemical processes to convert methane into carbon dioxide or biological processes to convert methane into biomass.[15] One AMR approach that is currently receiving attention is AOE. As the name suggests, AOE aims to enhance natural oxidation processes, whereby atmospheric methane reacts with hydroxyl and chlorine radicals, producing carbon dioxide and water vapor. Loss through oxidation in the atmosphere is the primary natural sink for methane and drives methane's relatively limited (compared to carbon dioxide) atmospheric lifetime of approximately 9 years.[16] AOE aims to accelerate the natural methane oxidation process, converting methane into carbon dioxide more quickly.

AOE involves introducing or generating airborne particles that increase the concentration of hydroxyl or chlorine radicals in the atmosphere. AOE could also involve the direct introduction of these radicals to the atmosphere. Scientists posit that enhanced concentrations of radicals would increase atmospheric methane oxidation, producing carbon dioxide and water. The carbon dioxide produced through this process could be removed from the atmosphere, for example using direct air capture technologies, and then stored underground or in long-lived products. However, even if the carbon dioxide produced via AOE is not removed and stored, the methane breakdown process would still have climate benefits given methane's high GWP. One recent study estimated that, due to the higher GWP of methane, "oxidizing it to [carbon dioxide could] reduce its 20-year warming impact by 99% or, if considered on a 100-year warming impact timescale, by 97%."[17] However, research into AOE is still at a very early stage; there have been limited modeling and laboratory studies and no in-the-field testing of AOE techniques. As a result, key questions remain about the climate mitigation potential of AOE, as well as the environmental, economic, and social costs and benefits that could result from its testing and deployment.

2.1 Substances Proposed for Use in AOE

Scientists have to date proposed three different AOE approaches: (1) iron salt aerosol, (2) photocatalytic aerosols, and (3) hydrogen peroxide dispersion.[18] Initial research suggests that there are certain scenarios in which dispersing these substances would increase the atmospheric oxidation capacity, enhancing the loss pathway for methane, resulting in conversion into carbon dioxide and other by-products.[19] The use of iron salt aerosol has been studied more extensively than photocatalytic aerosols or hydrogen peroxide. However, even iron salt aerosol studies have been limited to laboratory and modeling research, with no field testing. There

[15] *See* Nisbet-Jones et al., *supra* note 5.

[16] *Id.*

[17] *Id*.

[18] *See Approaches to Atmospheric Methane Removal*, SPARK CLIMATE SOLUTIONS (n.d.), https://www.sparkclimate.org/methane-removal/101/approaches (last visited May 28, 2024).

[19] *Id*.

are, thus, many open research questions about the efficacy and impacts of using any of these potential AOE approaches. Other approaches may also be possible, but at the time of writing are not publicly hypothesized or supported by published literature.

AOE strategies using iron salt aerosol are based on natural methane destruction processes, whereby sea salt spray reacts with iron from mineral dust in the air to create iron chloride compounds.[20] When sunlight interacts with these iron chloride compounds, they produce chlorine radicals, which may oxidize methane—as well as other species—in the atmosphere.[21] Scientists have suggested aerosolizing iron salt particles to increase the abundance of chlorine radicals in the air and thereby enhance the atmospheric oxidation of methane.[22]

AOE could, in theory, also be performed using photocatalytic aerosols such as titanium dioxide and zinc oxide. Dispersion of photocatalytic aerosols could enhance the process whereby molecular oxygen is photolyzed, thus increasing atmospheric oxidation capacity through increased radical production, and may result in increased oxidation of methane—as well as other species—in the atmosphere.[23] This is yet to be tested in either a laboratory setting or in the field; at the time of writing, only one modeling study had been published on this potential approach.[24]

AOE strategies involving hydrogen peroxide dispersal are, like those using photocatalytic aerosols, largely theoretical. No peer-reviewed scientific literature had been published on the subject at the time of writing. Still, some scientists have hypothesized that the dispersal of hydrogen peroxide in the atmosphere will accelerate methane oxidation. According to this hypothesis, hydrogen peroxide will be photolyzed by sunlight to form hydroxyl radicals, which may oxidize methane—as well as other species—in the atmosphere.[25]

2.2 Effectiveness and Impacts of AOE

Given the early stage of AOE research, there are many unanswered questions regarding the efficacy and impacts of AOE. Answering those questions will require expanded modeling and laboratory studies as well as controlled field trials. Some early studies have identified potential co-benefits from AOE, in addition to AMR, and discussed potential associated risks. Potential co-benefits include removal of other GHGs in addition to methane,

[20] Maarten M.J.W. van Herpen et al., *Photocatalytic chlorine atom production on mineral dust–sea spray aerosols over the North Atlantic*, 120 PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES: EARTH, ATMOSPHERIC, AND PLANETARY SCIENCES e2303974120 (July 24, 2023), https://doi.org/10.1073/pnas.2303974120.

[21] Franz Dietrich Oeste et al., *Climate Engineering by Mimicking Natural Dust Climate Control: The Iron Salt Aerosol Method*, 8 EARTH SYSTEM DYNAMICS 1 (Jan. 13, 2017), https://doi.org/10.5194/esd-8-1-2017.

[22] *Id*.

[23] *Id*.

[24] Richard Randall et al., Cost modeling of photocatalytic decomposition of atmospheric methane and nitrous oxide, 19 ENVIRONMENTAL RESEARCH LETTERS 064015 (2024), https://doi.org/10.1088/1748-9326/AD4376.

[25] Yuyin Wang et al., *Atmospheric Removal of Methane by Enhancing the Natural Hydroxyl Radical Sink*, 12 GREENHOUSE GASES: SCIENCE & TECHNOLOGY 784 (2022),https://doi.org/10.1002/ghg.2191.

improved air quality due to reduced airborne pollutants, increased crop yields, and increased cloud and ocean surface albedo. One key potential risk of AOE is that it could have the opposite of its intended effect and cause net positive radiative forcing depending on location and amount. Other potential risks include adverse impacts on human health, disruption of marine ecosystems, and unknown non-linear impacts on atmosphere chemistry.

2.2.1 Potential Climate Impacts of AOE

Due to the limited research into AOE to date, there is considerable uncertainty about its climate mitigation potential. Scientists estimate that global warming would be reduced by approximately 0.21 degrees Celsius for each petagram of methane removed from the atmosphere.[26] However, uncertainties regarding the side effects stemming from reactions associated with AOE, and the reactive nature of chlorine and hydroxyl radicals in the atmosphere, lead to uncertainties around the effectiveness of AOE as a climate mitigation technique.

As discussed above, AOE using iron salt aerosol would involve the stimulation of chlorine radicals in the atmosphere. Chlorine atoms are highly reactive, causing them to easily oxidize methane and other species in the atmosphere with highly non-linear outcomes.[27] Further research is required to understand the mechanism to assess whether iron salt aerosol may be net climate beneficial.

The climate change mitigation potential of photocatalytic aerosols is largely unknown due to a lack of research. Different photocatalysts are currently being explored. One study estimated that 42 percent of methane could be removed from ambient air using a zinc oxide photocatalyst coated onto a solar chimney power plant.[28] (Solar chimney power plants generate electricity by using heat from the sun to raise the temperature of an enclosed volume of air, creating pressure to drive turbines, combined with photocatalytic reactors at the air collection site of the power plant.) Further study is needed to determine whether photocatalytic aerosols have the same effect. Overall, the mitigation potential of this method is unclear and requires further investigation.

The effectiveness of AOE using hydrogen peroxide has also yet to be directly studied. There has, however, been substantial research into the oxidation of methane by hydroxyl radicals which may help estimate the impacts of hydrogen peroxide dispersal. Studies have shown that the rate of oxidation of methane by hydroxyl radicals is highly dependent on temperature and can vary significantly.[29] Due to the difficulty in measuring the reaction rate, it is theorized that approximately 15 percent of hydroxyl radicals react with methane, assuming no

[26] Sam Abernethy et al., *Methane removal and the proportional reductions in surface temperature and ozone*, 379 PHIL. TRANS. R. SOC. A. 20210104 (Sep. 27, 2021), https://doi.org/10.1098/rsta.2021.0104.

[27] James Temple, *These Startups Hope to Spray Iron Particles above the Ocean to Fight Climate Change*, MIT TECHNOLOGY REVIEW (Feb. 15, 2023), https://www.technologyreview.com/2023/02/15/1068495/these-startups-hope-to-spray-iron-particles-above-the-ocean-to-fight-climate-change/.

[28] *Id*. at 6.

[29] *See* Matthew Rigby et al., *Role of Atmospheric Oxidation in Recent Methane Growth*, 114 PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES: ENVIRONMENTAL SCIENCES 5373 (2017), https://doi.org/10.1073/pnas.1616426114.

efficiency losses.[30] Wide scale implementation of AOE using hydrogen peroxide may require a significant ramp up in hydrogen peroxide production. Current production is approximately 5 megatons per year,[31] which could be a limiting factor for AOE with hydrogen peroxide. Overall, further research is needed to more accurately assess the mitigation potential of this method.[32]

2.2.2 Potential Co-benefits of AOE

All AOE approaches could bring non-AMR climate mitigation co-benefits, because they would foster the creation of radicals. In addition to supporting atmospheric methane destruction, the radicals could react with a range of other climate-damaging substances, like sulfur dioxide, converting it into sulfuric acid.[33] However, that could contribute to other environmental problems, such as acid rain.[34]

AOE techniques that use iron salt aerosol could also help mitigate climate change in other ways. For example, iron salt aerosol could increase the albedo of the Earth[35] by increasing long-lived, bright tropospheric clouds, which cool the Earth by reflecting the sun's heat.[36] Additionally, iron salt aerosol could have the secondary effect of contributing to ocean CDR via ocean fertilization because at least some of the iron emitted as aerosol would ultimately be deposited on the ocean's surface, where it could stimulate the growth of phytoplankton that uptake carbon dioxide through photosynthesis.[37] Further research and testing is needed, however, to verify both the cloud brightening and CDR effects of iron salt aerosol dispersal.

All substances proposed for use in AOE also have the potential to reduce local air pollutants. Iron fuel additives could reduce soot and smoke from combustion by causing soot and smoke to be more easily washed out by

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[30] Yuanhong Zhao, *On the Role of Trend and Variability in the Hydroxyl Radical (OH) in the Global Methane Budget*, 20 ATMOSPHERIC CHEMISTRY & PHYSICS 13011, 13014 (2020), https://doi.org/10.5194/acp-20-13011-2020.

[31] *See* COHERENT MARKET INSIGHTS, HYDROGEN PEROXIDE MARKET ANALYSIS (Aug. 2022), https://www.coherentmarketinsights.com/market-insight/hydrogen-peroxide-market-3331.

[32] *See* Yuanhong Zhao, *Influences of Hydroxyl Radicals (OH) on Top-Down Estimates of the Global and Regional Methane Budgets*, 20 ATMOSPHERIC CHEMISTRY & PHYSICS 9525 (2020), https://doi.org/10.5194/acp-20-9525-2020 (discussing uncertainties in methane budget estimation and the factors that influence global and regional methane budgets).

[33] *See* Wang et al., *supra* note 25.

[34] *See generally Acid Rain: What is Acid Rain?* EPA, https://www.epa.gov/acidrain/what-acid-rain (last visited May 28, 2024).

[35] Albedo refers to the amount of energy reflected by a surface. Lighter surfaces have higher albedos because they reflect more energy, whereas darker surfaces have lower albedos. In the context of climate change, higher albedo leads to more energy being reflected back into space, thereby helping to cool the planet.

[36] *Iron Salt Aerosol: Brief Summary*, CLIMATE GAME CHANGERS (n.d.), https://climategamechangers.org/game-changers/climate-restoration/iron-salt-aerosol-brief-summary/ (last visited May 28, 2024).

[37] Tingzhen Ming et al., *A Nature-Based Negative Emissions Technology Able to Remove Atmospheric Methane and Other Greenhouse Gases*, 12 ATMOSPHERIC POLLUTION RESEARCH 101035 (2021), https://doi.org/10.1016/j.apr.2021.02.017.

precipitation, thus reducing pollution.[38] Hydroxyl radicals, created by emitting photocatalytic aerosols and hydrogen peroxide, could reduce concentrations of sulfur dioxide, carbon monoxide, and tropospheric ozone, all of which pose serious health risks. For example, exposure to sulfur dioxide can harm the human respiratory system,[39] exposure to carbon monoxide can exacerbate heart disease,[40] and increased levels of tropospheric ozone can increase the incidence of morbidity and premature mortality.[41] Thus, to the extent AOE helps to mitigate sulfur dioxide, carbon monoxide, and/or tropospheric ozone pollution, it could bring public health benefits. On the other hand, however, AOE also has the potential to increase certain forms of local air pollution (see section 2.2.3 below).

2.2.3 Potential Risks of AOE

AOE's complex, non-linear alterations to atmospheric chemistry could bring as-yet unknown risks. As discussed above, both chlorine and hydroxyl radicals are highly reactive, and could react with various atmospheric molecules other than methane, triggering deeply complex impacts to atmospheric chemistry and potentially leading to unintended consequences. It is not yet understood if—and under what conditions—AOE may lead to a net decrease in atmospheric methane, and under what conditions it may be net climate beneficial. A key potential risk of AOE is that it could increase radiative forcing, which is the opposite of its intended effect.

AOE could also increase certain forms of local pollution and thus cause associated human health harms. Studies have shown that the oxidation of methane by hydroxyl radicals can lead to the formation of formaldehyde, carbon monoxide, and tropospheric ozone when in the presence of sufficiently high levels of nitrogen oxides.[42] Exposure to formaldehyde can cause irritation to the skin, throat, and eyes, and repeated exposure can lead to cancer.[43] Additionally, as explained above, carbon monoxide can increase heart disease[44] and tropospheric ozone can increase mortality.[45] That hydroxyl radicals might both increase and decrease carbon monoxide and

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[38] *See Iron Salt Aerosol: Brief Summary*, *supra* note 36.

[39] *Sulfur Dioxide (SO2) Pollution: Sulfur Dioxide Basics*, EPA (Jan. 31, 2024), https://www.epa.gov/so2-pollution/sulfur-dioxide-basics (last visited May 28, 2024).

[40] *Carbon Monoxide & Health*, CALIFORNIA AIR RESOURCES BOARD (n.d.), https://ww2.arb.ca.gov/resources/carbon-monoxide-and-health (last visited May 28, 2024).

[41] Sabine S. Lange et al., *What are the Net Benefits of Reducing the Ozone Standard to 65 PPB? An Alternative Analysis*, 15 INT. J. ENVIRONMENTAL RESEARCH & PUBLIC HEALTH 1586 (2018), https://doi.org/10.3390/ijerph15081586 (discussing the health impacts of ozone, and arguing that EPA methodologies overestimated the long-term health impacts of ozone at a 65 parts-per-billion standard).

[42] Donald J. Wuebbles & Katharine Hayhoe, *Atmospheric Methane and Global Change*, 57 Earth-Science Reviews 177 (2002) https://doi.org/10.1016/s0012-8252(01)00062-9

[43] *See Formaldehyde*, Centers for Disease Control & Prevention (June 21, 2019), https://www.cdc.gov/niosh/topics/formaldehyde/default.html (last visited May 28, 2024).

[44] *See Carbon Monoxide & Health*, *supra* note 40.

[45] *See* Lange et al., *supra* note 41.

tropospheric ozone levels demonstrates the uncertainty around their atmospheric effects. Further study of the effects of AOE on atmospheric chemistry is needed to better understand these risks.

As previously discussed, AOE techniques that use iron salt aerosol could lead to ocean fertilization and increased phytoplankton production. This could, in turn, cause a variety of ecosystem harms, ranging from ecosystem alterations due to certain forms of phytoplankton outcompeting others to creating potentially harmful algal blooms.[46]

2.3 Potential AOE Deployment Pathways

Scientists have hypothesized methods to release iron salt aerosol and other substances into the atmosphere for the purpose of AOE. Since the field is new, further AOE approaches and deployment methods may be considered in the future. In this paper, we group current proposed methods into releases from stationary sources and mobile sources. This distinction, along with the location of the dispersal, plays a key role in the legal analysis because stationary and mobile sources are governed by significantly different legal regimes.

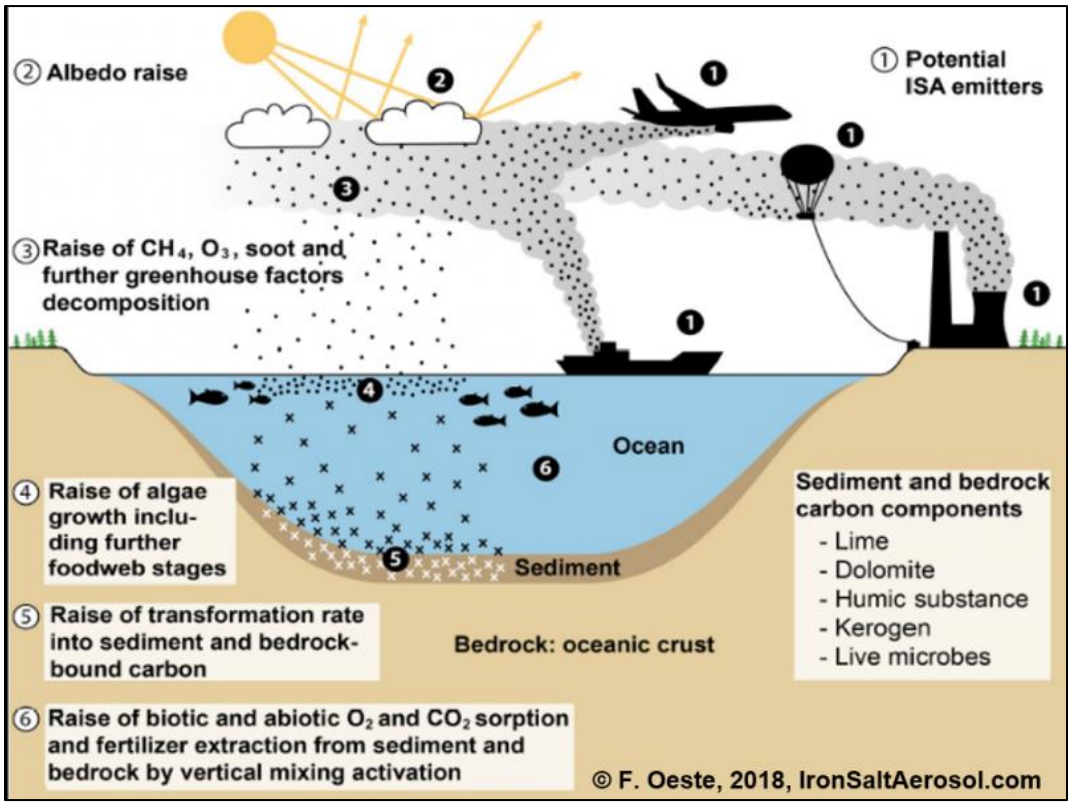

Figure 1: Graphical Representation of Possible AOE Deployment Pathways[47]

[46] Nermin A. El Semary, *Iron-Marine Algal Interactions and Impacts: Decreasing Global Warming by Increasing Algal Biomass*, 14 Sustainability 10372 (2022), https://doi.org/10.3390/su141610372.

[47] *Home*, IRON SALT AEROSOL AUSTRALIA (2019), https://www.ironsaltaerosol.com/.

2.3.1 Stationary Sources

Each of the three substances proposed for use in AOE—iron salts, photocatalysts, and hydrogen peroxide—could be released into the atmosphere from stationary sources. One method of dispersal would be from towers that directly emit aerosols into the atmosphere.[48] The dispersal towers could be located either on land or in the ocean. On land, coastal areas may be preferred sites for AOE towers, particularly those dispersing iron salt aerosol, given the important role that sea spray plays in the methane oxidation process.[49] For the same reason, there might also be interest in installing towers offshore, on platforms that are moored to the seafloor or floating. Locating towers offshore or in sparsely populated onshore areas might also be appealing to minimize the (as-yet understudied) impact of AOE projects on neighboring communities. As an alternative method of dispersal, iron or other additives could be combined with the fuel combusted in power plants or other industrial facilities.[50] Combustion of the fuel would produce iron aerosol, which would be released into the air as part of the facilities' exhaust gas.

2.3.2 Mobile Sources

AOE could also be performed using mobile sources, such as ships, aircraft, and tethered and untethered balloons.[51] Like stationary sources, mobile sources could disperse reactive materials into the air directly (e.g., using an aerial sprayer on an aircraft), or via fuel exhaust. In the latter case, iron or other substances could be added to shipping or aircraft fuels, which would produce exhaust containing iron aerosol or similar reactive materials when combusted.[52] Some scientists have proposed conducting trial runs for AOE mobile deployment and dispersal in areas with little or no population to avoid health risks. In addition, certain geographic areas may have background atmospheric concentrations that are more favorable for AOE.[53] Commonly discussed areas for research include the Southern Ocean[54] and the Southern Caribbean Sea.[55]

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[48] *See* Oeste et al., *supra* note 21, at 31.

[49] *See id*.

[50] *See* Oeste et al., *supra* note 21, at 33.

[51] *See id*. at 31–34.

[52] *Id*. at 31.

[53] Luisa Pennacchio et al., *Catalytic efficiencies for atmospheric methane removal in the high-chlorine regime,* Preprint submitted to Envtl. Res. Letters, https://chemrxiv.org/engage/api-gateway/chemrxiv/assets/orp/resource/item/652666e08bab5d20551aaaa1/original/catalytic-efficiencies-for-atmospheric-methane-removal-in-the-high-chlorine-regime.pdf.

[54] *See generally* Ming et al., *supra* note 37.

[55] Timothy M. Surtz, Peter T. Jenkins, & Renaud de Richter, *Environmental Impact Modeling for a Small-Scale Field Test of Methane Removal by Iron Salt Aerosols*, 14 SUSTAINABILITY 14060 (2022), https://doi.org/10.3390/su142114060.

3. Jurisdiction Over Atmospheric Oxidation Enhancement Projects

The laws governing AOE projects will be determined by where, and how, those projects take place. Generally speaking, under international law, each country has jurisdiction over persons and events occurring within its territory.[56] A country's territory includes its land mass and, in the case of countries bordering the ocean, adjacent waters (see below). In some circumstances, countries may also assert jurisdiction over activities taking place in ocean waters that fall outside their territory (e.g., in the territorial waters of another country or the high seas). This is permitted under the "nationality principle" of international law, which recognizes the right of each country to adopt laws governing the conduct of its nationals while outside the country's territory.[57] Countries often apply different legal frameworks to activities taking place within their land territory versus those occurring in ocean areas. Additionally, some countries, including the United States, have multiple layers of government with distinct geographical jurisdictions. For this reason, the laws governing AOE projects may differ based on the precise location at which an activity takes place, whether on land or in the ocean. This Part discusses the application of different bodies of U.S. law—arising at the federal, tribal, state, and local levels—to AOE projects conducted on land and in the ocean.

3.1 Projects Occurring on Land

In the United States, jurisdiction over land-based activities is divided between federal, tribal, state, and local authorities. At the federal level, legislative power rests with Congress,[58] but it can only act in certain, enumerated areas set out in Article 1, Section 8 of the U.S. Constitution.[59] The Tenth Amendment to the Constitution declares that "[t]he powers not delegated to the United States by the Constitution . . . are reserved to the states."[60] One such reserved power, the general "police power," offers states significant authority over activities that occur within their jurisdiction. The U.S. Supreme Court has held that the police power gives states broad authority to regulate on matters such as "[p]ublic safety, public health, morality, peace and quiet, law and order," but concluded that any "attempt to define [its full] reach or trace its outer limits is fruitless."[61] It is clear, though, that states' general police power is extremely broad. States, in turn, delegate many of their powers and duties to local governments like cities and counties, whose authority may vary significantly across

[56] *See generally*, Hannah L. Buxbaum, *Territory, Territoriality, and the Resolution of Jurisdictional Conflict,* 57 AM. J. COMP. L. 631, 636 (2009).

[57] W.R. Bisschop, *Nationality in International Law*, 37 AM. J. IN'T L. 320 (1943)

[58] U.S. Const. Art. I, § 1.

[59] *Id.* Art. I, § 8.

[60] U.S. Const. amend. X.

[61] *Berman v. Parker*, 348 U.S. 26, 32 (1954).

the country.[62] One important power that is frequently delegated to municipalities is the power to control the use and development of land within their jurisdiction.[63]

Arguably the most important category of law applicable to AOE projects conducted on land in the United States is federal environmental law. Pursuant to its Constitutional authority to regulate interstate commerce,[64] Congress has enacted a number of environmental statutes addressing topics such as air and water pollution, species protection, and waste management. As explained further in Section 5 below, many of those federal laws could have implications for the conduct of AOE projects in the United States. The federal laws will apply regardless of precisely where a project takes place and, in some cases, they may preempt state and local regulation. In this regard, the Constitution provides that "the Laws of the United States . . . shall be the supreme Law of the Land; and the Judges in every State shall be bound thereby, any Thing in the Constitution or Laws of any State to the Contrary notwithstanding."[65] Courts have interpreted this language to create the doctrine of preemption, under which federal law supersedes state law when the two conflict.[66] Many federal environmental laws include provisions, often referred to as "preemption clauses," that expressly prevent state and local regulation. For example, title II of the federal Clean Air Act ("CAA") deals with the regulation of emissions from mobile sources, and includes an express preemption clause stating: "No state or any political subdivision thereof shall adopt or attempt to enforce any standard relating to the control of emissions from new motor vehicles or new motor vehicle engines subject to this part."[67]

Notwithstanding the above, some federal environmental statutes adopt a cooperative federalism approach, which leaves space for state and local regulation. For example, some federal statutes provide for the establishment of minimum standards that apply nationwide, but allow states to adopt additional requirements. One example is the federal Resource Conservation and Recovery Act ("RCRA"), which establishes a national framework for the regulation of solid waste.[68] Under RCRA, the federal Environmental Protection Agency ("EPA") establishes minimum standards for the management of non-hazardous wastes, but those standards are implemented through state and local programs, which may incorporate additional or more stringent

[62] *State and Local Government*, THE WHITE HOUSE (n.d.), https://www.whitehouse.gov/about-the-white-house/our-government/state-local-government (last visited May 28, 2024).

[63] *See* John R. Nolon, *Death of Dillon's Rule: Local Autonomy to Control Land Use*, 36 J. LAND USE & ENVTL. L. 7, 10 (2020).

[64] *Zabel v. Tabb*, 430 F.2d 199, 206 (5th Cir. 1970).

[65] U.S. Const. Art. VI, § 2.

[66] *See generally* CONGRESSIONAL RESEARCH SERVICE, R45825, FEDERAL PREEMPTION: A LEGAL PRIMER 6 (2018), https://sgp.fas.org/crs/misc/R45825.pdf.

[67] 42 U.S.C. § 75432(a).

[68] *Id*. §6901 et. seq.

requirements (i.e., beyond those established by EPA).[69] Thus, projects in different states or localities may be subject to different waste handling, transport, and disposal requirements.

State and local law could also govern other aspects of AOE project development, such as the use of land and construction of facilities. For example, local zoning ordinances might impact where fixed structures can be constructed for AOE projects, and those structures may be subject to set-back and other construction-related requirements imposed by local governments. Additional considerations would apply to the construction of fixed structures on state- or federally-owned land.[70]

AOE project developers will also need to be cognizant of tribal law. Under federal law, Native American tribes are considered "domestic dependent nations"[71] that retain sovereign power over their people, property, and activities that affect them, "except as divested by the United States."[72] Under this authority, tribal law may apply to AOE projects conducted within tribal reservations or on other tribal lands. Tribal law might also have implications for AOE projects conducted in other areas. Federal agencies must consult with tribes, on a government-to-government basis, before undertaking or approving actions that could affect tribal sovereignty, rights, resources, or land.[73] Even AOE projects that are relatively far-removed from tribal lands could affect the exercise of historical tribal rights—for instance, through the ocean fertilization impact on fisheries of iron salt aerosol AOE—and thus trigger the consultation requirements.[74]

3.2 Projects Occurring in the Ocean

Jurisdiction over activities occurring in the ocean depends, primarily, on how far offshore the activities occur. Under international law, coastal countries generally have jurisdiction over ocean areas within 200 nautical miles of their shores, and further offshore in some circumstances. In total, around 40 percent of the ocean falls under national jurisdiction, while the remaining 60 percent comprises so-called "areas beyond national jurisdiction." However, even within those areas, countries may exercise jurisdiction over particular activities. In the case of the United States, jurisdiction is often shared among the federal government, coastal states, and sometimes localities within those states.

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[69] *Resource Conservation and Recovery Act (RCRA) Overview*, EPA (Feb. 21, 2024), https://www.epa.gov/rcra/resource-conservation-and-recovery-act-rcra-overview (last visited May 28, 2024).

[70] This is discussed further in Part 5.2.1 below.

[71] *Cherokee Nation v. Georgia*, 30 U.S. 1 (1831).

[72] U.S. Dep't of Justice, Memorandum on Indian Sovereignty (June 1, 1995), https://www.justice.gov/archives/ag/attorney-general-june-1-1995-memorandum-indian-sovereignty

[73] *Id. See also* Executive Order 13175 (Nov. 6, 2000) ("Each agency shall have an accountable process to ensure meaningful and timely input by tribal officials in the development of regulatory policies that have tribal implications.")

[74] For example, some Native American tribes have entered into treaties with the U.S. government which secure the rights of the tribe to fish in historical fishing waters. *See e.g.*, Treaty with the Dwamish, Suquamish, etc., (commonly known as the Treaty of Point Elliott), Art. 5, January 22, 1855, 12 Stat. 927.

3.2.1 International Legal Framework Governing Offshore Jurisdiction

The relevant international law governing offshore jurisdiction is set out in the 1982 United Nations Convention on the Law of the Sea[75] ("UNCLOS"). Often described as the "constitution for the ocean," UNCLOS provides the foundation for international regulation of ocean-based activities.[76] UNCLOS has wide acceptance within the international community, having been ratified or otherwise adopted by 167 countries and the European Union.[77] An additional 14 countries have signed, but not ratified or adopted, UNCLOS.[78] Strictly speaking, those 14 countries are not bound by UNCLOS, but they do have an obligation under international law to refrain from acts that would defeat the object and purpose of the Convention.[79] The United States has neither signed nor ratified UNCLOS but it recognizes many of its provisions, including those defining countries' jurisdiction over the ocean, as forming part of customary international law and thus has pledged to "act in accordance with" them.[80]

Under UNCLOS, ocean areas are categorized based on how far they are from a coastal countries' baseline, which is normally defined as "the low water line along the coast."[81] Ocean areas within 12 nautical miles of a country's baseline comprise the country's territorial sea and form part of its sovereign territory.[82] That is, within its territorial sea, the country has full sovereign rights over the water, the underlying submerged land, and the airspace above. In exercising those rights, the country must act in accordance with international law, and must not infringe upon the rights conferred on other countries by international law (e.g., the right of innocent passage). Subject to this limited restriction, countries may regulate activities occurring within their territorial sea, just as they regulate activities occurring on land.

Ocean waters extending beyond a coastal country's territorial sea, 12 to 200 nautical miles from its baseline, comprise the country's exclusive economic zone ("EEZ").[83] The underlying submerged land forms part of the

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[75] United Nations Convention on the Law of the Sea, 1833 UNTS 3 (adopted Dec. 10, 1982; entered into force Nov. 16, 1994) [*hereinafter* "UNCLOS"].

[76] Wil Burns, *Governance of Ocean-Based Carbon Dioxide Removal Research Under the United Nations Convention on the Law of the Sea*, 75 ME. L. REV. 37 (2023).

[77] *See Status of Treaties: United Nations Convention on the Law of the Sea*, UNITED NATIONS TREATY COLLECTION (last visited May 28, 2024), https://treaties.un.org/pages/ViewDetailsIII.aspx?src=TREATY&mtdsg_no=XXI-6&chapter=21&Temp=mtdsg3&clang=_en.

[78] *Id.*

[79] *See Glossary of terms relating to Treaty actions*, UNITED NATIONS TREATY COLLECTION (n.d.), https://treaties.un.org/pages/Overview.aspx?path=overview/glossary/page1_en.xml (last visited May 28, 2024).

[80] President Ronald Reagan, Statement on United States Oceans Policy (Mar. 10, 1983) (on file with the National Archives, available at https://www.reaganlibrary.gov/archives/speech/statement-united-states-oceans-policy).

[81] UNCLOS, *supra* note 75, Art. 5. In some circumstances, however, an alternative baseline may be used. For example, where a country's coastline is indented with bays or fringed by islands, the country may elect to use "straight baselines" that are drawn by "joining appropriate points" along the coast with a straight line. *See id*. Art. 7.

[82] *Id.*, Art. 2.

[83] *Id.*, Art. 55.

country's "continental shelf."[84] Unlike the territorial sea, the EEZ and continental shelf do not form part of the sovereign territory of coastal countries, but the country has certain sovereign rights in those areas. Specifically, the coastal country has "sovereign rights for the purpose of exploring and exploiting, conserving and managing the natural resources . . . and with regard to other activities for the economic exploitation and exploration" of its EEZ.[85] The coastal country also has jurisdiction over "the establishment and use of artificial islands, installation and structures," "marine scientific research," and "the protection and preservation of the marine environment" within its EEZ.[86] This provides ample scope for coastal countries to regulate AOE projects occurring within their EEZs. Such regulation would be permissible where, for example, projects involve the construction of structures in the ocean or are conducted for the purposes of research. Even if those requirements are not met, coastal countries that are interested in regulating offshore AOE activity could justify such regulation by arguing that it helps to protect and preserve the marine environment.

More difficult issues will arise when AOE projects are conducted outside the territorial sea or EEZ of any country. Under UNCLOS, ocean waters lying more than 200 nautical miles from any country are known as the "high seas," and are open to use by all.[87] UNCLOS provides for "freedom of the high seas," which includes, "for both coastal and land-locked states: (a) freedom of navigation; (b) freedom of overflight; (c) freedom to lay submarine cables and pipelines . . . ; (d) freedom to construct artificial islands and other installations . . . (e) freedom of fishing . . . ; [and] (f) freedom of scientific research."[88] As such, no country has sovereign rights with respect to the high seas, but individual countries may exercise jurisdiction over activities occurring on the high seas in some circumstances. For example, according to UNCLOS, ships must "sail under the flag of one [country] only and . . . shall be subject to its exclusive jurisdiction on the high seas."[89] Thus, if an AOE project were performed on the high seas using a vessel registered or "flagged" in the U.S., that project would be subject to U.S. jurisdiction. Additionally, if a foreign vessel were used but U.S. nationals were involved, that could also trigger regulation under U.S. law. Various U.S. laws, including many environmental laws that might be relevant to AOE projects, apply to nationals operating on the high seas. The Endangered Species Act ("ESA"), for example, prohibits "any person subject to United States jurisdiction" from killing, injuring, or otherwise "taking" any listed endangered or threatened species on the high seas. Similarly, the Marine Mammal Protection Act prohibits the taking of

[84] The continental shelf comprises the "seabed and subsoil of the submarine areas that extend beyond [the country's] territorial sea throughout the natural prolongation of its land territory to the outer edge of the continental margin or" the outer edge of the EEZ (whichever is further). If the natural prolongation of the country's land territory extends beyond 200 nautical miles from the baseline, its continental shelf will end 60 nautical miles from the foot of the continental shelf, or at the point where sediment thickness is one percent of the distance thereto. However, the breadth of the continental shelf cannot exceed 350 nautical miles from the baseline, or 100 nautical miles from the 2500 meter isobath. *See id*. Art. 76.

[85] *Id.*, Art. 56(1)(a). Similarly, the coastal country "exercises over its continental shelf sovereign rights for the purpose of exploring it and exploiting its natural resources." *Id.*, Art. 77(1).

[86] *Id*., Art. 56(1)(b).

[87] *Id*., Art. 86.

[88] *Id.*, Art. 87(1).

[89] *Id.*, Art. 92(1).

"any marine mammal on the high seas" by "any person subject to the jurisdiction of the United States." The broad definition of "taking" under the statutes means that even activities that may injure protected animals may trigger the statutes' provisions. This could occur through, for example, ecosystem harms from ocean fertilization or local air pollution side effects of certain AOE techniques.

3.2.2 U.S. Jurisdictional Areas

Consistent with international law, the U.S. has claimed jurisdiction over ocean waters within 200 nautical miles of its baseline, as well as the underlying submerged land. Jurisdiction is shared among the federal government, coastal states, and in some areas, localities within those states.

The Submerged Lands Act of 1953 declares that the boundaries of each coastal state extend three nautical miles from its coastline, except in the Gulf of Mexico, where the boundaries of Texas and Florida extend nine nautical miles from the coastline.[90] For the purposes of the Submerged Lands Act, a state's "coastline" is defined as "the line of ordinary low water along that portion of the coast which is in direct contact with the open sea and the line marking the seaward limit of inland waters."[91]

Offshore areas within state boundaries fall under the primary jurisdiction of the relevant coastal state. (Offshore areas within state boundaries are referred to as "state waters" in this paper.) With limited exceptions, coastal states have title to, and ownership of, lands beneath their state waters and the right to take natural resources (including minerals, marine animals, and plant life) within those lands and waters.[92] The federal government has relinquished all of its property rights to, and interests in, land and resources within state waters.[93] However, the federal government retains authority to regulate in state waters "for the constitutional purposes of commerce, navigation, national defense, and international affairs."[94] Thus, for example, many federal environmental laws apply to activities conducted in state waters. Local law may also apply in some areas. For instance, in parts of New York local governments hold title to, and thus regulate, the submerged lands underlying state waters.[95] In

[90] 43 U.S.C. § 1312 (providing that "[t]he seaward boundary of each original coastal State is approved and confirmed as a line three geographic miles distant from its coast line"). *See also id*. § 1301(b) (defining the term "boundaries" and providing that "in no event shall the term boundaries . . . be interpreted as extending from the coast line more than three geographical miles in the Atlantic Ocean or the Pacific Ocean, or more than three marine leagues into the Gulf of Mexico"). A "marine league" is equivalent to three nautical miles. Thus, in the Gulf of Mexico, the boundaries of Texas and Florida extend nine nautical miles. from the coastline. *See generally U.S. v. Louisiana*, 100 S.Ct. 1618 (1980), 420 U.S. 529 (1975), 394 U.S. 11 (1969), 389 U.S. 155 (1967), 363 U.S. 1 (1960), 339 U.S. 699 (1950) (addressing a series of disputes between the United States and the State of Louisiana around jurisdictional boundaries).

[91] 43 U.S.C. § 1301(c).

[92] *Id*. § 1311(a)(1).

[93] *Id*. § 1311(b).

[94] *Id*. § 1314.

[95] In some areas, local governments own the submerged lands underlying state waters pursuant to colonial patents. *See e.g.*, Town of Oyster Bay v. Commander Oil Corp., 96 N.Y.2d 566, 572 (N.Y., 2001) (holding that the Town of Oyster Bay "owns the underwater land beneath Oyster Bay by virtue of a colonial patent"). The New York state government has also ceded title to some submerged

practice, this means that AOE projects conducted in state waters may be subject to multiple layers of domestic law at the federal, state, and sometimes local levels.

AOE projects conducted in so-called "federal waters"–waters lying beyond state boundaries, up to 200 nautical miles from shore–will be subject only to federal law. This is because federal waters fall under the exclusive jurisdiction of the federal government. The federal government also has exclusive jurisdiction over the submerged lands lying beyond state boundaries, to the outer limit of U.S. jurisdiction as defined under UNCLOS (see above). That area is known as the U.S. outer continental shelf ("OCS").[96]

4. International Legal Framework for Atmospheric Oxidation Enhancement Projects

International law may influence whether, when, where, and how AOE projects take place. In assessing the implications of international law for AOE, one must consider not only relevant international agreements and treaties, but also customary international law. The latter comprises a set of rules and principles derived from general state practice that are accepted as law and are, generally speaking, binding on all countries (except where a country has "persistently objected" to a particular rule or principle).[97] In contrast, international agreements and treaties are only binding on those countries that have specifically consented to them. A country may signal its consent by signing and ratifying or otherwise formally adopting the agreement or treaty, at which point it becomes a party thereto. Some of the international agreements relevant to AOE have only a small number of parties which may limit their effectiveness as governance tools.

It is also important to note that international law does not directly govern private actors, and does not generally impose obligations on individuals, corporations, or other non-state actors. However, to comply with their international obligations, countries may adopt domestic laws that govern the conduct of those private actors. Countries vary in terms of how they incorporate international law into their domestic legal frameworks. In the U.S., some international agreements are treated as "self-executing" and automatically become part of domestic

lands to local governments through legislative enactments. *See e.g.,* N.Y. Envtl. Conservation Law § 13-0302 (stating that "all the right, title and interest in which the people of the state of New York have in and to the lands under water of Gardiner's and Peconic bays in the county of Suffolk, except underwater lands within one thousand feet of the high water market is hereby ceded to such county, for the purposes of shellfish cultivation").

[96] *See* 43 U.S.C. § 1331(a) (defining the term "outer continental shelf").

[97] *See generally*, JAMES A. GREEN, THE PERSISTENT OBJECTOR RULE IN INTERNATIONAL LAW (2016), https://doi.org/10.1093/law/9780198704218.001.0001.

law when ratified, even if no formal action is taken to implement them.[98] Other agreements that are not deemed self-executing must be implemented by domestic legislation.[99]

There are no international agreements or rules of customary international law that specifically address AOE. However, even where AOE is not expressly addressed, international agreements and customary rules might still apply because AOE projects involve activities or have impacts that the agreements and rules were designed to control. For example, a number of international instruments address so-called "geoengineering activities," which might apply to AOE.[100] Similarly, several international instruments are designed to prevent or limit transboundary environmental harms, such as cross-border air pollution[101] and damage to marine ecosystems,[102] which AOE could cause. This Part provides an overview of those and other key international instruments that could shape, or bar, AOE projects.

4.1 Relevant International Agreements

4.1.1 International Agreements Addressing Geoengineering or Similar Activities

This Section focuses on international instruments that have been adopted to regulate geoengineering activities. At the outset, it is important to note that there is no universally accepted definition of "geoengineering," but the term is generally used in international discussions to refer to activities involving deliberate, large-scale intervention in the Earth's natural systems or processes, including activities designed to counteract climate change. Since AOE aims to accelerate the natural methane oxidation process–the process by which methane in the atmosphere is converted into carbon dioxide–it might be viewed as a form of geoengineering under international legal instruments.[103]

(A) Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques

One early agreement addressing geoengineering is the Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques[104] ("ENMOD Convention"), which was adopted in

[98] CONGRESSIONAL RESEARCH SERVICE, INTERNATIONAL LAW AND AGREEMENTS: THEIR EFFECT UPON U.S. LAW (2023), https://crsreports.congress.gov/product/pdf/RL/RL32528.

[99] *Id.*

[100] *See infra* Part 4.1.1.

[101] *See infra* Part 4.1.3.

[102] *See infra* Part 4.1.2.

[103] We note that some scientists and others may object to the use of the term "geoengineering" to describe AMR. However, "geoengineering" is a legal term of art widely used in the international community to refer to CDR and is likely to be similarly applied to AMR, at least in some contexts.

[104] Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques, 1108 U>n>T.S. 151 (adopted Dec. 10, 1976; entered into force Oct. 5, 1978) [hereinafter "ENMOD Convention"].

December 1976 and entered into force in October 1978.[105] At the time of writing, the ENMOD Convention had 78 parties,[106] each of which had agreed "not to engage in military or any other hostile use of environmental modification techniques having widespread, long-lasting or severe effects."[107] For the purposes of the ENMOD Convention, an "environmental modification technique" is one that is intended to change, "through the deliberate manipulation of natural processes, the dynamics, composition or structure of the Earth."[108] This would encompass activities like AOE, which involves the manipulation of the natural methane oxidation process and thereby changes the composition of the Earth's atmosphere. Notably, however, the ENMOD Convention would only prohibit the use of AOE for "military" or other "hostile" purposes. It would not apply to AOE projects undertaken solely to mitigate climate change or for other peaceful purposes.

(B) Convention on Biological Diversity

Since the adoption of the ENMOD Convention, there have been attempts to regulate geoengineering activities conducted for peaceful purposes, including to mitigate climate change. For example, in recent years the parties to the Convention on Biological Diversity[109] ("CBD") have addressed geoengineering in a series of decisions dealing with "climate change and biodiversity." While the decisions are not legally binding, they carry significant weight, in part because the CBD has been ratified or otherwise adopted by 195 countries and the European Union.[110] Given this broad membership, one scholar has argued that decisions adopted by the parties to the CBD "represent the political will of almost all States worldwide."[111] One notable exception is the U.S., which is not a party to the CBD.

The CBD was first adopted in June 1992 and entered into force in December 1993.[112] The overarching aim of the CBD is to promote "the conservation of biological diversity [and] the sustainable use of its components."[113] To this end, each party to the CBD must "[d]evelop national strategies, plans or programs for the conservation and

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[105] United Nations, *Status of Treaties: Convention on the Prohibition of Military of any Other Hostile Use of Environmental Modification Techniques,* https://treaties.un.org/Pages/ViewDetails.aspx?src=IND&mtdsg_no=XXVI-1&chapter=26&clang=_en (last visited May 28, 2024).

[106] *Id*.

[107] ENMOD Convention, *supra* note 104, Art. I.

[108] *Id.*, Art. II.

[109] Convention on Biological Diversity, 1760 UNTS 79 (adopted June 5, 1992; entered into force Dec. 29, 1993) [*hereinafter* "CBD"].

[110] *Status of Treaties: Convention on Biological Diversity*, UNITED NATIONS TREATY COLLECTION (n.d.), https://treaties.un.org/pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-8&chapter=27 (last visited May 28, 2024).

[111] Harald Ginzky, *Marine Geo-Engineering*, *in* HANDBOOK ON MARINE ENVIRONMENTAL PROTECTION: SCIENCE, IMPACTS, AND SUSTAINABLE MANAGEMENT (Markus Salomon & Till Markus, eds., 2018).

[112] *Status of Treaties: Convention on Biological Diversity supra* note 110.

[113] CBD, *supra* note 109, Art. 1.

sustainable use of biological diversity."[114] The CBD directs parties to designate, and take special measures to protect, areas as necessary "to conserve biological diversity."[115] Activities conducted within or outside those areas that "have or are likely to have significant adverse impacts on the conservation or sustainable use of biological diversity" must be undertaken in a way that mitigates and manages those impacts.[116] The CBD directs parties to, "as far as possible and as appropriate," adopt "procedures requiring environmental impact assessment of . . . proposed projects that are likely to have significant adverse effects on biological diversity with a view to avoiding or minimizing such effects and, where appropriate, allow for public participation in such processes."[117] If a project presents "imminent or grave danger or damage . . . to biological diversity under the jurisdiction of other [countries] or in areas beyond the limits of national jurisdiction," the party conducting or overseeing the project must "notify immediately the potentially affected" country, "initiate action to prevent or minimize such danger or damage," and have in place "national arrangements for emergency responses."[118] Parties to the CBD would need to be mindful of these requirements when conducting or authorizing AOE projects which, as explained in Part 2 above, could raise various biodiversity-related risks.

The CBD does not expressly mention climate change. The parties to the CBD have, however, recognized that both climate change itself and efforts to address it might affect biodiversity and thus implicate the Convention. A decision adopted at the conference of the parties ("COP") to the CBD in 2008 "[u]rges Parties to enhance the integration of climate-change considerations related to biodiversity in their implementation of the Convention" by, among other things, fully assessing the "impacts of climate change mitigation and adaptation activities on biodiversity" and taking steps to address any adverse impacts caused by such activities.[119] The decision also included more specific guidance on the use of ocean fertilization to address climate change. The decision noted "the current absence of reliable data covering all relevant aspects of ocean fertilization" and concluded that, without such data, it was impossible to fully assess its potential risks.[120] Given this, the decision "*requests* Parties and *urges* other Governments . . . to ensure that ocean fertilization activities do not take place until there is an adequate scientific basis on which to justify such activities, including assessing associated risks, and a global, transparent and effective control and regulatory mechanism is in place for these activities."[121] The decision did provide an exception for "small scale scientific research studies within coastal waters," which it said may "be authorized if justified by the need to gather specific scientific data," after conducting "a thorough . . . assessment

[114] *Id*., Art. 6(a).

[115] *Id*., Art. 8.

[116] *Id*., Art. 7(c) & 8(l).

[117] *Id*., Art. 14(a).

[118] *Id*., Arts. 14(d)-(e).

[119] Report of the Conference of the Parties to the Convention on Biological Diversity on the Work of its Ninth Meeting, Decision IX/16, Art. A(4) (2008), https://www.cbd.int/decision/cop?id=11659.

[120] *Id.* Art. C(3).

[121] *Id*. Art. C(4) (emphasis original).

of the potential impacts . . . on the marine environment."[122] According to the decision, ocean fertilization research projects should "be strictly controlled, and not be used for generating and selling carbon offsets or any other commercial purposes."[123]

There is some uncertainty as to whether the 2008 decision, which was focused on ocean fertilization, might also be applied to AOE activities. The 2008 decision did not include a definition of ocean fertilization. Notably, however, the parties referred to a statement that had been issued the previous year by the scientific group under the Convention on the Prevention of Marine Pollution by Dumping of Waste and Other Matter[124] ("London Convention") and the Protocol to that Convention[125] ("London Protocol"). That statement used the term "ocean fertilization" to refer to "fertilization of ocean waters using micro-nutrients such as iron to stimulate phytoplankton growth in order to sequester carbon dioxide."[126] The focus, at the time, was on direct discharge of iron into the ocean from vessels. While there was no discussion of activities that involve aerosolizing iron, as would occur in some AOE projects, they would have similar impacts on phytoplankton growth. Some might argue that the goal of AOE is to destroy methane, not to sequester carbon dioxide, but others could counter that the end result is the same, and thus 2008 decisions should apply to AOE activities, at least where they are conducted in ocean areas.

Regardless of how one views the 2008 decision, there is little doubt that AOE activities would fall within the scope of subsequent CBD decisions on "geoengineering," at least where those activities are conducted at a large-scale. In a 2010 decision, the COP to the CBD offered "guidance . . . on ways to conserve, sustainable use and restore biodiversity and ecosystem services while contributing to climate change mitigation and adaptation."[127] Among other things, the 2010 decision recommended that parties and other governments ensure "that no climate-related geo-engineering activities that may affect biodiversity take place, until there is an adequate scientific basis on which to justify such activities and appropriate consideration of the associated risks for the environment and biodiversity and associated social, economic and cultural impacts."[128] Again, the decision included an exception for "small scale scientific research studies," but indicated that such studies

[122] *Id*.

[123] *Id*.

[124] Convention on the Prevention of Marine Pollution by Dumping of Waste and Other Matter, 1046 UNTS 15749 (adopted Nov. 13, 1972; entered into force Aug. 30, 1975) [*hereinafter* "London Convention"].

[125] 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972 (adopted Nov. 17, 1996; entered into force Mar. 24, 2006) [*hereinafter* "London Protocol"].

[126] Statement of Concern Regarding Iron Fertilization of the Oceans to Sequester CO_2, LC-LP.1/Circ.14 (July 13, 2007).

[127] Report of the Conference of the Parties to the Convention on Biological Diversity on the Work of its Tenth Meeting, Decision X/33, Art. 8 (2010), https://www.cbd.int/decision/cop/default.shtml?id=12299#cop-10-dec-33-fn76

[128] *Id*. Art. 8(w).

should be "conducted in a controlled setting[,] . . . justified by the need to gather specific scientific data[, and] subject to a thorough prior assessment of the potential impacts on the environment."[129]

The 2010 decision defined geoengineering to mean "any technologies that deliberately reduce solar insolation or increase carbon sequestration on a large scale that may affect biodiversity."[130] However, the COP to the CBD subsequently agreed that the definition should be broadened to include any "[d]eliberate intervention in the planetary environment of a nature and scale intended to counteract anthropogenic climate change and its impacts."[131] That broader definition would encompass AOE projects undertaken to mitigate climate change and thus, under the terms of the 2010 decision, countries should prevent those projects taking place if they "may affect biodiversity." While the 2010 decision does allow research projects, they must be conducted in a controlled setting, which could be a significant restriction. Some scholars have argued that "only research conducted in a laboratory or mesocosm (i.e., an enclosed outdoor experimentation system that enables an examination of the natural environment under controlled conditions) occurs in a controlled setting."[132] Under this view, the 2010 decision would prevent outdoor experimentation in the open environment.

The 2010 decision was reaffirmed by the COP to the CBD in 2012[133] and 2016.[134] None of the decisions are legally binding but they are, as indicated above, highly influential. It is notable that the decisions call for geoengineering activities to be restricted by parties and non-parties alike, and include only a very narrow exception for research conducted in a controlled setting. As such, the decisions could have a chilling effect on both AOE field research and subsequent deployment (if any).

Additional rules have been adopted for geoengineering activities conducted in the ocean by parties to the Convention on the Prevention of Marine Pollution by Dumping of Waste and Other Matter ("London Convention") and the Protocol to that Convention. Those rules are discussed in Section 4.1.2 below on agreements governing ocean-based activities.

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[129] *Id*.

[130] *Id.* at Note 76.

[131] Report of the Conference of the Parties to the Convention on Biological Diversity on the Work of its Eleventh Meeting, Decision XI/20, Art. 5(b) (2012), https://www.cbd.int/decision/cop/default.shtml?id=13181.

[132] Romany M. Webb et al., *International Laws Governing Ocean CDR*, *in* OCEAN CARBON DIOXIDE REMOVAL FOR CLIMATE MITIGATION: THE LEGAL FRAMEWORK 47, 56 (Romany M. Webb et al., eds, 2023). The 2010 framework has not, to date, been applied to regulate any individual ocean fertilization project.

[133] Report of the Conference of the Parties to the Convention on Biological Diversity on the Work of its Eleventh Meeting, Decision XI/20, Art. 1 (2012), https://www.cbd.int/decision/cop/default.shtml?id=13181.

[134] Report of the Conference of the Parties to the Convention on Biological Diversity on the Work of its Thirteen Meeting, Decision XIIII/4, preamble (2016), https://www.cbd.int/doc/decisions/cop-13/cop-13-dec-04-en.pdf.

4.1.2 International Agreements Governing Activities Taking Place In, or Affecting, the Ocean (Including Marine Geoengineering Activities)

Due to the shared nature of the ocean, there is a large body of international law governing ocean-based activities, including some instruments dealing specifically with geoengineering activities in the ocean. This Section discusses three of key ocean agreements that could have implications for AOE projects: (1) UNCLOS, (2) the London Convention, and (3) the London Protocol.

(A) United Nations Convention on the Law of the Sea

The foundation for the global ocean governance regime is UNCLOS, which was adopted in December 1982 and entered into force in November 1994. Three later agreements add detail to UNCLOS' often general, and sometimes vague, provisions. These are: (1) the 1994 agreement on the implementation of the seabed mining provisions in Part XI of UNCLOS (commonly known as the "Seabed Mining Agreement"),[135] (2) the 1995 agreement on the implementation of the provisions of UNCLOS relating to the conservation and management of straddling fish stocks and highly migratory fish stocks (commonly known as the "Straddling Fish Stocks Agreement"),[136] and (3) the agreement under UNCLOS on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction (commonly known as the "BBNJ Agreement").[137]

Various provisions of UNCLOS could have implications for the conduct of AOE projects in, or affecting, the ocean. Part XIII of UNCLOS, dealing with "marine scientific research" ("MSR"), will be particularly relevant to AOE research projects. Part XIII is generally supportive of research, requiring countries and international organizations to "promote and facilitate" MSR.[138] It does, however, impose certain restrictions on when, where, and how MSR is conducted. As a general matter, MSR must be "conducted exclusively for peaceful purposes," and must "not unjustifiably interfere with other legitimate uses of the" ocean.[139] Each coastal country is responsible for overseeing MSR within its territorial waters (*i.e.*, in its territorial sea and EEZ) and may conduct

[135] Agreement Relating to the Implementation of Part XI of the United Nations Convention on the Law of the Sea of 10 December 1982, 1836 UNTS 3 (adopted July 28, 1994; entered into force Nov. 16, 1994).

[136] Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 Relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks, 2167 UNTS 3 (adopted Aug. 4, 1995; entered into force Dec. 11, 2001).

[137] Agreement Under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction (adopted June 19, 2023, not in force) [hereinafter "BBNJ Agreement"]. The BBNJ Agreement had not entered into force at the time of writing. However, if / when the Agreement does enter into force, it could have implications for the conduct of AOE projects conducted on, or affecting, the high seas or the underlying seabed. For example, the BBNJ Agreement includes detailed requirements with respect to environmental impact assessment, which could apply to some AOE projects. This is discussed further in Part 4.2 below.

[138] UNCLOS, *supra* note 75, Art. 239.

[139] *Id.*, Art. 240.

research projects itself or authorize others to do so in those waters.[140] All countries, both coastal and landlocked, also have the right to conduct MSR on the high seas.[141]

UNCLOS mandates that coastal countries "shall, in normal circumstances, grant their consent for [MSR] projects by other [countries] or competent international organizations in their [EEZ] . . . in order to increase scientific knowledge of the marine environment for the benefit of all mankind."[142] However, a coastal country may withhold consent for an MSR project that "is of direct significance for the exploration and exploitation of natural resources," involves "the introduction of harmful substances into the marine environment," or "involves the construction, operation or use of artificial islands, installations and structures."[143] This provides ample scope for coastal countries to refuse to allow AOE research projects within their territorial waters. Countries could justify their refusal on the basis that a project involves the introduction of harmful substances into the marine environment (as some portion of the aerosol released in AOE will end up landing on the surface of the ocean where they could harm fish or other species). In addition, where AOE research is performed using offshore platforms or other structures, that could provide another basis for the country to refuse to allow it.

If a country chooses to allow AOE research within its territory, it has the right to participate in that research. UNCLOS requires a country or international organization undertaking MSR in the EEZ of a coastal country to provide the host country with an opportunity "to be represented . . . on board research vessels and other craft or scientific research installations."[144] The host country must also be provided with copies of preliminary and final research reports and given access to data, samples, and research results.[145] The host country may "require the suspension of any [MSR] activities in progress" within its EEZ if these requirements are not met.[146]

As well as imposing specific requirements for MSR, UNCLOS also incorporates more general rules with respect to the protection and preservation of the marine environment, which could have implications for AOE projects (both research and non-research). Part XII of UNCLOS imposes a general obligation on parties "to protect and preserve the marine environment."[147] Parties must, among other things, take "all measures . . . necessary to prevent, reduce and control pollution of the marine environment from any source."[148] Pollution is defined broadly in UNCLOS to mean:

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[140] *Id.*, Arts. 245-246.

[141] *Id.*, Art. 257.

[142] *Id.*, Art 246(3).

[143] *Id.*, Art. 246(5).

[144] *Id.*, Art. 249(1)(a).

[145] *Id.*, Arts. 249(1)(b)-(d).

[146] *Id.*, Art. 253(1).

[147] *Id.*, Art. 192.

[148] *Id.*, Art. 194(1).

> [T]he introduction by man, directly or indirectly, of substances or energy into the marine environment . . . which results or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of qualify for use of sea water and reduction of amenities.[149]

As the International Tribunal for the Law of the Sea ("ITLOS") has noted, this "definition does not provide a list of pollutants or forms of pollution of the marine environment. Instead, it sets out three criteria to determine what constitutes such pollution: (1) there must be a substance or energy; (2) this substance or energy must be introduced by humans, directly or indirectly, into the marine environment; and (3) such introduction must result or be likely to result in deleterious effects."[150] Applying these three criteria, ITLOS has found that anthropogenic GHG emissions into the atmosphere constitute marine pollution within the terms of UNCLOS.[151] It follows, then, that parties to UNCLOS must "take all necessary measures with a view to reducing and controlling existing marine pollution from [GHG] emissions and eventually preventing such pollution from occurring at all."[152] ITLOS has emphasized the need for both joint and individual action by countries to limit GHG emissions.[153] The precise actions to be taken by any country will depend, in part, on its "scientific, technical, economic and financial capabilities."[154] Generally speaking, however, each country has a "due diligence" obligation to adopt an appropriate national system for controlling emissions and effectively implement and enforce that system.

Following ITLOS' reasoning, AOE activities could, at least in some circumstances, qualify as sources of marine pollution under UNCLOS. For example, where AOE is performed by releasing iron into the air from vessels, some portion of the iron released would ultimately end up landing on the surface of the water, where it would affect phytoplankton growth, potentially leading to harmful algae blooms, nutrient robbing, or other adverse effects. In this scenario, the three criteria for marine pollution identified by ITLOS would seem to be satisfied: (1) there would be a substance (i.e., iron), (2) that substance would have been indirectly introduced into the ocean by humans (i.e., via the release from vessels), and (3) that introduction would have deleterious effects (i.e., leading to potentially harmful changes in ocean ecosystems).

Assuming AOE is viewed as a source of marine pollution under UNCLOS, parties would have an obligation to take "all measures . . . necessary to prevent, reduce and control" such pollution. UNCLOS specifically requires parties to, among other things, adopt measures "designed to minimize, to the fullest extent possible[,] the

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[149] *Id.*, Art. 1(1)(4).

[150] Request for an Advisory Opinion Submitted by the Commission of Small Island States on Climate Change and International Law, Advisory Opinion ¶ 161, International Tribunal for the Law of the Sea (May 21, 2024) [hereinafter "ITLOS Advisory Opinion on Climate Change"].

[151] *Id*. ¶ 179.

[152] *Id*. ¶ 199.

[153] *Id*. ¶ 201-202.

[154] *Id*. ¶ 225.

release of toxic, harmful or noxious substances . . . from land-based sources, from or through the atmosphere or by dumping" from vessels or other structures in the ocean.[155] Thus, in order to meet their obligations under UNCLOS, parties may need to impose controls on AOE activities occurring both on land and offshore. Such controls would be particularly important where an AOE project could result in transboundary environmental harm. Under UNCLOS, parties have a special obligation to "ensure that activities under their jurisdiction or control" do not "cause damage by pollution to other [countries] and their environment," and that pollution arising from such activities "does not spread beyond areas where they exercise sovereign rights."[156] (Other international agreements aimed at preventing transboundary environmental harm are discussed in Part 4.1.3 below.)

It should be noted that the above reasoning could also apply to certain CDR techniques, which might similarly be viewed as sources of marine pollution, at least where they involve the introduction of substances into the ocean (e.g., as occurs in ocean fertilization and ocean alkalinity enhancement).[157] However, some scholars have argued that, given ITLOS' conclusion that anthropogenic GHG emissions constitute marine pollution, CDR could also be viewed as a form of pollution control.[158] Indeed, many ocean CDR activities are designed to remove carbon dioxide from the upper ocean, and thus could help to limit the effects of anthropogenic carbon dioxide emissions. Nevertheless, UNCLOS could be read as preventing such activities. Article 195 of UNCLOS states that, "[i]n taking measures to prevent, reduce and control pollution of the marine environment, [parties] shall act so as not to . . . transform one type of pollution into another."[159] ITLOS has opined that "[m]arine geoengineering would be contrary to article 195 if it has the consequence of transforming one type of pollution into another." This could be relied upon to justify or require restrictions on AOE activities.[160]

(B) The London Convention and London Protocol

As noted above, UNCLOS imposes a general requirement on parties to prevent pollution of the marine environment as a result of dumping from vessels, aircraft, or other structures at sea. This general requirement is elaborated in two other international agreements – the London Convention and London Protocol – which establish more specific rules for ocean dumping.[161] The London Convention was adopted first in November 1972

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[155] UNCLOS, *supra* note 75, Art. 194(3)(a).

[156] *Id.*, Art. 194(2).

[157] *See generally*, Romany M. Webb, *The ITLOS Advisory Opinion and Marine Geoengineering: More Questions, Few Answers*, CLIMATE LAW BLOG (May 24, 2024), https://blogs.law.columbia.edu/climatechange/2024/05/24/the-itlos-advisory-opinion-and-marine-geoengineering-more-questions-few-answers/.

[158] *Id.*

[159] UNCLOS, *supra* note 75, Art. 195.

[160] ITLOS Advisory Opinion on Climate Change, supra note 150, ¶ 231.

[161] UNCLOS directs parties to "establish global . . . rules, standards and recommended practices and procedures with respect to dumping." *Id.*, Art. 210. Some legal scholars have argued that the London Convention and London Protocol reflect the applicable global rules and standards, but others counter that the Convention and Protocol only have fairly limited membership and thus

and entered into force in August 1975.[162] 21 years later, in November 1996, the London Protocol was adopted to update and modernize the London Convention.[163] The London Protocol is intended to eventually replace the London Convention, but the Protocol must first be ratified or otherwise adopted by all of the parties to the Convention. At the time of writing, there were 87 parties to the London Convention and 55 parties to the London Protocol.[164] Countries that are only party to the London Convention, and not the London Protocol, are bound only by the former. However, where countries are party to both instruments, the London Protocol supersedes the Convention.

Both the London Convention and London Protocol require parties to adopt domestic laws to regulate the dumping of waste and other matter in the ocean. Generally speaking, however, the London Protocol requires countries to impose more restrictions on dumping than the London Convention. Under the London Convention, parties are required to prohibit the dumping of eight blacklisted substances identified in Annex I to the Convention, but may permit the dumping of any other (unlisted) substance. The London Protocol takes the opposite approach, requiring parties to prohibit the dumping of all substances, except for eight that are listed in Annex I to the Protocol. Those eight substances may be dumped with a permit.

For the purposes of the London Convention and London Protocol, dumping is defined broadly to mean "the deliberate disposal of waste or other matter at sea from vessels, aircraft, platforms, or other man-made structures."[165] In both instruments, the definition of dumping notably excludes the "placement of matter for a purpose other than mere disposal thereof, provided that such placement is not contrary to the aims of" the London Convention or London Protocol (the "placement exception"). This has generated significant controversy in the CDR context. There is an ongoing debate as to whether and when CDR projects that involve the discharge of materials into ocean waters will fall within the definition of dumping or qualify for the placement exception. A similar debate is likely to arise in the context of AOE projects, which involve aerosolizing iron or other substances, some portion of which will end up falling on the ocean and be left there. It might, therefore, be argued that AOE involves the disposal of matter in the ocean. On the other hand, though, it could be said that the substances are not being put in the ocean to get rid of them–as normally occurs in disposal–but rather as part of an effort to reduce atmospheric methane levels and thereby mitigate climate change. According to this

cannot be considered "global." The outcome of this debate is important because, if the London Convention and Protocol are viewed as the "global rules and standards" envisioned under UNCLOS, they would be binding on all parties to UNCLOS, regardless of whether they had ratified or otherwise adopted the London Convention and Protocol. *See generally* G. Hoon Hong & Y. Joo Lee, *Transitional Measures to Combine Two Global Ocean Dumping Treaties into a Single Treaty,* 55 MARINE POLICY 47 (2015).

[162] *The London Convention and Protocol*, INTERNATIONAL MARITIME ORGANIZATION (n.d.), https://www.imo.org/en/KnowledgeCentre/ConferencesMeetings/Pages/London-Convention-Protocol.aspx (last visited May 28, 2024).

[163] *Id*.

[164] *Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter*, INTERNATIONAL MARITIME ORGANIZATION(n.d.), https://www.imo.org/en/OurWork/Environment/Pages/London-Convention-Protocol.aspx (last visited May 28, 2024).

[165] London Convention, *supra* note 124, Art. III; London Protocol, *supra* note 125, Art. I.

view, AOE would involve a placement of matter for a purpose other than mere disposal and thus be excluded from the definition of dumping, provided it were found not to be contrary to the aims of the London Convention and London Protocol.

The aim of both the London Convention and London Protocol is to protect the marine environment from harms associated with dumping. In the CDR context, the parties have adopted a series of non-binding decisions, addressing when ocean CDR activities should be viewed as contrary to the aims of the London Convention and London Protocol. Specifically, in a 2008 decision, the parties indicated that deployment of ocean fertilization is contrary to the aims of the London Convention and London Protocol because it has the potential for significant adverse impacts on the marine environment.[166] Given this, the parties concluded that ocean fertilization deployment should be regulated as dumping under the London Convention and London Protocol.[167] Notably, however, the parties took a different view of ocean fertilization research, concluding that it may qualify for the placement exception if certain requirements are met.[168] Those requirements are set out in a 2010 assessment framework.

Under the 2010 assessment framework, to qualify for the placement exception, an ocean fertilization project must involve "legitimate scientific research" and conditions must be "in place to ensure that, as far as practicable, environmental disturbance [from the project] would be minimized and the scientific benefits maximized."[169] The country with jurisdiction over an ocean fertilization project must conduct a review to confirm that the project has "proper scientific attributes" to be classed as "legitimate scientific research" and evaluate its likely environmental impacts. Consistent with this approach, the parties to the London Convention and London Protocol recently suggested that other CDR activities involving the addition of materials to the ocean (e.g., ocean alkalinity enhancement and seaweed cultivation and sinking) should similarly only be allowed if they involve legitimate scientific research, and following an assessment of their environmental impacts.[170]

There is reason to believe that parties to the London Convention and London Protocol may treat AOE activities similarly to CDR projects. Some AOE projects may use iron aerosol, and thus be viewed by the parties as a form of ocean fertilization. The parties have defined ocean fertilization as "any activity undertaken by humans with the principal intention of stimulating primary productivity in the ocean."[171] AOE project developers might argue that the principal purpose of AOE is to destroy methane, not to stimulate primary production in the ocean, and

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[166] Resolution LC-LP.1(2008) on the Regulation of Ocean Fertilization, Art. 8 [*hereinafter* 2008 Resolution].

[167] *Id*. at Art. 8.

[168] *See id*. at Arts. 3–6.

[169] CONTRACTING PARTIES TO THE LONDON CONVENTION AND PROTOCOL, ASSESSMENT FRAMEWORK FOR SCIENTIFIC RESEARCH INVOLVING OCEAN FERTILIZATION § 4.1 (Oct. 14, 2010), https://cdrlaw.org/wp-content/uploads/2021/10/LC-Geo-Assessment-Framework-2010.pdf.

[170] CONTRACTING PARTIES TO THE LONDON CONVENTION AND PROTOCOL, STATEMENT ON MARINE GEOENGINEERING (2022),https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/LC_LP/LP%20LC%20Statement%20on%20Marine%20Geoengineering_%20LC%2044-17%20annex%202.pdf

[171] 2008 Resolution, *supra* note 166, Art. 2.

thus their projects fall outside the definition of ocean fertilization. Others might, however, counter that what matters is the end result and both AEO using iron aerosol and more traditional ocean fertilization projects do, in fact, stimulate primary productivity in the ocean. Moreover, all forms of AOE present unknown, but potentially significant risks to the marine environment. In this sense they are similar to ocean fertilization and other CDR activities. The uncertainty regarding the environmental impacts of ocean CDR activities was a key reason why parties chose to allow certain ocean CDR research but limit deployment. The same, if not more, uncertainty exists with respect to the impacts of AOE so it might be treated similarly.

Additional considerations might arise where AOE projects rely on the combustion of materials to produce aerosol. The London Convention requires parties to "prohibit incineration at sea of wastes or other matter."[172] The London Protocol is slightly more permissive; only incineration of industrial waste is outright prohibited by the London Protocol but other forms of incineration at sea must still be permitted.[173] For the purposes of the London Convention and London Protocol, "incineration at sea" means "the combustion . . . at sea of wastes or other matter for the purposes of their deliberate disposal by thermal destruction."[174] This raises similar issues to those discussed above – where AOE is performed by combusting materials on a ship or offshore platform, does that qualify as incineration at sea, or is it excluded from the definition because the combustion is not done for the purpose of disposing of the materials by thermal destruction but rather to produce aerosols that will react with methane in the atmosphere? Notably, unlike in the placement exception, there is no requirement in the London Convention and Protocol that incineration of materials for a purpose other than disposal be consistent with the aims of the London Convention and London Protocol. Given this, the parties might be more willing to find that AOE projects involving the combustion of materials do not qualify as incineration of waste, and should be allowed.

(C) London Protocol Amendment on Marine Geoengineering

AOE might, in the future, be regulated under an amendment to the London Protocol dealing specifically with marine geoengineering.[175] The amendment was adopted in 2013 but has yet to enter into force. If and when it does, it will insert a new provision into the London Protocol as follows:

> Contracting Parties shall not allow the placement of matter into the sea from vessels, aircraft, platforms or other man-made structures at sea for marine geoengineering activities listed in

[172] London Convention, *supra* note 124, Art. 5.

[173] London Protocol, *supra* note 125, Annex I, Art. 10.

[174] London Convention, *supra* note 124, Art. 1(5.1); London Protocol, *supra* note 125, Annex I, Art. 10(d).

[175] Resolution LP.4(8), Amendment to the 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972 to Regulate Marine Geoengineering (Oct. 18, 2013).

> annex 4 [to the London Protocol], unless the listing provides that the activity . . . may be authorized under a permit.[176]

Marine geoengineering is defined broadly to mean any "deliberate intervention in the marine environment to manipulate natural processes, including to counteract climate change and/or its impacts, and that has the potential to result in deleterious effects, especially where those effects may be widespread, long lasting or severe."[177] However, as noted above, the amendment only restricts the placement of matter in the ocean in connection with a *listed* marine geoengineering activity. At the time of writing, only ocean fertilization was listed, and the listing provided for the issuance of permits for research projects (but not deployment).[178] The parties were considering listing four other ocean CDR and solar radiation management ("SRM") activities under the 2013 amendment at the time of writing.[179]

It is unclear whether and how the 2013 amendment might be applied to AOE activities. As noted above, it is possible that the parties will view AOE activities performed using iron aerosol as a form of "ocean fertilization," which is covered by the amendment. It is also possible that the parties might expand the list of activities covered by the amendment to specifically to include AOE. However, that could only happen if AOE activities were deemed to involve "marine geoengineering," as defined in the 2013 amendment. It could be argued that AOE projects don't fall within the scope of the definition. As noted above, AOE projects involve the dispersal of materials into the atmosphere in order to destroy methane, and thereby counteract climate change. Some of the materials dispersed in AOE may end up in the ocean, where they may alter natural processes, but that is merely incidental to the atmospheric release. It might, therefore, be argued that AOE does not involve any "deliberate intervention in the marine environment." That argument is likely to be more compelling where AOE is performed on land as opposed to at sea (i.e., using vessels or offshore platforms). In the latter situation, it is virtually certain that some portion of the aerosol released will end up on the surface of the ocean, and thus any resulting alteration of natural processes might be viewed as "deliberate." For the same reason, it will likely also be easier to show that AOE projects conducted offshore involve "placement of matter" in the ocean, and are thus within the scope of the 2013 amendment.

If AOE activities (or some subset thereof) were to be listed under the 2013 amendment, the parties might be expected to treat them similarly to ocean fertilization, allowing the issuance of permits for AOE research but not deployment. However, the practical effect of this would be somewhat limited since the 2013 amendment

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[176] *Id*., Annex 1, Art. 1.

[177] *Id*.

[178] *Id*.

[179] The four activities being considered for listing were: (1) "macroalgae cultivation and other biomass sequestration including artificial upwelling," (2) "enhancing ocean alkalinity," (3) "marine cloud brightening," and (4) "microbubbles/reflective particles/material." *See* IMO, 44TH CONSULTATIVE MEETING OF CONTRACTING PARTIES TO THE LONDON CONVENTION AND THE 17TH MEETING OF CONTRACTING PARTIES TO THE LONDON PROTOCOL (2022), https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/44th-Consultative-Meeting-of-Contracting-Parties-to-the-London-Convention-and-the-17th-Meeting-of-Contracting-Parties-to-th.aspx (last visited May 28, 2024).

has not yet entered into force, and thus is not legally binding. In June 2023, a working group appointed by the parties to consider the provisional application of the 2013 amendment (before it enters into force) issued a draft statement, indicating:

> "Parties to the LP who accepted the 2013 amendment [shall][should] refrain from acts which would defeat the object and purpose of the amendment pending its entry into force . . . Parties to the LP who have not yet accepted the amendment, and Parties to the LC are strongly encouraged to refrain from such acts."[180]

The square brackets above reflect disagreement amongst the working group members on the language to be used. This disagreement highlights the uncertainty and confusion regarding the effect of the 2013 amendment and the consequences of listing additional activities under it.

(D) Other International Agreements Governing Shipping

International agreements governing shipping could also have implications for the conduct of AOE projects. One notable example is the International Convention on the Prevention of Pollution from Ships[181] ("MARPOL"), which was adopted in November 1973 and entered into force in October 1983.[182] MARPOL aims to "prevent the pollution of the marine environment by the discharge of harmful substances" into the sea and covers both operational and accidental releases of pollution from vessels.[183] Six technical annexes have been adopted under MARPOL, each aimed at controlling a different type of vessel pollution. Of particular relevance to AOE projects is Annex VI, which deals with the "prevention of air pollution" from vessels. Specifically, Annex VI prohibits the intentional release of ozone depleting substances from vessels, and establishes limits for vessel exhaust emissions of nitrogen oxide and sulfur oxide. Additionally, Annex VI also provides for the establishment of so-called "emission control areas," where vessels are required to meet more stringent emissions limits. Historically, emission control areas could only be established for sulfur oxide but, in 2008, Annex VI of MARPOL was amended to allow the designation of areas in which nitrous oxide and particular matter ("PM") pollution is controlled.[184]

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[180] Progress report from the Legal Intersessional Correspondence Group on Marine Geoengineering, IMO Doc. LC45/4/1 (June 30, 2023).

[181] International Convention for the Prevention of Pollution from Ships, 2057 UNTS 68 (adopted Nov. 2, 1973; entered into force Oct. 2, 1983) [*hereinafter* "MARPOL"].

[182] *International Convention for the Prevention of Pollution from Ships (MARPOL)*, INTERNATIONAL MARITIME ORGANIZATION (n.d.), https://www.imo.org/en/about/Conventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-(MARPOL).aspx (last visited May 28, 2024).

[183] MARPOL, *supra* note 181, Art. 1.

[184] *See generally Area based management tools: Emission Control Areas*, NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION, INTERNATIONAL SECTION, https://www.noaa.gov/gc-international-section/area-based-management-tools-emission-control-areas# (last visited May 28, 2024) (discussing the 2008 amendments to Annex VI of MARPOL) .

This could have implications for AOE projects which involve the release of ultrafine particles and thus could be a source of PM pollution.

Another important international agreement governing shipping is the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal ("Basel Convention"). Adopted in March 1989, the Basel Convention regulates the import and export of certain hazardous wastes.[185] For the purposes of the Convention, "waste" is defined to mean "substances or objects which are disposed of or intended to be disposed of."[186] Annex IV to the Convention includes a list of activities that constitute "disposal" and includes, among the listed activities, "[r]elease into seas/oceans."[187] Under this definition, AOE projects that involve the release of materials over ocean areas might qualify as "disposal," since some portion of the released materials will land on the surface of the water and be left there. However, even if that were the case, the Basel Convention would only apply if the materials used in AOE were considered hazardous. AOE project proponents would need to review the list of hazardous wastes identified in Annex I to the Convention and any relevant domestic laws to determine whether materials used in AOE qualify.[188] AOE project proponents should also note that the Basel Convention does not apply to the discharge of materials, where that discharge is "covered by another international agreement."[189] Thus, to the extent that AOE activities end up being regulated under other international agreements, such as the London Convention and/or London Protocol, the Basel Convention will not apply.

4.1.3 International Agreements Aimed at Preventing Transboundary Environmental Harm

A number of international agreements have been adopted to prevent, mitigate, and manage transboundary environmental harms.[190] Several agreements specifically target transboundary air pollution and its impact on shared resources (e.g., the ozone layer). These agreements could have implications for AOE projects that involve the release of potentially harmful substances into the air.

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[185] *Convention on the Control of Transboundary Movements of Hazardous Waste and their Disposal*, UNITED NATION TREATY SERIES, https://treaties.un.org/pages/ViewDetails.aspx?src=IND&mtdsg_no=XXVII-3&chapter=27&clang=_en (last visited May 28, 2024).

[186] Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, 1673 UNTS 57 (adopted Mar. 22, 1989; entered into force May 5, 1992), Art. 2(1).

[187] *Id*. Art. 2(4) & Annex IV(A).

[188] The Basel Convention defines "hazardous wastes" to mean "wastes that belong to any category contained in Annex I, unless they do not possess any of the hazardous characteristics contained in Annex III," and other wastes that "are defined as, or considered to be, hazardous wastes by the domestic legislation of the Party of export, import or transit." *See id*. Art. 1(1).

[189] *Id*. Art. 1(4).

[190] Transboundary environmental harm is also addressed under customary international law. Relevant principles of customary international law are discussed in Part 4.2 below.

(A) Convention on Long-Range Transboundary Air Pollution

The Convention on Long-Range Transboundary Air Pollution[191] ("LRTAP") was adopted in November 1979 and entered into force in March 1983.[192] At the time of writing, there were 51 parties to LRTAP,[193] each of which had pledged to "endeavour [sic] to limit, and as far as possible, gradually reduce and prevent air pollution including long-range transboundary air pollution."[194] LRTAP defines "air pollution" similarly to the way in which UNCLOS defines marine pollution. According to LRTAP:

> "Air Pollution" means the introduction by man, directly or indirectly, of substances or energy into the air resulting in deleterious effects of such a nature as to endanger human health, harm living resources and ecosystems and material property and impair or interfere with the amenities and other legitimate uses of the environment.[195]

LRTAP specifically targets "transboundary air pollution," which is defined as air pollution that originates in areas under the jurisdiction of one country but has adverse effects in areas under a different country's jurisdiction.[196] In order to limit transboundary air pollution, parties to LRTAP agreed to "develop . . . policies and strategies [for] combatting the discharge of air pollutants" (among other things).[197] Between 1985 and 1999, the parties adopted seven protocols, each of which aims to control a specific pollutant(s).[198] An eighth protocol adopted under LRTAP deals with financing for a monitoring program to collect emissions data and measure air quality in Europe.[199] Not all parties to LRTAP are party to all of the protocols. The U.S., for example, joined LRTAP in 1981 but is a party to just four of the eight protocols adopted under it.[200]

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[191] Convention on Long-range Transboundary Air Pollution, 1302 U.N.T.S. 217 (adopted Nov. 13, 1974; entered into force March 16, 1986) [*hereinafter* "LRTAP"].

[192] *Status of Treaties: Convention on Long-range Transboundary Air Pollution*, UNITED NATIONS TREATY SERIES, https://treaties.un.org/Pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-1&chapter=27&clang=_en (last visited May 28, 2024).

[193] *Id*.

[194] LRTAP, *supra* note 191, Art. 2.

[195] *Id.*, Art. 1(a).

[196] *Id.*, Art. 1(b).

[197] *Id.*, Art. 3.

[198] United Nations Economic Commission for Europe, *Protocols*, The Air Convention and its Protocols, https://unece.org/protocols (last visited May 28, 2024).

[199] *See* Protocol to the 1979 Convention on Long-range Air Pollution on Long-term Financing of the Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe,1491 U.N.T.S. 167 (adopted Sept. 28, 1984; entered into force Jan. 28, 1988).

[200] U.S. Department of State, Office of Environmental Policy, *Convention on Long-Range Transboundary Air Pollution*, –U.S. DEPARTMENT OF STATE (n.d.), https://www.state.gov/key-topics-office-of-environmental-quality-and-transboundary-issues/convention-on-long-range-transboundary-air-pollution/ (last visited May 28, 2024).

Most relevant to AOE is the Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone[201] ("Gothenburg Protocol") which was first adopted in November 1999. The original 1999 version of the Gothenburg Protocol entered into force in May 2005. It was subsequently amended in May 2012, with the amendment entering into force in October 2019.[202] The overarching aim of the Gothenburg Protocol (as amended) is to "control and reduce emissions of sulphur [sic], nitrogen oxides, ammonia, volatile organic compounds and particulate matter that are caused by anthropogenic activities and are likely to cause adverse effects on human health and the environment, natural ecosystems, materials, crops, and the climate in the long and short term due to acidification, eutrophication, particulate matter or ground-level ozone."[203] To this end, the Gothenburg Protocol sets national emissions limits for the five covered pollutants: (1) sulfur, (2) nitrogen oxides, (3) ammonia, (4) VOCs, and (5) PM.[204] For pollutants (1) through (4), separate national emissions limits are set for the period from "2010 up to 2020," and then "2020 and beyond."[205] Notably, however, the Gothenburg Protocol only includes one set of national emissions limits for PM for 2020 and beyond.[206] This is because PM was not addressed in the original, 1999 version of the Gothenburg Protocol, but added in the 2012 amendments.

The PM limits cover emissions of ultrafine inhalable particles, measuring 2.5 micrometers or less in diameter ("PM2.5"). For most countries, the Gothenburg Protocol specifies a numeric limit for PM2.5 emissions; the limits vary significantly between countries, requiring reductions of between 10 and 46 percent, compared to national emissions levels in 2005.[207] For example, the limit for Cyprus is 2,900 metric tons of PM2.5 per year, which reflects a reduction of 46 percent from 2005 levels. In comparison, Italy's limit is set at 166,000 metric tons of PM2.5, which is just 10 percent lower than 2005 levels.

Notably, while both Canada and the United States are party to the Gothenburg Protocol, no numeric emissions limits are set for those countries. Rather, Canada and the United States have merely agreed to reduce emissions of PM2.5 (and other covered pollutants) as required under domestic law.[208] For example, the United States pledged to implement "a mobile source emission control program for light-duty vehicles, light-duty trucks,

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[201] Protocol to the 1979 Convention on Long-Range Transboundary Air Pollution to Abate Acidification, Eutrophication and Ground-level Ozone, 2319 U.N.T.S. 81 (adopted Nov. 30, 1999; May 17, 2005) [*hereinafter* "Gothenburg Protocol"].

[202] *Amendment of the Text and Annexes II to IX of the Protocol to the 1979 Convention on Long-Range Transboundary Air Pollution to Abate Acidification, Eutrophication and Ground-Level Ozone and the Addition of new Annexes X and XI*, UNITED NATIONS TREATY COLLECTION, https://treaties.un.org/Pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-1-k&chapter=27&clang=_en (last visited May 28, 2024).

[203] Gothenburg Protocol, *supra* note 201, Art. 2.

[204] *Id.*, Art. 3 & Annexes I - XI.

[205] *Id.*, Annex II.

[206] *Id.*, Annex II, Table 6.

[207] *Id.*, Annex II, Table 6.

[208] *Id.*, Annex VIII & X.

heavy-duty trucks and fuels to the extent required by . . . the [CAA]" and to enforce emissions limits established for stationary sources in regulations adopted under that Act.[209]

The provisions of the Gothenburg Protocol dealing with PM2.5 pollution could have implications for AOE projects. Those projects may involve the release of fine particles—e.g., iron salt aerosol measuring less than 1 micrometer in diameter[210]—and thus be a source of PM2.5 pollution. Countries for which numeric PM2.5 emissions limits have been set in the Gothenburg Protocol may, therefore, need to restrict AOE projects to meet the limits. That would not be true for the U.S., however. To meet its obligations under the Gothenburg Protocol, the U.S. would only need to ensure that AOE projects comply with domestic regulatory requirements established under the CAA. As a result, compared to other Gothenburg Protocol parties, the United States may have greater flexibility to allow AOE projects.

While currently a potential restriction on AOE projects, LRTAP might be used in the future to advance those projects as a means of controlling methane emissions. Neither LRTAP nor any of its protocols currently address methane emissions. However, methane would qualify as an "air pollutant" under the LRTAP definition, and emissions of methane contribute to air quality issues that LRTAP protocols are designed to address (e.g., ground-level ozone). Notably, in a 2018 decision, the parties to the Gothenburg Protocol noted that reducing methane emissions is essential to reduce the formation of tropospheric ozone and thus achieve the goals of the Protocol.[211] The Parties agreed to review the Gothenburg Protocol and consider, among other things, "the need to further reduce emissions of the pollutants currently covered by th[e] protocol . . . as well as appropriate steps towards reducing emissions of black carbon, methane (as an ozone precursor) and emissions from shipping."[212] That review was ongoing at the time of writing.

(B) Vienna Convention for the Protection of the Ozone Layer and Montreal Protocol on Substances that Deplete the Ozone Layer

Another international regime with potential relevance to AOE is that established under the Vienna Convention for the Protection of the Ozone Layer[213] ("Vienna Convention"). Adopted in March 1985, the Vienna Convention entered into force in September 1988 and now has universal global participation, with 198 parties.[214] The

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[209] *Id*.

[210] *Iron Salt Aerosol: Climate Restoration with Iron Salt Aerosol,* CLIMATE GAME CHANGERS, https://climategamechangers.org/game-changers/iron-salt-aerosol/ (last visited May 28, 2024).

[211] Decision 2018/5, Long-term Strategy for the Convention on Long-Range Transboundary Air Pollution for 2020-2030 and Beyond, ¶ 37 (2018), https://unece.org/fileadmin/DAM/env/documents/2018/Air/EB/correct_numbering_Decision_2018_5.pdf.

[212] *Id*. ¶ 50.

[213] Vienna Convention for the Protection of the Ozone Layer, 1513 U.N.T.S. 293 (adopted Mar. 22, 1985, entered into force Sept. 22, 1988) [hereinafter "Vienna Convention"].

[214] *Vienna Convention for the Protection of the Ozone* Layer, UNITED NATIONS TREATY SERIES (n.d.), https://treaties.un.org/pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-2&chapter=27&clang=_en (last visited May 28, 2024).

Convention aims to "protect human health and the environment against adverse effects resulting or likely to result from human activities which modify or are likely to modify the ozone layer."[215] To this end, parties agree to cooperate on research and share information "in order to better understand and assess the effects of human activities on the ozone layer," and to adopt "measures . . . to control, limit, reduce or prevent human activities . . . found [to] have or [be] likely to have adverse effects resulting from modification or likely modification of the ozone layer," among other things.[216] Beyond that, however, the Vienna Convention does not require parties to take specific actions to protect the ozone layer. More detailed requirements were agreed to later in the Montreal Protocol on Substances that Deplete the Ozone Layer ("Montreal Protocol")[217] and the Kigali Amendment to that Protocol.[218]

The Montreal Protocol was adopted in September 1987, entered into force in January 1989, and has 198 parties.[219] The Protocol established mandatory timelines for parties to phase out the production and consumption of 96 ozone-depleting substances, including chlorofluorocarbons ("CFCs") and hydrochlorofluorocarbons ("HCFCs"), which are also highly potent GHGs.[220] The timelines for phase out by developed countries were shorter than those for developing countries. For example, developed countries were required to phase out CFCs by the end of 1995 and most HCFCs by the end of 2020 (with limited exceptions), whereas developing countries had until 2010 to phase out CFCs and 2020 to phase out most HCFCs (again with limited exceptions).[221] In most cases, CFCs and HCFCs were initially replaced with hydrofluorocarbons ("HFCs"), but those substances also contribute to ozone depletion and climate change.[222] As a result, in October 2016, the parties to the Montreal Protocol adopted the Kigali Amendment on HFCs. The Kigali Amendment entered into force in 2019 and, at the time of writing, had 156 parties.[223] Those parties had agreed to phase-down the production and consumption of HFCs on a set timetable. Developed country parties are required to reduce HFCs

[215] Vienna Convention, *supra* note 213, Art. 2(1).

[216] *Id*., Art. 2(2).

[217] Montreal Protocol on Substances that Deplete the Ozone Layer, 1522 U.N.T.S. 3 (adopted Sept. 16, 1987; entered into force Jan. 1, 1989).

[218] Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer (adopted Oct. 15, 2016; entered into force Jan. 1, 2019).

[219] *Montreal Protocol on Substances that Deplete the Ozone Layer*, United Nations Treaty Series (n.d.), https://treaties.un.org/Pages/ViewDetails.aspx?src=IND&mtdsg_no=XXVII-2-a&chapter=27&clang=_en (last visited May 28, 2024).

[220] *See generally* Webb, *supra* note 14.

[221] *Ozone Depleting Substances and Synthetic Greenhouse Gases: Montreal Protocol on Substances that Deplete the Ozone Layer,* AUSTRALIAN GOVERNMENT, DEPARTMENT OF CLIMATE CHANGE, ENERGY, THE ENVIRONMENT AND WATER (Oct. 3, 2021), https://www.dcceew.gov.au/environment/protection/ozone/montreal-protocol (last visited May 28, 2024).

[222] Webb, *supra* note 14, at 146.

[223] *Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer*, UNITED NATIONS TREATY SERIES (n.d.), https://treaties.un.org/Pages/ViewDetails.aspx?src=IND&mtdsg_no=XXVII-2-f&chapter=27&clang=_en

by 85 percent by 2036 (with interim targets), while developing countries must reduce HFCs by 80 percent by 2040 (again with interim targets).

AOE projects would not be performed using any ozone depleting substance covered by the Montreal Protocol and thus would not be directly impacted by the phase-down requirements discussed above. However, to the extent that AOE affects the ozone layer, it may be targeted for future regulation under the Montreal Protocol. In this regard, it is notable that the parties to the Montreal Protocol recently called for a review of the impacts of SRM by the Scientific Assessment Panel, Environmental Effects Assessment Panel, and Technology and Economic Assessment Panel established under the Protocol.[224] As a result, the 2022 Scientific Assessment of Ozone Depletion included an SRM chapter, which concluded that SRM via stratospheric aerosol injection has the potential to reduce global average temperatures, but that it cannot fully offset the effects of climate change and may have unintended consequences, including causing additional ozone depletion.[225] Australia and Canada subsequently suggested that the parties to the Montreal Protocol should adopt a decision on "stratospheric aerosol injection and protection of the ozone layer."[226] The proposed decision "[i]nvites the global scientific community to address risks and uncertainties for the ozone layer in any scientific studies or assessments undertaken in relation to stratospheric aerosol injection" and "[r]equests the Scientific Assessment Panel to engage with the global scientific community regarding, and to continue to bring to the attention of the parties, any important developments with respect to stratospheric aerosol injection."[227] The decision had not been adopted at the time of writing.

4.1.4 Other Potentially Relevant International Agreements

All of the agreements discussed above are global in nature. However, there are also various regional agreements that might have implications for AOE projects, depending on where they occur. Many of the relevant regional agreements are designed to prevent or limit damage to the environment in a particular area. One example is the Convention on the Protection of the Marine Environment of the North-East Atlantic ("OSPAR Convention") which was adopted in September 1992 and entered into force in March 1998. The OSPAR Convention had just 16 parties at the time of writing but, nevertheless, has important implications for activities undertaken in the North-East Atlantic region. Similar to the London Convention and Protocol, the OSPAR Convention aims to prevent pollution of the marine environment as a result of dumping. Parties to the OSPAR Convention are required to prohibit dumping in their internal waters, territorial seas, and EEZs, and on the high seas in the North-East Atlantic, with limited exceptions. (The OSPAR Convention adopts a similar approach to the London

[224] Decisions adopted by the Thirty-First Meeting of the Parties to the Montreal Protocol, Decision XXXI/2 5(g), Nov. 11, 2019, https://ozone.unep.org/system/files/documents/MOP-31-9-Add-1E.docx.

[225] World Meteorological Organization, Scientific Assessment of Ozone Depletion (2022), https://csl.noaa.gov/assessments/ozone/2022/

[226] Draft decisions for consideration by the Thirty-Fifth Meeting of the Parties to the Montreal Protocol, Draft Decision XXXV/B, July 19, 2023, https://ozone.unep.org/system/files/documents/MOP-35-3E.pdf

[227] *Id.*

Protocol, identifying a list of substances that the parties may allow to be dumped if certain requirements are met.)

There are also regional agreements aimed at protecting polar areas, which could have implications for AOE projects conducted in those areas. One example is the Antarctic Treaty,[228] which was adopted in December 1959, entered into force in June 1961, and had 54 parties at the time of writing.[229] The Antarctic Treaty includes specific provisions governing the conduct of scientific research in the "area south of 60° South Latitude" (defined as "Antarctica" in the Treaty).[230] Among other things, parties must undertake an environmental review of any proposed research project to evaluate its "possible impacts on the Antarctic environment and dependent and associated ecosystems and on the value of Antarctica for the conduct of scientific research."[231] Projects must be planned and conducted so as to have "limited adverse impacts on the Antarctic environment and dependent and associated ecosystems" and to avoid, among other things, "significant adverse effects on air or water quality" and "significant changes in the atmospheric, terrestrial[,] . . . glacial or marine environments."[232] As discussed in Part 2 above, AOE aims to change the composition of the atmosphere and could impair air quality or cause other environmental harms that the Antarctic Treaty seeks to prevent. As such, consistent with the Treaty, parties might restrict AOE research in Antarctica. At a minimum, any AOE research in Antarctica would need to comply with the environmental review and other requirements in the Antarctic treaty. Similarly, AOE activities in the Arctic would need to be conducted in accordance with agreements adopted by the Arctic Council, including the 2017 Agreement on Enhancing International Arctic Scientific Cooperation. That agreement sets out requirements for conducting scientific research in the Arctic, including rules with respect to the establishment of research facilities and collection and use of research data.

There are also a number of regional agreements that establish rules for decision-making in the context of environmentally risky activities such as AOE. Examples include the 1998 Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters ("Aarhus Convention"), and the 2018 Regional Agreement on Access to Information, Public Participation and Justice in Environmental Matters in Latin America and the Caribbean ("Escazú Agreement"). The Aarhus Convention includes parties from Europe and Asia, whereas parties to the Escazú Agreement come from Latin America and the Caribbean. However, the two agreements are similar in that they both require parties to ensure public access to information, and public participation in decision-making, on environmental matters. In a similar vein is the 1991 Convention on Environmental Impact Assessment in a Transboundary Context ("Espoo Convention") which establishes procedures for evaluating, with public input, the environmental impacts of certain activities.

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[228] Antarctic Treaty, 402 U.N.T.S. 71 (adopted Dec. 1 1959; entered into force June 23, 1961) [hereinafter "Antarctic Treaty"].

[229] Secretariat of the Antarctic Treaty, *The Antarctic Treaty*, https://www.ats.aq/e/antarctictreaty.html (last visited May 28, 2024).

[230] Antarctic Treaty, *supra* note 228, Art. II & VI.

[231] Protocol on Environmental Protection to the Antarctic Treaty (adopted Oct. 4, 1991; entered into force Jan. 14, 1998), Art. 3 & 8.

[232] *Id*. Art. 3.

AOE projects might also implicate a variety of regional and global human rights agreements, such as the 1966 International Covenant on Economic, Social, and Cultural Rights, the 1979 International Convention on the Elimination of all Forms of Discrimination Against Women, the 1989 International Covenant on the Rights of the Child, the 1990 International Convention on the Protection of the Rights of All Migrant Workers and Members of their Families, and the 2006 International Covenant on the Rights of Persons with Disabilities. In 2019, the committees that implement those Conventions issued a joint statement on human rights and climate change, which noted that "climate change poses significant risks to the enjoyment of the human rights protected in the" conventions.[233] Specifically, the impacts of climate change "threaten, among others, the right to life, to adequate food, to adequate housing, to health and to water, and cultural rights."[234] According to the statement, "[f]ailure to take measures to prevent foreseeable harm to human rights caused by climate change, or to regulate activities contributing to such harm, could constitute a violation of [countries'] human rights obligations."[235] This could be used to justify AOE activities, since they have the potential to mitigate climate change and thus prevent harm to human rights. At the same time, however, countries must be careful to ensure that AOE and other climate change mitigation activities do not themselves harm human rights. In this regard, the 2019 statement notes "the risk of social and environmental damage resulting from poorly designed climate measures," and highlights the importance of applying "human rights norms" when designing and implementing such measures.[236]

4.2 Relevant Principles of Customary International Law

In addition to international agreements, principles of customary international law might also affect whether, when, and how AOE activities take place. Arguably most relevant is the so-called "no harm" rule of customary international law, which requires each country to "ensure that activities within their jurisdiction or control do not cause damage to the environment or other [countries] or of areas beyond the limits of national jurisdiction."[237] Areas beyond the limits of national jurisdiction include the high seas, the underlying seabed, and the air above.

The no harm rule has been interpreted as imposing a "due diligence" obligation on countries, requiring them "to use all the means at [their] disposal" or "do the[ir] utmost" to avoid or minimize transboundary environmental harm.[238] Exactly what this requires will depend on the circumstances, including the nature of the

[233] United Nations, Statement on Human Rights and Climate Change, HRI/2019/1, ¶ 3.

[234] *Id*.

[235] *Id*. ¶ 10.

[236] *Id*. ¶ 6.

[237] Declaration of the United Nations Conference on Environment and Development, UN Doc. A/CONF.151/26/Rev. 1, June 3-14, 1992, Principle 2.

[238] International Tribunal for the Law of the Sea, Advisory Opinion: Responsibilities and Obligations of States Sponsoring Persons and Entities with Respect to Activities in the Area, ITLOS Reports 2011 [*hereinafter* "ITLOS Advisory Opinion on Activities in the Area"];

activity being undertaken, and what is known about the risk of harm it presents. As ITLOS has noted, the due diligence obligation may "change over time as measures considered sufficiently diligent at a certain moment may become not diligent enough in light, for instance, of new scientific or technical knowledge."[239] Generally speaking, however, countries are at a minimum expected to carefully oversee and manage environmentally risky activities (e.g., by adopting and enforcing relevant domestic laws).[240] In this regard, the International Court of Justice ("ICJ") has viewed the due diligence obligation as "entail[ing] not only the adoption of appropriate rules and measures, but also a certain level of vigilance in their enforcement and the exercise of administrative control applicable to public and private operators, such as the monitoring of activities undertaken by such operators."[241]

Relatedly, countries also have a procedural obligation under customary international law to undertake an environmental impact assessment ("EIA") for any project that may cause "significant" transboundary environmental damage.[242] While there is no agreed upon definition of "significant damage," the International Law Commission has suggested that the EIA requirement will apply where a project may cause damage that is more than merely "detectable," but not necessarily "serious" or "substantial."[243] This would need to be assessed on a case-by-case basis. In theory, however, many AOE activities could cause more than "detectable" damage to the environment.

Customary international law mandates that, where an activity has the potential to cause transboundary environmental harm, the country overseeing that activity must conduct a preliminary review to determine whether there is a risk of significant damage.[244] If such a risk exists, the country must conduct a more extensive EIA before undertaking or authorizing the activity. Countries have significant discretion in how they conduct EIAs, however. According to the ICJ, international law does not "specify the scope and content" of an EIA, and thus "it is for each [country] to determine in its domestic legislation or in the authorization for the project, the specific content . . . required in each case."[245] Some international agreements also provide guidance on the conduct of EIAs. One notable example is the BBNJ Agreement which was adopted in June 2023 but, at the time of writing, had not yet entered into force. Part IV of the BBNJ Agreement sets out a detailed, multi-stage process for assessing the environmental and other impacts of certain ocean-based activities. First, where a country

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International Court of Justice, Case Concerning Pulp Mills on the River Uruguay (Argentina v. Uruguay), Judgement, ICJ Rep. 2010 [*hereinafter* "Pulp Mills Case"].

[239] ITLOS Advisory Opinion on Activities in the Area, *supra* note 238, ¶ 117.

[240] *Id*. *See also* Pulp Mills Case, *supra* note 238, ¶¶ 187 & 19

[241] Pulp Mills Case, *supra* note 238, ¶ 197.

[242] International Court of Justice, Certain Activities Carried out by Nicaragua in the Border Area (Costa Rica v. Nicaragua), Judgement, ICJ Rep. 2015, ¶¶ 665, 706-707 [*hereinafter* "Certain Activities Case"].

[243] International Law Commission, Draft Articles on Prevention of Transboundary Harm from Hazardous Activities, with Commentaries (2001),https://legal.un.org/ilc/texts/instruments/english/commentaries/9_7_2001.pdf

[244] Certain Activities Case, *supra* note 242, ¶¶ 706-707.

[245] Pulp Mills Case, *supra* note 238, ¶ 205.

determines that an activity under its jurisdiction or control "may have more than a minor or transitory effect on the marine environment or the effects of the activity are unknown or poorly understood," the country must "conduct a screening of the activity" to determine if it "may cause substantial pollution of or significant and harmful changes to the marine environment."[246] Second, if there are "reasonable grounds for believing that the activity" may have such effects, the country must conduct a full EIA to identify the activity's environmental impacts and any "associated impacts, such as economic, social, cultural, and human health impacts."[247] The EIA must be conducted in a "transparent and inclusive" manner" and provide "opportunities for participation" by Indigenous Peoples and local communities with relevant traditional knowledge, relevant global, regional, subregional and sectoral bodies, civil society, the scientific community, and the public."[248]

5. Domestic (U.S.) Laws Governing Atmospheric Oxidation Enhancement

Domestic law in the United States does not specifically address AOE projects. However, AOE projects will inevitably involve activities, or have impacts, that are regulated under domestic legal frameworks. For example, AOE projects that involve the release of potentially harmful materials into the air may be regulated under the federal CAA as a source of air pollution; AOE projects that are performed in the ocean may be regulated under federal laws governing ocean-based activities, such as the Outer Continental Shelf Lands Act ("OCSLA") and the Marine Protection, Research, and Sanctuaries Act ("MPRSA"). Similarly, many types of AOE projects will be subject to state and local laws. For example, projects involving the construction of fixed structures on land or in near-shore areas under the jurisdiction of coastal states will be impacted by state property laws, and may need to comply with local land use requirements.

This Part identifies and analyzes a number of key domestic laws that could have implications for AOE projects. This Part primarily focuses on federal environmental laws since, as noted in Part 3 above, those laws are likely to have the greatest bearing on whether, when, where, and how AOE projects take place.[249] This Part also discusses several areas where state and local laws may affect AOE projects. However, this discussion is necessarily general; legal requirements often vary significantly between states and localities in the U.S., and a full 50-state review of all potentially applicable requirements is beyond the scope of this paper.

This Part begins with a discussion of generally applicable laws that could be triggered by a wide range of AOE project designs and then examines laws that are likely to apply to only certain classes of AOE projects. With respect to the latter, we distinguish between AOE projects that are performed using stationary structures (discussed in Part 5.2) and those that involve the use of mobile facilities, such as vessels and aircraft (discussed

[246] BBNJ Agreement, *supra* note 137, Art. 30(1).

[247] *Id*. Art. 30-31.

[248] *Id*. Art. 32.

[249] The federal environmental laws that apply to any AOE project will depend on a variety of factors, including the precise activities involved and where they would take place. As such, additional federal environmental laws, not discussed in this paper, might also apply to some projects. Tribal, state, and local law might also apply.

in Part 5.3). Under U.S. law this distinction is crucial, because stationary and mobile emissions sources are subject to significantly different environmental laws and regulatory regimes. Additionally, within each category, the laws applicable to a specific facility may vary significantly depending on whether the facility operates on land or in the ocean.

5.1 Generally Applicable Domestic Laws

This Part focuses on broadly applicable domestic laws that are likely to affect most, if not all, AOE projects. Many of these laws establish procedural, rather than substantive, requirements. For example, the National Environmental Policy Act ("NEPA") and state and local equivalents set out requirements for *ex-ante* review of, and public participation in decision-making around, proposed activities. Other laws, such as the federal Weather Modification Reporting Act ("WMRA") and state equivalents, oblige those undertaking certain activities to provide advance notice of those activities to the government or other interested parties. However, with limited exceptions, these laws do not generally dictate how the activities are conducted. One notable exception to this is species protection laws, which do impose substantive requirements, aimed at minimizing the impacts of activities on sensitive plants and animals.

5.1.1 Environmental Review Requirements Under NEPA and State and Local Equivalents

Signed into law by President Nixon in 1970, NEPA declares "that it is the continuing policy of the Federal Government . . . to use all practicable means and measures . . . to create and maintain conditions under which man and nature can exist in productive harmony, and fulfill the social, economic, and other requirements of present and future generations of Americans."[250] Under NEPA, the federal government has a continuing responsibility to (among other things) "attain the widest range of beneficial uses of the environment without degradation, risk to health or safety, or other undesirable and unintended consequences."[251] One way in which NEPA seeks to ensure this responsibility is fulfilled is by requiring federal government agencies to carefully consider and disclose the environmental risks associated with their activities.

Under NEPA, before moving ahead with any "major federal action significantly affecting the quality of the human environment," federal agencies must prepare a detailed environmental impact statement ("EIS").[252] The EIS must include a discussion of the "reasonably foreseeable environmental effects of the proposed agency action," including any effects "which cannot be avoided" if the action is taken, and possible alternative actions.[253] This is intended to ensure that agencies take a "hard look" at the environmental risks posed by their activities before

[250] 42 U.S.C. § 4331(a).

[251] *Id*. § 4331(b)(3)

[252] *Id*. § 4332(2)(C).

[253] *Id*. § 4332(2)(C)(i)-(iii).

deciding whether to move ahead.[254] As the courts have recognized, each federal agency must "consider every significant aspect of the environmental impact of a [proposed] action"[255] and ensure that the environmental analysis is "incorporated as part of the agency's process for deciding whether to pursue [the] action."[256] The agency must also provide opportunities for public participation in decision-making, for example, by publishing the findings of its environmental review and accepting comments from the public.[257] In this way, NEPA should "provide for informed decision making and foster excellent action."[258] Importantly, however, the statute does not impose substantive requirements on agencies to avoid or minimize environmental harms from their activities. Thus, provided they meet their procedural obligations under NEPA, agencies may pursue activities even if they are environmentally harmful.

As noted above, under NEPA, federal agencies are only required to prepare an EIS for "major federal actions significantly affecting the quality of the human environment." For the purposes of NEPA, federal actions include "projects and programs entirely or partly financed, assisted, conducted, regulated, or approved by Federal agencies."[259] Thus, where a federal agency proposes to undertake an AOE project itself, that would qualify as a "federal action" under NEPA. AOE projects proposed by non-federal actors (e.g., private individuals or companies) might also qualify if the projects are funded, approved, or otherwise regulated by a federal agency. In the latter case, however, the project will only be considered a federal action under NEPA if it is "subject to Federal control and responsibility."[260] As discussed in Part 5.2.3 below, many privately developed AOE projects will likely require federal permits and thus be subject to federal control.

Where an AOE project involves a federal action under NEPA, an EIS will need to be prepared for the project if it is found to have significant environmental effects. Large-scale AOE deployments will, almost by definition, have significant environmental effects. Some smaller AOE research projects, particularly short-duration, controlled research projects, may not require preparation of an EIS. Instead, these projects may fall into categories that require less scrutiny: (1) projects that qualify for a categorical exclusion ("CE") from NEPA, and (2) projects that are subject to an environmental assessment ("EA"), but do not require a full EIS.

Under NEPA, federal agencies can issue CEs for categories of actions that they determine, in advance, will not normally have significant effects on the human environment.[261] Actions covered by a CE typically do not require

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[254] *New York Natural Res. Def. Council, Inc. v. Kleppe*, 429 U.S. 1307, 1311 (1976).

[255] LINDA LUTHER, CONGRESSIONAL RESEARCH SERVICE, RL33152, THE NATIONAL ENVIRONMENTAL POLICY ACT: BACKGROUND AND IMPLEMENTATION 1 (2008), https://perma.cc/UFN3-P7H6.

[256] *Baltimore Gas & Electric Co. v. Natural Res. Def. Council, Inc.*, 462 U.S. 87, 100 (1983).

[257] Luther, *supra* note 255, at 26.

[258] 40 C.F.R. § 1500.1(a).

[259] *Id*. § 1508.1(q)(2).

[260] *Id*. § 1508.1(q).

[261] *Id*. § 1501.4(a).

an EIS, unless the agency determines that, due to extraordinary circumstances, the action will significantly affect the environment. Some small-scale AOE research projects may be covered by existing CEs.[262] For example, the U.S. Department of Energy ("DOE") has issued a CE for "[s]mall-scale research and development," which covers the "[s]iting, construction, modification, operation, and decommissioning of facilities for small scale research and development projects; conventional laboratory operations . . . and small-scale pilot projects (generally less than 2 years) frequently conducted to verify a concept before demonstration actions."[263] Another DOE-issued CE covers "[o]utdoor terrestrial ecological and environmental research in a small area (generally less than 5 acres)."[264] Some early-stage AOE research projects that have small footprints, are of short duration, and pose minimal risks, may fall within the scope of these CEs (or similar ones adopted by other agencies). It is, however, notable that DOE's CEs do not cover "demonstration actions . . . that are undertaken to show whether a technology would be viable on a larger scale and suitable for commercial deployment."[265] The dividing line between "small scale" research projects and "demonstration actions" will often be blurry.

When determining whether to apply a CE to a proposed action, agencies conduct individualized reviews of the specific proposed activity to determine whether it fits into the terms of the CE, and assess whether any "extraordinary circumstances . . . might give rise to significant environmental effects requiring further analysis."[266] While this review may be perfunctory for routine actions like "personnel actions or purchases of small amounts of supplies," more complex activities merit more sophisticated review.[267] For example, when the DOE considers whether a project qualifies for the "small scale research and development" CE discussed above, it conducts a nuanced and individualized evaluation. "In assessing whether a proposed action is small, in addition to the actual magnitude of the proposal, DOE considers factors such as industry norms, the relationship of the proposed action to similar types of development in the vicinity of the proposed action, and expected outputs of emissions or waste."[268] Courts "tend to be deferential" to agency decisions arising from CE evaluations.[269]

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[262] *Id*. § 1501.4(b).

[263] 10 C.F.R. Pt. 1021, Subpt. D, App. B, § B3.6.

[264] *Id*. § B3.8.

[265] *Id*. § B3.6.

[266] *See* ESTABLISHING, APPLYING, AND REVISING CATEGORICAL EXCLUSIONS UNDER THE NATIONAL ENVIRONMENTAL POLICY ACT, COUNCIL ON ENVIRONMENTAL QUALITY (Nov. 23, 2010), https://ceq.doe.gov/docs/ceq-regulations-and-guidance/NEPA_CE_Guidance_Nov232010.pdf.

[267] *Id*.

[268] 10 C.F.R. § 1021.410(g)(2).

[269] George Cameron Coggins & Robert L. Glicksman, *Exemptions and Exclusions from NEPA Obligations—Categorical Exclusions*, *in* 2 PUB. NAT. RESOURCES L. § 17:11 (2nd ed. Feb. 2024); *see also Nat'l Tr. for Historic Pres. in U.S. v. Dole*, 828 F.2d 776, 781 (D.C. Cir. 1987) (holding that "traditional arbitrary-and-capricious review is sufficient where the question is whether [a federal agency] properly invoked a [categorical exemption]."); *Los Padres ForestWatch v. United States Forest Serv.*, 25 F.4th 649, 654 (9th Cir. 2022) (applying an "arbitrary and capricious" standard to review of an agency's application of a categorical exclusion).

Where an action does not qualify for a CE, but the relevant federal agency determines that it is "not likely to have significant effects . . . or the significance of the effects is unknown," the agency may prepare an EA.[270] Given the currently limited understanding of AOE, many projects are likely to have unknown effects, and thus require an EA. EAs are less detailed than EIS's, and include only a brief analysis of the environmental impacts of the proposed action and alternatives.[271] Where, based on that brief analysis, the agency determines that the action could have significant environmental impacts, it must prepare a full EIS. However, if the analysis shows that the project presents minimal risks, it may issue a finding of no significant impact.[272]

Federal agencies must publicly disclose information about, and provide opportunities for public participation in, environmental reviews conducted under NEPA. To this end, federal agencies must publish a notice when they apply CEs or decide to conduct EAs or EISs. In the latter case, agencies must also publish drafts of their EAs and EISs, and accept and consider public comments thereon, before issuing final versions of the documents.[273] Given this, the NEPA process could provide valuable opportunities for the public to learn about, and weigh in on, proposals to conduct AOE. Project developers will still need to conduct additional public outreach and engagement, however. As noted above, not all projects may undergo NEPA review and, even where that review does happen, some stakeholders may find participating in it challenging. EAs and EISs are often very lengthy and technically complex documents. This is likely to be particularly true for EAs / EISs relating to AOE projects, which are themselves very complex scientific endeavors. As a result, members of the public may find it difficult to meaningfully comment on EAs / EISs prepared for AOE projects, or to otherwise participate in decision-making regarding such projects.[274]

It should also be noted that NEPA is not, by itself, an effective tool for regulating the conduct of AOE projects. As a purely procedural statute, NEPA does not impose any substantive requirements on federal agencies to prevent, avoid, or mitigate damage to the environment.[275] There is, thus, nothing in NEPA that would prevent AOE projects even if they are shown to pose serious risks to the environment or communities. Nor is there anything in NEPA to ensure that projects are conducted in a safe and responsible manner. The same is generally

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[270] 40 C.F.R. § 1501.5(a).

[271] *Id*. § 1501.5(c).

[272] *Id*. § 1501.6.

[273] *See* Daniel R. Mandelker et al., *Agency Procedures: Required – Public Participation*, *in* NEPA LAW AND LITIG. § 7:26 (2023-2024)

[274] *See id*. (noting that, while "[a]gency disclosure of documents must be meaningful," where public hearings are held and relevant decision-making material is disclosed, courts "have been generous in finding that notice and public participation were adequate"). For a discussion of the dynamics of public participation in NEPA processes, and an assessment of NEPA's impact on environmental justice, *see* Nicola Ulibarri, Omar Pérez Figueroa, & Anastasia Grant, *Barriers and Opportunities to Incorporating Environmental Justice in the National Environmental Policy Act*, 97 ENVIRONMENTAL IMPACT ASSESSMENT REVIEW 106880 (2022), https://doi.org/10.1016/j.eiar.2022.106880.

[275] *See* Ray Vaughan, *Necessity and Sufficiency of Environmental Impact Statements under the National Environmental Policy Act*, *in* 38 AMERICAN JURISPRUDENCE PROOF OF FACTS 3D 547 (Sept. 2023 update) ("NEPA is a procedural statute only; it makes no substantive demands on the federal agencies" and "mandates no particular result from the consideration of environmental impacts, but only that those impacts be identified and considered.")

true of state and local environmental review laws, though a small number of those do impose more substantive requirements.[276]

Fifteen states, the District of Columbia, and Puerto Rico have enacted their own environmental review statutes modeled on NEPA.[277] Environmental review requirements have been established by executive order in one other state, while some localities (e.g., New York City) and regional bodies (e.g., the Tahoe Regional Planning Agency) have adopted their own requirements. Whereas NEPA requires environmental reviews for certain federal actions, the so-called "little NEPAs" adopted at the state and local levels typically require review of actions that are undertaken, funded, or permitted by state or local bodies.[278] Similar to NEPA, most state and local equivalents only require preparation of an EIS (or similar document) for actions with significant environmental impacts, though some apply different standards. In Virginia, for example, an environmental impact report (equivalent to a federal EIS) is required for any "major state project" that involves the acquisition or land or construction of facilities costing $500,000 or more.[279] All of the state and local laws include requirements for public notice and consultation similar to those in NEPA.

A few state and local environmental review laws go beyond NEPA's procedural requirements and also include substantive or "action forcing" provisions that require certain decisions or actions to be taken based on the outcome of the environmental review process. One example is the California Environmental Quality Act ("CEQA") which requires state and local agencies to prepare an EIR for "any project which they propose to carry out or approve that may have significant effect on the environment."[280] CEQA further mandates that, before moving ahead with such a project, the "agency shall mitigate or avoid the significant effects on the environment . . . whenever it is feasible to do so."[281] This requirement does not, however, apply where "economic, social, or other conditions make it infeasible to mitigate one or more significant effects on the environment."[282] Where that is the case, the project may go ahead "at the discretion of [the] agency," provided it is "otherwise permissible under applicable laws and regulations."[283]

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[276] *See* Daniel R. Mandelker et al., *State Environmental Policy Acts*, *in* NEPA LAW AND LITIG. § 12:1 (2023-2024) ("In a few states, such as Washington and California, the environmental policy law has a limited substantive effect. Other states have limited the legal effect of an impact statement by providing that it is to be treated solely as an informational document.").

[277] *See* Council on Environmental Quality, *State and Local Jurisdictions with NEPA-like Environmental Planning Requirements*, NEPA.GOV (n.d.), https://ceq.doe.gov/laws-regulations/states.html (last visited May 28, 2024).

[278] Some state laws require environmental review of state actions only. Under others, both state and local actions are subject to environmental review.

[279] Virginia Code 10.1-1188.

[280] Cal. Pub. Res. Code, § 21100.

[281] *Id*. § 21002.1(b).

[282] *Id*. § 21002.1(c).

[283] *Id*.

The District of Columbia Environmental Policy Act ("DCEPA") includes even stronger "action forcing" provisions. Under the DCEPA, where the EIS prepared for an action "identifies an adverse effect" from that action and finds "that the public health, safety, or welfare is imminently and substantially endangered by the action," government officials must "disapprove the action, unless the applicant proposes mitigation measures or substitutes a reasonable alternative to avoid the danger."[284] This would give government authorities scope to regulate the conduct of AOE activities to ensure they occur in a safe and responsible manner.

5.1.2 Notice Requirements Under the Weather Modification Reporting Act and State Equivalents

AOE projects could trigger reporting requirements under the WMRA[285] and equivalent state statutes. Enacted in 1972, the WMRA makes it unlawful for any person to "engage, or attempt to engage, in any weather modification activity in the United States" unless the person submits a report on the activity to the National Oceanic and Atmospheric Administration ("NOAA").[286] When first enacted, the primary target of the WMRA was cloud seeding, which at the time was being used commercially to clear fog, increase snow and rainfall, and reduce destruction by hail.[287] However, recognizing that other weather modification techniques were also being explored, Congress did not limit the WMRA's application solely to cloud seeding.

The WMRA applies broadly to any "weather modification" activity, which the act defines as "any activity performed with the intention of producing artificial changes in the composition, behavior, or dynamics of the atmosphere."[288] Regulations issued under the WMRA provide further guidance on what qualifies as weather modification. According to the regulations:

> The following, when conducted as weather modification activities, shall be subject to reporting:
> (1) Seeding or dispersing of any substance into clouds or fog to alter drop size distribution, produce ice crystals or coagulation of droplets, alter the development of hail or lightening, or influence in any way the natural development cycle of clouds or the environment;
> (2) Using fires or heat sources to influence convective circulation or to evaporate fog;
> (3) Modifying the solar radiation exchange of the earth or clouds, through the release of gases, dusts, liquids, or aerosols into the atmosphere;

[284] DC Act. 8-65, § 5.

[285] 15 U.S.C. § 330 et seq.

[286] *Id*. § 330a.

[287] U.S. DEP'T OF COMMERCE, A REPORT TO THE PRESIDENT AND THE CONGRESS: NATIONAL WEATHER MODIFICATION POLICIES AND PROGRAMS (1979), https://library.oarcloud.noaa.gov/noaa_documents.lib/Digitization_Scans/FY23_Scans/National_Weather_Modification_Policies_and_Programs_Submitted_by_the_Secretary_of_Commerce_in_Compliance_with_Public_Law_94-490.pdf. *See also* Albert C. Lin, *U.S. Law*, *in* CLIMATE ENGINEERING AND THE LAW 154, 160 (Michael B. Gerrard & Tracy Hester, eds, 2018).

[288] 15 U.S.C. § 330(3).

(4) Modifying the characteristics of land or water surfaces by dusting or treating with powders, liquid sprays, dyes, or other materials;
(5) Releasing electrically charged or radioactive particles, or ions, into the atmosphere;
(6) Applying shock waves, sonic energy sources, or other explosive or acoustic sources to the atmosphere;
(7) Using aircraft propeller downwash, jet wash, or other sources of artificial wind generation; or
(8) Using lasers or other sources of electromagnetic radiation.[289]

The regulations make clear that this is a non-exhaustive list and that "other similar activities falling within the definition of weather modification . . . are also subject to reporting."[290]

AOE activities are designed to produce "artificial changes in the composition . . . of the atmosphere"—i.e., by converting methane in the atmosphere into carbon dioxide—and thus would fall within the definition of "weather modification" in the WMRA. Notably, however, the reporting requirements in the WMRA would only apply to AOE projects that are conducted by non-federal entities. Under the WMRA, only "persons" are required to file reports, and the definition of "persons" expressly excludes those "acting solely as an employee, agent, or independent contractor of the Federal Government."[291]

To comply with the WMRA, persons engaging in weather modification activities must provide NOAA with an initial report at least 10 days before commencement of the activity,[292] and interim reports at least annually for so long as the activity continues.[293] A final report must be submitted to NOAA within 45 days of completion of the activity.[294] NOAA must make all reports publicly available.[295] In this way, then, the WMRA could help to increase the visibility of AOE projects and ensure that the government and public have up to date information about when, where, and how they are conducted. However, like NEPA, the WMRA does not impose substantive requirements that would ensure activities proceed in a safe and responsible manner.

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[289] 15 C.F.R. § 908.3(a).

[290] *Id*. § 908.3(b).

[291] For the purposes of the WMRA, "person" means "any individual, corporation, company, association, firm, partnership, society, joint stock company, any State or local government or any agency thereof, or any other organization . . . who is performing weather modification activities, except where acting solely as an employee, agent, or independent contractor of the Federal Government." *See* 15 U.S.C. § 330(2). This definition notably does *not* exempt state and local governments from the WMRA's reporting requirements.

[292] 15 C.F.R. § 908.4.

[293] *Id*. § 908.5.

[294] *Id*. § 908.6.

[295] NOAA must not, however, disclose any confidential information. *See* 15 U.S.C. § 330b; 15 C.F.R. § 908.12.

Some states have enacted their own weather modification laws that do impose more substantive requirements. One example is the Colorado Weather Modification Act ("Colorado WMA") which, like the federal WMRA, was enacted in 1972. Similar to the federal WMRA, the Colorado WMA defines "weather modification" to mean "any program, operation or experiment intended to induce changes in the composition, behavior, or dynamics of the atmosphere by artificial means."[296] This definition would, again, encompass AOE activities that change the composition of the atmosphere by converting methane into carbon dioxide.

Whereas the federal WMRA only requires reporting of weather modification activities, the Colorado WMA goes further, requiring those activities to be permitted by the state Department of Natural Resources.[297] Permit applications must include, among other things, an operational plan that specifies where and how the weather modification activity will take place.[298] The applicant must meet certain qualification and experience requirements and provide proof of financial responsibility adequate to meet obligations reasonably likely to be attached to, or result from, the proposed weather modification activity.[299] The applicant may satisfy the financial responsibility requirements by providing evidence of a liability policy for at least $1 million or three times the value of the weather modification activity (whichever is greater).[300]

Before permitting a weather modification activity, the Colorado Department of Natural Resources must hold a public hearing, and consider the testimony provided there.[301] A permit may only be issued if the Department determines that the activity:

- can be "reasonably expected to benefit the people" of Colorado or the specific area in which the activity will take place;
- is "scientifically and technically feasible;"
- does not "involve a high degree of risk of substantial harm to land, people, health, safety, property, or the environment;"
- is "designed to include adequate safeguards to prevent substantial damage to land, water rights, people, health, safety, or the environment;"
- "will not adversely affect another project;" and

[296] Colo. Rev. Stat. § 36-20-104.

[297] *Id*. § 36-20-109.

[298] *Id*. § 36-20-112(1).

[299] *Id*. *See also* Colorado Weather Modification Rules and Regulations, Rule 6(B).

[300] Colorado Weather Modification Rules and Regulations, Rule 6(B).

[301] Colo. Rev. Stat. § 36-20-112(2)-(3).

- is "designed to minimize risk and maximize economic gains or economic benefits to the residents of the area or the state."[302]

Where an activity is permitted, the person conducting it must maintain and submit to the Colorado Department of Natural Resources daily logs, annual reports, and additional documentation for aircraft-based operations.[303]

5.1.3 Requirements Imposed by Species and Habitat Protection Laws

AOE activities could pose risks to species and thus implicate various domestic species protection laws. It should be noted that, to date, there has been little scientific research focused specifically on the potential impacts of AOE on species. However, some scientists have posited that certain AOE approaches could impact the mercury cycle, with adverse consequences for species.[304] Additionally, AOE approaches that involve the dispersal of iron salt aerosol over the ocean could lead to ocean fertilization, which has previously been shown to pose risks to marine species.[305] For example, phytoplankton growth associated with iron fertilization could divert macronutrients from other ocean regions (a phenomenon known as "nutrient robbing"), with significant ecological impacts.[306] Ocean fertilization could also cause algae blooms that are known to be toxic to wildlife.[307]

A number of federal and state laws have been adopted to protect species and their habitats. Perhaps most notable is the federal ESA of 1973, which establishes "a program for the conservation of . . . endangered species and threatened species," and "the ecosystems upon which [they] depend."[308] Under the ESA, primary responsibility for species protection rests with two federal bodies: (1) the Fish and Wildlife Service ("FWS"), which is within the U.S. Department of the Interior and is responsible for terrestrial and freshwater species, and (2) the National Marine Fisheries Service ("NMFS"), which is within the Department of Commerce and is

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[302] *Id*. § 36-20-112(3).

[303] Colorado Weather Modification Rules and Regulations, Rule 13.

[304] Personal communication with Katrine Gorham, Spark Climate (Feb. 27, 2024). Atmospheric radicals, including hydroxyl and chlorine radicals that are central to some proposed AOE approaches, are one of the few natural mechanisms for removing long-lasting atmospheric mercury. *See* Che-Jen Lin & Simo O. Pehkonen, *Aqueous Phase Reactions of Mercury with Free Radicals and Chlorine: Implications for Atmospheric Mercury Chemistry*, 38 CHEMOSPHERE 1253 (1999), https://doi.org/10.1016/S0045-6535(98)00526-8, *see also* Chelsea R. Stephens et al., *The Relative Importance of Chlorine and Bromine Radicals in the Oxidation of Atmospheric Mercury at Barrow, Alaska*, 117 JOURNAL OF GEOPHYSICAL RESEARCH: ATMOSPHERES (2011), https://doi.org/10.1029/2011JD016649 (discussing the relative importance of different radicals in the oxidation of atmospheric mercury). For more information about the species-level impacts of atmospheric mercury, *see* D.C. EVERS, T. TEAR, & M. BURTON, MERCURY: A THREAT TO BIOLOGICAL DIVERSITY, BIODIVERSITY RESEARCH INSTITUTE (2022), https://briwildlife.org/wp-content/uploads/2023/03/FINAL-Mercury-and-Biodiversity-3-25-23.pdf.

[305] *See generally* SCOTT C. DONEY ET AL., A RESEARCH STRATEGY FOR OCEAN-BASED CARBON DIOXIDE REMOVAL AND SEQUESTRATION 86-90 (The National Academies Press, 2022).

[306] *Id*. at 87.

[307] *Id*. at 89.

[308] 16 U.S.C. § 1531(b).

responsible for marine species.[309] However, while FWS and NMFS take the lead, the ESA makes clear that "all Federal agencies [must] seek to conserve endangered species and threatened species."[310]

Under Section 4 of the ESA, FWS and NMFS must publish and maintain a list of "endangered species," which are "in danger of extinction throughout all or a significant portion of [their] range."[311] FWS and NMFS must also list "threatened species" which are "likely to become . . . endangered species within the foreseeable future throughout all or a significant portion of [their] range."[312] When a species is listed as endangered or threatened, FWS and NMFS must "concurrently . . . designate any habitat of such species which is then considered to be critical habitat."[313]

The ESA includes two primary mechanisms for protecting endangered and threatened species and their critical habitat. The first, set out in Section 7 of the ESA, is intended to prevent harm to species from federal government actions.[314] To this end, Section 7 of the ESA requires federal agencies to ensure that actions they undertake, fund, and authorize are "not likely to jeopardize the continued existence of any endangered species or threatened species or result in the destruction or adverse modification of [the species' critical] habitat."[315] The second mechanism, Section 9 of the ESA, prohibits both federal and nonfederal actors from killing, harming, harassing, or otherwise "taking" endangered species.[316]

Section 7 of the ESA will apply where a federal government body proposes to undertake, fund, or authorize an AOE project that poses risks to endangered or threatened species. The ESA recognizes that, to meet their Section 7 obligations, federal agencies may require "the assistance of" FWS and NMFS.[317] The ESA thus establishes a process by which federal agencies can consult with FWS and NMFS about proposed actions. Consultation is required whenever a federal agency action may affect listed species.[318] If the agency determines that its action "may affect, but is not likely to adversely affect" a listed species, it may ask to consult with

[309] The ESA imposes obligations on "the Secretary" and defines that term to mean "the Secretary of the Interior or the Secretary of Commerce as program responsibilities are vested pursuant to the provisions of Reorganization Plan Numbered 4 of 1970." *See* 16 U.S.C. § 1532(15). The Secretary of the Interior has delegated program responsibilities to FWS, while the Secretary of Commerce has delegated program responsibilities to NMFS. *See Listing & Classification: About Us*, U.S. FISH AND WILDLIFE SERVICE, https://www.fws.gov/program/listing-and-classification/about-us (last visited May 28, 2024).

[310] 16 U.S.C. § 1531(c)(1).

[311] *Id*. §§ 1532(6) & 1533(a)(1).

[312] *Id*. §§ 1532(20) & 1533(a)(1).

[313] *Id*. § 1533(a)(3).

[314] *Id*. § 1536.

[315] *Id*. § 1536(a)(2).

[316] *Id*. § 1538. *See also id*. § 1532(19) (defining "take").

[317] *Id*. § 1536(a)(2).

[318] *Id*. § 1536(a)(3).

FWS/NMFS on an informal basis.[319] FWS/NMFS will then conduct a short (typically less than 60 day) review and, if FWS/NMFS agrees that adverse effects are unlikely, issue a concurrence letter that effectively terminates the consultation and allows the action to go ahead without further review under the ESA.[320] In contrast, where an agency action has the potential for adverse impacts on listed species, a more extensive formal consultation process is required.[321] As part of that process, FWS/NMFS will evaluate whether the action is likely to jeopardize the continued existence of listed species or destroy or adversely modify critical habitat, and detail its findings in a Biological Opinion.[322] The Biological Opinion must typically be issued within 135 days, unless the agencies involved agreed to a longer-review, which is not uncommon.[323]

If a federal agency action is considered likely to jeopardize listed species or adversely modify critical habitat, FWS/NMFS must notify the agency of any alternative methods of implementing the action that would avoid violation of the ESA (known as "reasonable and prudent alternatives").[324] It is, however, ultimately up to the agency to determine whether and how to proceed with the proposed action.[325]

While the above consultation requirements only apply to federal agencies, Section 9 of the ESA establishes a broad prohibition on the "take" of endangered species, which applies to both federal and non-federal actors alike. Section 9 of the ESA makes it "unlawful for any person subject to the jurisdiction of the United States to . . . take any [endangered] species within the United States or the territorial sea of the United States . . . [or] upon the high seas."[326] While the take prohibition in Section 9 only applies to endangered species, FWS and NMFS can and have issued regulations expanding it to also apply to threatened species.[327]

While the impacts of AOE activities on species remain uncertain, it is possible that those activities might result in "take," as defined in the ESA, at least in some circumstances. For the purposes of the ESA, take is defined broadly to mean "harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct."[328] The definition includes a range of activities that would indirectly harm protected

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[319] 50 C.F.R. § 402.13.

[320] *Id*. § 402.13(c).

[321] Id. § 402.14.

[322] *Id*. § 402.14(h).

[323] The formal consultation process must typically be concluded within 90 days of its initiation, with a biological opinion issued within 45 days after the conclusion of the consultation process. *See* 16 U.S.C. § 1536(b)(1)(A); 50 C.F.R. § 402.14(e). For a discussion of the typical length of formal consultations, *see* Melinda Taylor et al., *Protecting Species or Hindering Development? How the Endangered Species Act Impacts Energy Projects on Western Public Lands,* 46 ENVIRONMENTAL LAW REPORTER 10924 (2016).

[324] 50 C.F.R. § 402.14(h)(2).

[325] *Id*. § 402.15.

[326] 16 U.S.C. § 1538(a)(1)(B)-(C).

[327] *Id*. § 1533(d); 50 C.F.R. §§ 17.21 & 17.71 & Part 223.

[328] 16 U.S.C. § 1532(19).

species, including "significant habitat modification or degradation [which] actually kills or injures [species] by significantly impairing essential behavioral patterns, including breeding, feeding or sheltering."[329] Thus, even if an AOE project does not directly kill any listed endangered or threatened species, it might still be found to qualify as a take if it results in major changes to a species' habitat and those changes lead to death or injury of one or more individual members of the species.

It should be noted that, for an actor to be liable under the ESA for indirect take of a listed species, that take must be reasonably and foreseeably traceable to the actor's activities. "To prove 'harm' to a listed species, a plaintiff must show: (1) actual death or injury, (2) to identifiable members of a listed species, (3) which must be proximately caused by the challenged activity and be foreseeable."[330] However, "[t]he ESA does not require the defendant to be the sole threat to the species,"[331] and relatively indirect harm can still constitute a prohibited take.

For example, in *Defenders of Wildlife v. Boyles*, two environmental organizations sued the South Carolina Department of Natural Resources and a pharmaceutical company under Section 9 of the ESA, alleging that they had conducted an impermissible take of *rufa* red knots, a protected migratory seabird. Operating under a permit from the South Carolina Department of Natural Resources, the pharmaceutical defendants conducted a catch-and-release program through which they temporarily removed horseshoe crabs from Carolina's coastal waters, extracted blood from the crabs for use in pharmaceutical research, and then returned the crabs to their home waters.[332] The plaintiffs alleged that this activity constituted a take of the red knots under Section 9 of the ESA because the defendants' actions reduced the supply of horseshoe crab eggs and thereby "significantly disrupt[ed] the normal feeding patterns" of the red knots.[333] A Federal District Court for the District of South Carolina rejected defendants' motion to dismiss these claims, holding that defendants' interference with the horseshoe crab population, and its alleged impacts on the red knots, plausibly alleged an impermissible take in violation of Section 9 of ESA.[334] Other courts have upheld a wide range of Section 9 claims alleging similarly indirect takes, including a dam's failure to maintain and repair a fish ladder, "caus[ing] debris to fill up and block

[329] 50 C.F.R. § 17.3; *see also Babbitt v. Sweet Home Chapter of Communities for a Great Oregon*, 515 U.S. 687, 703–04 (1995) (holding that restrictions on habitat modification were a reasonable interpretation of ESA's prohibition on the indirect "take" of endangered species).

[330] *Cascadia Wildlands v. Scott Timber Co.*, 618 F. Supp. 3d 1038, 1066 (D. Or. 2022) (citing *Babbitt v. Sweet Home Chapter of Communities for a Greater Oregon*, 515 U.S. 687 (1995)).

[331] *Defs. of Wildlife v. Boyles*, 608 F. Supp. 3d 336, 346 (D.S.C. 2022).

[332] *Id. at* 340.

[333] *Id. at* 346.

[334] *Id*. at 345.

the ladder,"[335] and a state agency's failure to remove feral cats from a state park, resulting in the death of threatened wild birds.[336]

Given these broad interpretations of the ESA, AOE projects that harm or kill listed species, either directly or indirectly through changes to their habitat, would likely result in a prohibited take within the ESA definition. Even so, such projects may be permitted by FWS/NMFS in certain circumstances. Under Section 10 of the ESA, FWS/NMFS may issue permits authorizing acts that result in the take of listed species, if those acts are undertaken "for scientific purposes" or if the take "is incidental to, and not for the purpose of, the carrying out of an otherwise lawful activity."[337] Permit applications must include a habitat conservation plan that specifies the likely impact of the taking, measures the applicant will take "to minimize and mitigate such impacts, and the funding that will be available" therefor, as well as "what alternative actions . . . the applicant considered and the reasons why such alternatives are not being utilized."[338] FWS/NMFS may grant an application and issue a permit if satisfied that, among other conditions, "the taking will not appreciably reduce the likelihood of the survival and recovery of the species in the wild."[339] Small-scale AOE projects, particularly early-stage research projects, are likely to have fairly limited impacts on species and thus may qualify for "incidental take" permits if the project proponent has a valid plan for managing any adverse impacts and the project is otherwise conducted in accordance with applicable laws and regulations.

In addition to the ESA, a number of other species protection laws might also apply to AOE projects, depending on where and how they are conducted. For example, projects that occur offshore may implicate the Marine Mammal Protection Act, which prohibits the take of marine mammals without a permit issued by FWS or NOAA Fisheries.[340] Offshore projects could also be subject to the Magnuson-Stevens Fisheries Conservation Act, which requires federal agencies to consult with NMFS before undertaking, funding, or authorizing any action that could harm "essential fish habitat" designated under the Act.[341] Several states also have species protection laws that impose additional consultation and other requirements for projects undertaken, authorized, or funded by state bodies.[342]

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[335] *Los Molinos Mut. Water Co. v. Ekdahl*, No. 221CV01961DADDMC, 2023 WL 6386898, at *17 (E.D. Cal. Sept. 29, 2023).

[336] *See Am. Bird Conservancy v. Harvey*, 232 F. Supp. 3d 292 (E.D.N.Y. 2017).

[337] *Id*. § 1539(a)(1).

[338] *Id*. § 1539(a)(2)(A).

[339] *Id*. § 1539(a)(2)(B).

[340] *Id.* §§ 1372 & 1374.

[341] *Id*. § 1855.

[342] *See generally* Lin, *supra* note 287.

5.2 Domestic Laws Governing the Construction and Use of Fixed Structures for Atmospheric Oxidation Enhancement

AOE could be performed using fixed structures, such as towers, to disperse reactive materials into the air. The structures could, in theory, be located on land or in the ocean. The key legal issues associated with constructing and using structures for AOE are discussed in this part.

5.2.1 Land Use Laws Governing the Construction or Adaptation of Fixed Structures

AOE could be performed using fixed structures located on land. Some projects may seek to make use of existing structures (e.g., by attaching dispersal systems to existing communications towers or similar facilities), while others may involve construction of new facilities. Early research suggests that coastal areas may be ideal sites for AOE structures because of the role that sea spray plays in the methane oxidation process (see Part 2 above). The use of coastal or other land for AOE structures will need to be legally authorized. The approach to, and difficulty associated with, securing the necessary authorization will partly depend on the ownership of the relevant land.

(A) Constructing or Adapting Structures on Privately Owned Land

Approximately 60 percent of all land in the United States (1.37 billion acres) is privately owned.[343] From a legal perspective, obtaining access to privately owned land should be fairly straightforward, at least where the owner is willing to sell or lease the land or otherwise agrees to its use for AOE. However, even if a private landowner agrees to allow AOE on their land, the project must still comply with requirements imposed by federal, state, tribal, and local laws (including the permitting requirements discussed in Part 5.2.3 below). AOE project developers looking to erect structures on privately owned coastal land will need to be particularly mindful of state and local laws that restrict development along the coast.

In much of the United States, coastal tidelands (i.e., areas lying between the ordinary low and high tide lines that go from submerged to exposed as the tide moves) are owned by coastal states and sometimes localities within those states.[344] Most upland areas (i.e., areas lying inland of the high tide line) fall under private ownership,[345] but that privately owned land is often subject to public easements or other development restrictions. For example, several states have so-called "beach access laws" that aim to ensure public access to

[343] DANIEL P. BIGELOW & ALLISON BORCHES, UNITED STATES DEPARTMENT OF AGRICULTURE: ECONOMIC RESEARCH SERVICE, ECONOMIC INFORMATION BULLETIN NUMBER 198: MAJOR USES OF LAND IN THE UNITED STATES, 2012 (Aug. 2017), https://www.ers.usda.gov/webdocs/publications/84880/eib-178.pdf?v.

[344] There are some exceptions. In Maine, for example, tidelands can be and often are privately owned. *See generally,* JOHN DUFF, PUBLIC SHORELINE ACCESS IN MAINE: A CITIZENS GUIDE TO OCEAN AND COASTAL LAW, THIRD EDITION (2016), https://digitalcommons.mainelaw.maine.edu/cgi/viewcontent.cgi?article=1300&context=oclj.

[345] It is estimated that approximately 70 percent of coastal land in the U.S. is privately owned. *See* W*ho Owns the Beach?*, ON THE COMMONS (Oct. 12, 2005), https://www.onthecommons.org/who-owns-beach/index.html (last visited May 28, 2024).

tidelands by restricting development on upland areas that are under private ownership. In Texas, the Open Beaches Act declares that "the public has the right of ingress and egress" to and from certain beach areas, "extending from the line of mean low tide to the line of vegetation bordering on the Gulf of Mexico."[346] Under the Act, it is unlawful for "any person to create, erect, or construct any obstruction, barrier, or restraint" on land lying seaward of the "line of vegetation" if doing so "will interfere with the free and unrestricted right of the public . . . to enter or to leave" beach areas.[347] This restriction applies even if the land in question is under private ownership. Thus, for example, AOE towers could not be constructed in Texas on privately owned land lying seaward of the line of vegetation if the construction would obstruct public access to the beach. Importantly, the Texas Open Beaches Act declares that "the line of vegetation is dynamic and may move landward or seaward due to the forces of erosion or natural accretion," and thus the land on which development is restricted may change over time.[348] Structures that were initially installed on land lying inland of the line of vegetation may need to be removed later if the vegetation line shifts and they then become an impediment to public access to the beach.

(B) Constructing or Adapting Structures on Government-Owned Land

The federal government owns approximately 644 million acres of land, equivalent to roughly 28 percent of the total U.S. land area.[349] An additional 189 million acres, equivalent to eight percent of the total land area, is under state and local government ownership.[350] The construction of AOE towers or other structures on government-owned land, or the installation of AOE dispersal systems on existing structures on government-owned land, will require prior approval from the federal, state, or local body charged with management of the land. At the federal level, this will often be the Department of the Interior's Bureau of Land Management ("BLM"), which manages approximately 244 million acres of federally-owned land (commonly referred to as "public land"), located almost entirely in the 11 coterminous western states and Alaska.[351] Another important federal land manager is the U.S. Department of Agriculture's Forest Service, which oversees approximately 192 million acres (known as "forest land"), again mostly in the western U.S.[352] States and localities have their own land management agencies that are responsible for authorizing the use of state and locally-owned land, respectively.

In practice, the use of public land by nongovernmental entities usually involves a formal document like a lease or right-of-way that transfers and establishes rules around occupancy rights. Leases and similar land

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[346] Tex. Nat. Res. Code Ann. § 61.011.

[347] *Id*. § 61.013.

[348] *Id*. § 61.016(d).

[349] BIGELOW & BORCHES, *supra* note 343 at 42.

[350] *Id*.

[351] CAROL HARDY VINCENT ET AL., CONGRESSIONAL RESEARCH SERVICE, FEDERAL LAND OWNERSHIP: OVERVIEW AND DATA 1 (2020), https://fas.org/sgp/crs/misc/R42346.pdf.

[352] *Id*.

authorizations may contain a wide variety of terms and conditions, and a complete overview of such provisions is outside of the scope of this paper. Nevertheless, these authorizations often permit only a limited range of intended uses. Whether AOE dispersal projects seek to build dedicated AOE structures or modify existing structures (e.g., communications towers) for AOE dispersal, they would likely require the approval of any relevant government lessor. For example, BLM requires private users of public land to seek to amend their use agreements if there is "a proposed substantial deviation in location or use" of an existing occupancy right.[353] While BLM grants some tenants the right to sublease their facilities without prior approval, such subleases must generally fall into approved uses.[354] For the purposes of an AOE project on BLM-managed land, "[t]he requirements to amend an application or grant are the same as those for a new application."[355]

In managing federally-owned land, BLM and the Forest Service must follow the principles of "multiple use" and "sustained yield."[356] The multiple use principle requires that federal land and its resources be "utilized in the combination that will best meet the future needs of the American people."[357] It aims to ensure "a combination of balanced and diverse resource uses that takes into account the long-term needs of future generations for renewable and nonrenewable resources . . . and harmonious and coordinated management of the various uses without permanent impairment of the productivity of the land or the quality of the environment."[358] BLM and the Forest Service must also ensure "sustained yield," meaning "the achievement and maintenance in perpetuity of a high-level annual or regular periodic output of the various renewable resources of [federally-owned] land."[359] Where consistent with these principles, BLM and the Forest Service may authorize the use of federally-owned land by private parties. The two agencies follow broadly similar approaches to authorizing land use, but there are some important differences between their approaches.

BLM authorizes land use pursuant to the Federal Land Policy and Management Act of 1976 ("FLPMA").[360] Under Section 302(b) of FLPMA, BLM may authorize the use of public land for any activity that is "not specifically

[353] 43 C.F.R. § 2807.20(a).

[354] *See, e.g.*, 43 C.F.R. § 2806.36 (outlining BLM's requirements for tenants subleasing a multiple-use communication facility, like a cell tower, and noting that sublessees must either have their own use authorizations or fall under an existing approved use in their sublessor's agreement with BLM).

[355] 43 C.F.R. § 2807.20(b).

[356] The two agencies manage federal lands pursuant to different statutory regimes but both have a similar mandate to ensure multiple use and sustained yield. *See id*.

[357] 43 U.S.C. § 1702(c); 16 U.S.C. § 531(a).

[358] 43 U.S.C. § 1702(c); 16 U.S.C. § 531(a).

[359] 43 U.S.C. § 1702(h) ; 16 U.S.C. § 531(b).

[360] 43 U.S.C. § 1701 et seq.

authorized under other laws or regulations, and not specifically forbidden."[361] Authorization can take a number of forms:

(1) permits may be issued for short-term land uses (not exceeding 3 years) that involve little or no land improvement, construction, or investment;

(2) leases may be issued for longer-term land uses that involve substantial construction or land improvement, and the investment of large-amounts of capital; and

(3) easements may be issued for land uses that are compatible with other uses occurring on nearby land.[362]

The use of public lands for AOE is neither expressly authorized nor forbidden by law and thus could be approved by BLM under Section 302(b) of FLPMA. It is likely that a public land lease would be required, at least where the AOE project involved the construction of towers or other structures, which would remain in place for an extended period. If an AOE project also required the construction of roads (e.g., to access the towers), that construction would need to be separately authorized by BLM via a right-of-way. Under Section 501 of FLPMA, BLM may issue rights-of-way for roads, trails, and "other means of transportation."[363]

BLM can only issue a lease, right-of-way, or other land use authorization if the "proposed land use is in conformance with" any applicable Resource Management Plan ("RMP").[364] BLM issues, and periodically updates, RMPs to guide its management of specific tracts of public land.[365] Each RMP identifies resource goals and objectives for the covered tract of land and defines allowable uses and management practices that are designed to achieve those goals and objectives.[366] According to BLM regulations, a proposed land use will be in conformity with the applicable RMP if the use is "specifically provided for in the plan, or if not specifically mentioned, . . . clearly consistent with the terms, conditions, and decisions of the . . . plan."[367] At the time of writing, no RMP specifically provided for AOE on public lands. The types of land uses commonly envisioned in RMPs (e.g., oil and gas extraction, timber harvesting, and ranching) involve very different activities and risks to AOE. Given this, BLM might take the view that AOE projects are not in conformance with existing RMPs, and thus cannot be authorized unless and until the applicable RMPs are amended. This is typically a long process, requiring public notice and comment, consultation with other federal agencies and affected states, and an

[361] *Id*. § 1732(b).

[362] 43 C.F.R. § 2920.1-1.

[363] 43 U.S.C. § 1761.

[364] *Id.* §§ 1712 & 1732.

[365] *See generally*, BUREAU OF LAND MANAGEMENT, LAND USE PLANNING HANDBOOK (2005), https://www.blm.gov/sites/blm.gov/files/uploads/Media_Library_BLM_Policy_Handbook_h1601-1.pdf.

[366] *Id*. at 12-13.

[367] 43 C.F.R. § 1601.0-5(b).

environmental review under NEPA. Further consultations and environmental reviews would also be required before BLM would issue a lease or other form of authorization for AOE on public land.

AOE projects on federal forest land would require a special use authorization from the Forest Service. Under the National Forest Management Act of 1976 ("NFMA"), special use authorizations may be issued for any activity on federal forest land that does not involve the harvesting of timber or other forest products, mineral development, grazing and livestock use, or road use.[368] Before issuing an authorization, the Forest Service must undertake an environmental review and consult with relevant stakeholders. The Forest Service must also ensure that authorized uses are consistent with any applicable land use plan (i.e., the Forest Service equivalent to an RMP). Notably, the Forest Service considers an activity to be consistent with a land use plan if it occurs on land that the plan either (1) "identifies as suitable for that type of . . . activity" or (2) "is silent with respect to its suitability" for the activity.[369] This is different from the approach taken by BLM, discussed above, and suggests that the Forest Service might be more willing to authorize AOE projects without first amending the applicable land use plan. If a land use plan amendment is required, the Forest Service would have to follow a process similar to that set out above for BLM amendment of an RMP. Again, the process is typically lengthy, and it requires public consultation and an environmental review (among other things).

State-owned land could also be used for AOE projects. Use of state-owned land will generally require a permit or other form of authorization from the relevant state land management agency. States often prioritize mineral development, timber harvesting, and similar extractive uses of state-owned land, but many also allow for other activities thereon. In Montana, for example, the Board of Land Commissioners has broad authority to lease or otherwise authorize the use of state-owned land "for agriculture, grazing, mineral production, cabinsites, and other uses."[370] Authorization processes vary between states and sometimes within them (i.e., different rules might apply to the use of different types of land within a single state). Often, however, state land management agencies employ processes similar to those used by BLM and the Forest Service. For example, like their federal counterparts, state land management agencies often manage state-owned lands in accordance with the "multiple use" principle.[371] To assist them in balancing competing demands on state-owned land, many state agencies have developed land use plans that establish resource goals for different areas, specify management practices to achieve those goals, and identify uses consistent with the goals and practices.[372] State land use plans are typically developed with public input and, in states with little NEPA statutes, may require preparation of an EIS or similar environmental document.[373] Additional consultation and environmental review may be required before the state agency permits individual activities.

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[368] 16 U.S.C. § 1600 et seq.; 36 C.F.R. § 251.50(a).

[369] 36 C.F.R. § 219.15(d).

[370] Mont. Admin. R. 36.25.103.

[371] *See e.g.*, Ariz. Rev. Stat. Ann. § 37-311(1).

[372] *See e.g.*, *Recreation and Unit Management Plans*, N.Y. DEP'T OF ENVIRONMENTAL CONSERVATION (n.d.) https://dec.ny.gov/nature/forests-trees/dec-land-stewardship/rmp-ump (last visited May 28, 2024).

[373] For a discussion of little NEPA statutes, *see supra* Part 5.1.1.

5.2.2 Laws Governing the Construction of Fixed Structures Offshore

In the future, AOE might also be performed offshore from towers located on platforms anchored or otherwise attached to the seabed. The laws governing such offshore activities will depend on precisely where they occur. Generally speaking, near-shore activities in state waters may be subject to requirements imposed by federal, state, and sometimes local law, whereas only federal law will apply to activities occurring further offshore in federal waters.

(A) Offshore AOE Structures in State Waters

As explained in Part 2 above, coastal states have primary authority over near-shore areas within three nautical miles of the U.S. coast, and up to nine nautical miles from the coast in parts of the Gulf of Mexico. The submerged lands underlying state waters are generally controlled by the relevant coastal state or, in some cases, localities within that state. Approval from the relevant state or local authority is required to make use of the submerged lands (e.g., to construct platforms or other offshore structures). As an example, submerged lands within three nautical miles of the California coast are administered by the State Lands Commission, which may issue leases authorizing use of the land by others.[374] In some other jurisdictions, state environmental agencies are responsible for overseeing the use of offshore, submerged lands. In Massachusetts, for instance, the state Department of Environmental Protection must license use of the submerged lands. Some local governments have their own lease or licensing frameworks.[375] Those local frameworks are sometimes more restrictive than state laws and may, for example, only allow the issuance of leases or licenses for select purposes (e.g., aquaculture).[376]

In addition to needing a lease or other instrument authorizing use of offshore submerged land, persons wanting to develop offshore structures might also require construction or other permits. Different states have different permitting requirements. Many impose additional or stricter requirements for construction in wetlands or other sensitive environments. In Connecticut, for example, the "erection of structures" in wetlands requires a special permit from the state Department of Energy and Environmental Protection.[377] New York similarly imposes additional permitting requirements for construction in tidal wetlands and coastal erosion hazard areas.[378] The issuance of such permits may trigger the application of state environmental review laws where they exist (see Part 5.1.1 above).

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[374] Cal. Pub. Res. Code §§ 6216(a) & 6301.

[375] 310 Mass. Code Regs. §§ 9.03-9.05.

[376] *See e.g.,* Suffolk County Government, *Lease Program Overview and Program History,* Shellfish Aquaculture Lease Program, https://www.suffolkcountyny.gov/Departments/Economic-Development-and-Planning/Planning-and-Environment/Environmental-Planning-and-Aquaculture/Shellfish-Aquaculture-Lease-Program/Program-Overview (last visited May 28, 2024).

[377] Conn. Gen. Stat. § 22a-32 (requiring "regulated activities" in a wetland to be permitted). See also id. § 22a-29 (defining "regulated activity" to include "the erection of structures").

[378] NY Comp. Code R. & Regs, tit. 6, §§ 505.2 & 661.

Offshore construction in state waters may also require federal permits. While the federal government has relinquished all of its property rights in the submerged lands under state waters, it regulates the installation of structures on those lands pursuant to its authority over navigation. The federal Rivers and Harbors Act ("RHA") prohibits "the creation of any obstruction . . . to the navigable capacity of any waters of the United States" that is not "affirmatively authorized."[379] Under the RHA, a permit from the Army Corps of Engineers ("ACE") is required to authorize the "building of any . . . structures in any . . . [navigable] water of the United States."[380] Regulations adopted pursuant to the RHA clarify that "the navigable waters of the United States over which [ACE] regulatory jurisdiction extends includes all ocean and coastal waters within a zone three geographic (nautical) miles seaward from the baseline."[381] Before issuing permits for construction in state waters, ACE must comply with procedural requirements imposed by statutes, such as NEPA and the ESA. ACE may also need to consult with the relevant coastal state and ensure that its proposed action is consistent with any state plan adopted under the Coastal Zone Management Act ("CZMA").

(B) Offshore AOE Structures in Federal Waters

The federal government has exclusive authority over federal waters, lying beyond state waters out to 200 nautical miles from shore, and the underlying submerged land (known as the OCS). The courts have held that, while the federal government does not own the OCS in fee simple, the government does have "paramount rights" to it and thus any use of it by others (e.g., to construct platforms or structures) must be authorized by the government.[382]

The Bureau of Ocean Energy Management ("BOEM"), within the federal Department of the Interior, is responsible for issuing leases and rights-of-way over the OCS under the OCSLA. BOEM's authority under the OCSLA is somewhat limited, however, in that it can only issue leases or rights-of-way for activities that:

> (A) support exploration, development, production, or storage of oil and natural gas . . . ;
> (B) support transportation of oil or natural gas, excluding shipping activities;
> (C) produce or support production, transportation, or transmission of energy from sources other than oil and gas;
> (D) use, for energy-related purposes or for other authorized marine-related purposes, facilities currently or previously used for activities authorized under [the Act] . . . ; or

[379] 33 U.S.C. § 403.

[380] *Id*. *See also* 33 C.F.R. § 322.3(a) (stating that a permit is required "for structures and/or work in or affecting navigable waters of the United States").

[381] 33 C.F.R. § 329.12(a).

[382] U.S. v. California [1947] 322 U.S. 19. *See also* ADAM VANN, CONG. RESEARCH SERVICE, WIND ENERGY: OFFSHORE PERMITTING, https://crsreports.congress.gov/product/pdf/R/R40175/15.

(E) provide for, support, or are directly related to the injection of a carbon dioxide stream into sub-seabed geologic formations for the purpose of long-term sequestration."[383]

BOEM could not, pursuant to this grant of authority, issue leases for AOE-related activities. The OCSLA would, therefore, need to be amended by Congress to enable leasing of the OCS for use in AOE. Congress has previously amended the OCSLA to enable new activities on the OCS. For example, in 2022, paragraph (E) above was added to Section 8(p)(1) of the OCSLA to facilitate offshore storage of carbon dioxide.

Like structures in state waters, those in federal waters must also be approved by ACE. As noted above, under the RHA, an ACE permit is required to build "structures in any . . . [navigable] water of the United States."[384] While ocean waters lying more than three nautical miles from the coast are not covered by the RHA, Section 4 of the OCSLA extends ACE's "authority . . . to prevent obstruction to navigation . . . to [certain] artificial islands, installations, and other devices" on the OCS.[385] Specifically, under section 4, ACE has authority over:

> [A]ll artificial islands, and all installations and other decides permanently or temporarily attached to the seabed [of the OCS], which may be erected thereon for the purpose of exploring for, developing, or producing resources therefrom, or any such installation or other decide (other than a ship or vessel) for the purpose of transporting such resources.[386]

ACE has concluded, and the courts have agreed, that Section 4 gives the agency authority over all structures attached to the OCS regardless of how those structures are used.[387] ACE could, thus, issue permits for the construction of AOE-related structures on the OCS. Again, before issuing permits, ACE would need to comply with applicable procedural requirements under NEPA, the ESA, and other statutes.

It is unclear whether an ACE-issued permit would, by itself (i.e., absent a BOEM-issued lease), be sufficient to authorize AOE-related structures on the OCS. In *Alliance to Protect Nantucket Sound, Inc. v. U.S. Department of the Army,* the First Circuit Court of Appeals held that a structure that did not "infringe on any federal property interest" could be installed on the OCS pursuant to an ACE-issued permit, even if no BOEM-issued lease had been issued.[388] The case concerned ACE's issuance of a permit authorizing temporary installation of a data tower on the OCS to collect information about wind resources in the area. The court agreed with ACE that the tower would have "negligible impact on property ownership" given its small footprint and the fact that it would remain

[383] 43 U.S.C. § 1337(p)(1).

[384] *Id*. *See also* 33 C.F.R. § 322.3(a) (stating that a permit is required "for structures and/or work in or affecting navigable waters of the United States").

[385] 43 U.S.C. § 1333(e).

[386] *Id*. § 1333(a) & (e).

[387] *See Alliance to Protect Nantucket Sound, Inc. v. U.S. Dept. of the Army*, 398 F.3d 105, 109 (1st Cir. 2005).

[388] *Id*. at 107 & 114.

in place on the OCS for no more than 5 years.[389] According to the court, it is "inconceivable . . . that permission to erect a single, temporary scientific device like this, which gives the federal government information it requires [to assess the feasibility of offshore wind energy development] could be an infringement on any federal property ownership interest in the OCS."[390] The court thus held that the tower could be authorized through an ACE-issued permit and did not require additional authorization from BOEM.[391]

It may be possible to argue that certain AOE-related structures do not infringe on federal property rights in the OCS. The argument is likely to be strongest where the structures are installed in connection with an AOE research project, have a relatively small footprint, and will be removed from the OCS after a fairly short period of time (i.e., months or years rather than decades). Indeed, those factors led the court to conclude that the data tower at issue in *Alliance to Protect Nantucket Sound* would have negligible impact on federal property interests in the OCS. Small scale AOE research installations might be viewed similarly, and thus could be authorized solely via an ACE-issued permit and not require a separate BOEM-issued lease. However, since larger-scale AOE activities have greater potential to infringe on federal property interests in the OCS, they would likely require both an ACE permit and a BOEM lease.

5.2.3 Laws Imposing Environmental Permit or Similar Requirements

In addition to obtaining any necessary land use approvals, AOE project developers may also need to secure various environmental permits. The environmental permits required will depend on the specifics of the project, including where and how it is conducted. This Part highlights key permits that will often be required for AOE projects involving the dispersal of aerosol from fixed towers or other stationary sources either on land or offshore. Not all the listed permits will be required for all projects,[392] and some projects may require additional approvals not discussed in this Part.[393]

(A) FAA Permits

AOE projects that disperse aerosols from fixed towers or other stationary sources may be subject to oversight by the Federal Aviation Administration ("FAA"), which regulates and supervises a number of activities that may interfere with, or cause hazards to, aircraft navigation. Under regulations governing air traffic safety, anyone building tall facilities must provide notice of their activities to the FAA and will be subject to several regulatory requirements.

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[389] *Id*. at 114.

[390] *Id*.

[391] *Id*.

[392] For example, ocean dumping permits may be required for offshore projects, but they will not be needed for land-based projects.

[393] For example, as discussed in Part 5.1(C), some projects may also require incidental take permits under the ESA.

Any person constructing or modifying a structure that may interfere with air traffic must provide notice to the FAA by the earlier of 45 days before beginning construction, or 45 days before filing for construction permits.[394] Generally, the FAA requires notice for all objects that extend more than 200 feet above ground level, although the FAA has set shorter thresholds near airports and heliports.[395] Following such notice, the FAA may investigate the proposed construction to determine whether it will obstruct air traffic.[396] The FAA has established standards for determining whether a construction will be deemed "a hazard to air navigation," and any construction that extends over 2,000 feet above ground level is presumptively treated as a hazard unless proven otherwise.[397] However, the FAA has no authority to prohibit a facility's construction, and "[a] hazard/no-hazard determination has no enforceable legal effect."[398] Still, a determination by the FAA that an AOE-related structure poses a hazard to air navigation could make other permitting and financing processes more difficult, so in practice FAA hazard determinations can be quite important.[399] The FAA has also established lighting guidelines for tall objects designed to reduce hazards to air navigation.[400]

(B) Clean Air Act Permits

AOE research that involves dispersing aerosols within the territory of the United States will be subject to regulation under the federal CAA.[401] The CAA authorizes EPA to regulate a wide range of "physical, chemical, biological, radioactive," or other substances that are hazardous to human health or the environment, as well as "precursors to the formation of" any regulated air pollutant.[402] Pursuant to this authority, EPA has identified a number of harmful pollutants, and specific precursor chemicals that result in the formation of harmful pollutants, that are subject to regulation.

AOE project proponents should carefully review which air pollutants and air pollutant precursors are regulated under the CAA. If any of the regulated pollutants are released via an AOE project, the project will be subject to oversight by EPA and/or state regulators. Based on currently available information, it appears likely that most and perhaps all AOE projects will release PM, which is a regulated pollutant. EPA regulations identify two classes of PM: (1) PM10, which refers to inhalable particles with diameters of 10 micrometers or less, and (2) PM2.5,

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[394] 14 C.F.R. § 77.7.

[395] *Id*. § 77.9.

[396] *Id*. § 77.13; *see also id*. § 77.17 (establishing standards for determining whether a facility obstructs air traffic).

[397] *Id*. § 77.7(d).

[398] *BFI Waste Sys. of N. Am., Inc. v. F.A.A.*, 293 F.3d 527, 530 (D.C. Cir. 2002).

[399] *See id*. (noting that such a finding by the FAA could "hinder the project sponsor in acquiring insurance, securing financing or obtaining approval from state or local authorities.").

[400] *See* Federal Aviation Administration, Advisory Circular No. 70/7460-1M - Obstruction Marking and Lighting (Nov. 16, 2020), https://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.current/documentNumber/70_7460-1.

[401] 42 U.S.C. § 7401 et seq.

[402] 42 U.S.C. § 7602(g).

which refers to fine inhalable particles with diameters of 2.5 micrometers or less.[403] AOE projects—specifically iron salt aerosol techniques—could involve the release of aerosols measuring less than 2.5 micrometers in diameter,[404] bringing them within the class of PM regulated under the CAA. Given the potential significance of PM regulations to AOE projects, the remainder of this Section will primarily focus on CAA permitting requirements for PM-emitting facilities. This Section will also briefly discuss regulations applicable to other categories of pollutant. AOE project developers should be aware that they may be subject to distinct regulatory requirements based on the specific substances released from AOE facilities.

Permits for Facilities Emitting PM and Other Criteria Air Pollutions

Section 108 of the CAA directs EPA to identify common air pollutants "which may reasonably be anticipated to endanger public health or welfare" (known as "criteria pollutants").[405] EPA has identified six criteria pollutants: (1) carbon monoxide, (2) lead, (3) ground-level ozone, (4) PM, (5) nitrogen dioxide, and (6) sulfur dioxide.[406] For each identified criteria pollutant, EPA must establish primary and secondary national ambient air quality standards ("NAAQS"). Primary NAAQS are those deemed necessary "to protect the public health," while "secondary standards," which are designed "to protect the public welfare,"[407] protect a broader category of interests that includes environmental damage and property damage, among other things.[408] EPA must work with states to establish state-level pollution control plans, called "state implementation plans" ("SIPs"), to achieve the NAAQS.[409] SIPs contain a range of air pollution control measures and plans, including "emission limits for specified pollutants, compliance schedules . . . and ambient monitoring programs to measure attainment progress and compliance with the NAAQS, [and] permit and enforcement programs," among other features.[410]

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[403] *See Particulate Matter (PM) Basics*, EPA (Jul. 11, 2023), https://www.epa.gov/pm-pollution/particulate-matter-pm-basics (discussing sources of PM, and noting that PM includes "a mixture of solid particles and liquid droplets found in the air," whether emitted directly or formed "in the atmosphere as a result of complex reactions of chemicals."). For the purposes of CAA regulation, PM emissions "including gaseous emissions from a source or activity, which condense to form particulate matter at ambient temperatures." *See* 40 C.F.R. § 52.21(b)(50)(i)(a). EPA also regulates certain identified precursors to PM (and other criteria air pollutants), namely sulfur dioxide, nitrogen oxides, and volatile organic compounds in certain circumstances. *See* 40 C.F.R. § 52.21(b)(50)(i)(b).

[404] Personal communication with Katrine Gorham, Spark Climate Solutions (Feb. 27, 2024).

[405] 42 U.S.C. § 7408(a).

[406] *See Criteria Air Pollutants*, EPA (Feb. 16, 2024), https://www.epa.gov/criteria-air-pollutants. EPA also regulates certain substances that have been identified as "constituent[s] or precursor[s] for" criteria air pollutants, including volatile organic compounds. *See* 40 C.F.R. § 52.21(b)(50)(i)(a).

[407] 42 U.S.C. § 7409(b).

[408] *See* Carol Deck, *Ambient Air Quality Standards*, *in* CORP. COMPL. SERIES: ENVTL. § 1:75 (Jul. 2020).

[409] 42 U.S.C.§ 7410.

[410] Carol Deck, *Clean Air Act Definitions and Laws: State Implementation Plans*, *in* CORP. COMPL. SERIES: ENVTL. § 1:77 (Jul. 2020).

The CAA implements a "comprehensive federal operating permit program" for facilities that have the potential to emit significant amounts of any criteria pollutant. This program has two components: (1) an initial review process that determines the adequacy of a facility's pollution control, and (2) a permitting process that establishes monitoring requirements and emissions thresholds on a facility-by-facility basis. These processes are largely run at the state level pursuant to SIPs, but state programs must conform to federal standards set by EPA.[411] In this way, the CAA reflects a cooperative federalism approach to air pollution regulation.

"The principal feature of this [permitting] process, called new source review [("NSR")], requires pre-construction review for new buildings or for expansions of existing facilities that would create a significant increase of a regulated pollutant."[412] A facility, or connected series of facilities, qualifies as a "major source" of emissions if it has the potential to emit more than a defined threshold of criteria pollutants. Facilities are subject to different thresholds based on the industry in which the facility operates, the pollutant it releases, and the air quality of the region in which it is located. Generally, facilities are considered to be "major sources" of air pollution if they "directly emit, or have the potential to emit, 100 [tons per year] or more" of PM or any other regulated pollutant.[413] In areas where air quality falls far below NAAQS thresholds, a facility will be considered a major source if it has the potential to emit 70 tons per year of PM10.[414] For some particularly hazardous pollutants, annual emissions of as little as 10 tons per year can lead to a facility being deemed a "major source" of air pollution.[415] If a proposed facility is identified as a major source of air pollution, it must receive a permit from EPA or the relevant state permitting authority before beginning construction.[416]

The rigorousness of major source permitting under the CAA varies from region to region, based on the existing levels of regional air pollution. In areas that meet or surpass the NAAQS for criteria pollutants, new major sources of pollution must meet the so-called "prevention of significant deterioration" ("PSD") standard, which requires the owners or operators of proposed new or modified major sources to show that they plan to implement the best available emissions control technology.[417] What constitutes the best available control technology is determined "on a case-by-case basis taking into account energy, environmental and economic impacts and other costs" of implementing emissions controls.[418] Permit applicants must also analyze the impact

[411] *See* 42 U.S.C. § 7410 (outlining requirements for state implementation of federal environmental standards).

[412] Carol Deck, *New or Modified Activities—Permitting Requirements for Facilities*, *in* CORP. COMPL. SERIES: ENVTL. § 1:81 (Jul. 2020).

[413] 40 C.F.R. § 70.2; *see also* 42 U.S.C. § 7602(j) ("Except as otherwise expressly provided, the terms "major stationary source" and "major emitting facility" mean any stationary facility or source of air pollutants which directly emits, or has the potential to emit, one hundred tons per year or more of any air pollutant").

[414] 40 C.F.R. § 70.2.

[415] *See id*.

[416] 42 U.S.C. § 7661a(a).

[417] 40 C.F.R. § 51.166.

[418] *Id*. § 51.166(a)(12).

of their proposed emissions on the region's air quality, as well as "visibility, soils, and vegetation."[419] They must additionally show that the new activity, "in conjunction with all other applicable emissions increases or reductions (including secondary emissions)," would not violate national air quality standards in the applicable region."[420] In areas that already exceed the NAAQS for criteria pollutants, called "nonattainment areas," new or modified sources of air pollution are subject to additional, and more rigorous, requirements. Facilities and project sponsors seeking permits under an NSR program must have a history of compliance with air pollution standards[421] and demonstrate that (1) they have engaged in other actions to reduce pollution that "at least offset[s] the added pollutants" from the new source, (2) they are employing the most stringent possible pollution controls for all criteria pollutants, and (3) "[t]he state in which the applicant is siting its new major source [is] implementing its applicable" SIP.[422] Once a pre-construction application for a facility is approved, the facility will receive a permit that outlines that facility's emission limitations and standards, implementation and monitoring requirements, and a variety of other conditions.[423]

Facilities that emit criteria air pollutants but that do not qualify as "major sources" may be subject to similar NSR and permitting programs at the state level. However, the intensity of such regulation and permitting can vary significantly from state to state. The CAA requires states to establish NSR and permitting processes for non-major sources "as necessary to assure that national ambient air quality standards are achieved,"[424] but there are relatively few federal requirements for such programs, and states may vary in the extent to which they regulate non-major sources.[425]

At an early stage in their inception, AOE projects that may qualify as major sources of pollution or regulated non-major sources of pollution should carefully consider what emissions control strategies or offsets they might practically implement. AOE projects that involve the dispersal of aerosols that qualify as regulated pollutants may struggle to reduce their emissions without undermining the fundamental purpose of their activities. In considering emissions control technologies, EPA does not generally require an applicant "to change the fundamental scope of its project."[426] "In a classic and simple example, a coal-burning power plant need not consider a nuclear fuel option as a 'cleaner' fuel because it would require a complete redesign of the coal-

[419] *Id*. § 51.166 (m), (o).

[420] *Id*. § 51.166(k)(1).

[421] *See* 42 U.S.C. § 7503(a)(3).

[422] Steven Ferrey, *New Source Review*, *in* 2 L. OF INDEP. POWER § 6:51 (2023); *see also* 42 U.S.C. § 7503(a).

[423] *See* 40 C.F.R. § 70.6.

[424] 42 U.S.C. § 7410(a)(2)(C).

[425] *Texas v. U.S. E.P.A.*, 690 F.3d 670, 675 (5th Cir. 2012) ("Understandably, Congress and the EPA have devoted much less attention to Minor NSR. The EPA's regulations of Minor NSR span only two pages of the Code of Federal Regulations," and states have "a measure of discretion" beyond those requirements).

[426] *In the Matter of: Old Dominion Electric Cooperative Clover, Virginia, Permit Applicant*, 1992 WL 92372, at *12.

burning power-plant."[427] In *Helping Hand Tools v. EPA*, the Ninth Circuit defined EPA's "purpose" review as a two-step process:

> "First, the permit applicant initiates the process and defines the proposed facility's end, object, aim or purpose—that is the facility's basic design. The purpose must be objectively discernable. Additionally, the applicant's proposed definition 'must be for reasons independent of air permitting' and cannot be motivated by cost savings or avoidance of risks. Second, EPA takes a 'hard look' at the proposed definition to determine which design elements are inherent to the applicant's purpose and which elements can be changed to reduce pollutant emissions without disrupting the applicant's basic business purpose."[428]

AOE projects may also look for opportunities to offset any regulated emissions. Offsets for any major source emissions must directly offset the criteria pollutant emitted by that source, but because a wide range of activities emit different particles classified as PM, emissions of specific PM or PM precursors may be offset by reductions in other types of PM or PM precursors.[429] As one legal scholar has noted, NSR "[o]ffsets can be quite creative. In California, offsets for ozone and particulates for a 48 [megawatt] cogeneration facility were obtained by the project sponsor agreeing to buy and destroy up to 175 older polluting cars per year."[430]

Permits for Facilities Emitting Hazardous Air Pollutants

Along with criteria pollutants, EPA also regulates the emission of 188 substances that have been identified as "hazardous air pollutants."[431] Major sources of hazardous air pollutants, defined as facilities with the potential to emit, "in the aggregate, 10 tons per year or more of any hazardous air pollutant or 25 tons per year or more of any combination of hazardous air pollutants,"[432] are subject to specific regulation under the CAA. The regulatory structure is similar to the NSR and PSD process described above.[433] Under the CAA, EPA is required to publish and periodically update a list of industries and activities that commonly represent major sources of

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[427] *Helping Hand Tools v. U.S. Env't Prot. Agency*, 848 F.3d 1185, 1194 (9th Cir. 2016).

[428] *Id*.

[429] 40 C.F.R. § Pt. 51, App. S.IV.A.3 ("Except as provided in paragraph IV.G.5 of this Ruling (addressing PM2.5 and its precursors), only intrapollutant emission offsets will be acceptable (e.g., hydrocarbon increases may not be offset against SO2 reductions)."); *see also* 40 C.F.R. § Pt. 51, App. S(IV)(G)(5) (allowing intra-PM offsets).

[430] Ferrey, supra note 422.

[431] *See Initial List of Hazardous Air Pollutants with Modifications*, EPA (Dec. 7, 2023), https://www.epa.gov/haps/initial-list-hazardous-air-pollutants-modifications.

[432] 42 U.S.C. § 7412(a)(1).

[433] Prior to the 1990 amendments to the Clean Air Act, hazardous air pollutants were regulated through PSD standards, and some states still "elect to regulate new and modified sources of hazardous air pollutants under their PSD programs." David R. Wooley & Elizabeth M. Moss, *New and Modified Sources of Hazardous Air Pollutants—Application of PSD Requirements*, *in* CLEAN AIR ACT HANDBOOK § 6:20 (2023).

pollution.[434] EPA must then publish industry-specific standards, called national emissions standards for hazardous air pollutants ("NESHAPs"),[435] for each source category, which prescribe emissions controls that reflect the "maximum achievable control technology" ("MACT"). In creating industry-specific NESHAPs, the CAA directs EPA to establish separate "research or laboratory facilities . . . whose primary purpose is to conduct research and development into new processes and products."[436] As with major sources of criteria pollutants, no person may construct, reconstruct, or modify a major source of hazardous air pollutants "unless [EPA] (or the [applicable] State) determines that the [MACT] emission limitation under this Section for new sources will be met."[437] If no NESHAP has been set for an applicable source category, MACT emissions limits for major sources are determined on a case-by-case basis.[438]

Stationary sources that emit hazardous air pollutants but do not qualify as "major sources" are referred to as "area sources."[439] The CAA requires EPA to establish NESHAPs for most types of area sources.[440] However, these NESHAPs are frequently less onerous than those applied to major sources. The CAA authorizes EPA, at its discretion, to either apply the same MACT standards used for major sources or set lower emissions limits for categories of area sources based on "generally available control technologies" ("GACTs").[441] The CAA does not define this term, but courts interpreting the phrase have looked to the legislative history of the CAA's 1990 amendments to define GACTs as:

> "[M]ethods, practices and techniques that are commercially available and appropriate for application by the sources in the category considering economic impacts and the technical capabilities of the firms to operate and maintain the emissions control systems."[442]

Unlike major sources, emissions from area sources are not regulated by default; if no NESHAP has been established for an area source category, the CAA does not require a case-by-case MACT determination.[443] Area sources are also subject to less burdensome permitting requirements than major sources. The owners of area

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[434] 42 U.S.C. § 7412(c)(1).

[435] *See National Emission Standards for Hazardous Air Pollutants Compliance Monitoring*, EPA (Jan. 24, 2024), https://www.epa.gov/compliance/national-emission-standards-hazardous-air-pollutants-compliance-monitoring (last visited May 28, 2024).

[436] 42 U.S.C. § 7412(c)(7).

[437] *Id*. § 7412(g)(2).

[438] *Id.* § 7412(g)(2)(A).

[439] 42 U.S.C. § 7412(a)(2) ("The term 'area source' means any stationary source of hazardous air pollutants that is not a major source.").

[440] 42 U.S.C. § 7412(c)(3).

[441] 42 U.S.C. § 7412(d)(5).

[442] *United States Sugar Corp. v. Env't Prot. Agency*, 830 F.3d 579, 595 (D.C. Cir.).

[443] *See* 42 U.S.C. § 7412(g)(2)(A).

sources subject to NESHAPs must notify EPA of their intended construction activities, but these projects do not require pre-construction approval from EPA.[444]

To the extent that AOE projects have the potential to emit hazardous air pollutants, project proponents should assess whether their proposed activities represent a major source or an area source of hazardous air pollutants. Once that determination has been made, project proponents must determine whether their proposed activities fall under an existing NESHAP source category (e.g., those standards set for "Coal- and Oil-Fired Electric Utility Steam Generating Units"),[445] or whether they will be regulated on a case-by-case basis (if a major source of pollutants).

(C) Clean Water Act Permits

Some AOE projects might also require permits under the Federal Water Pollution Control Act (commonly known as the Clean Water Act ("CWA")).[446] First enacted in 1949 and substantially revised in 1972, the CWA aims to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters."[447] The federal government and states are expected to work together to achieve this goal. The CWA establishes a federal permitting regime for certain so-called "point source discharges" of pollution into waterways but allows states to administer that regime if they so choose. States are also responsible for regulating nonpoint sources of water pollution, which are not covered by the federal permitting regime. Thus, like the CAA, the CWA reflects a cooperative federalism approach under which the federal government and states partner to achieve the common goal of protecting water resources.[448]

The CWA prohibits "the discharge of any pollutant by any person" without a permit issued by EPA or an authorized state agency under the National Pollutant Discharge Elimination System ("NPDES"). This standard has been referred to as a "zero discharge standard," because the CWA contains no minimum threshold for liability; instead, it "absolutely prohibits the discharge of any pollutant by any person, *unless* the discharge is made according to the terms of a [NPDES] permit."[449]

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[444] 40 C.F.R. § 63.5(b)(4).

[445] For a list of source categories and NESHAPs, *see National Emission Standards for Hazardous Air Pollutants (NESHAP)*, EPA (Feb. 22, 2024), https://www.epa.gov/stationary-sources-air-pollution/national-emission-standards-hazardous-air-pollutants-neshap-8 (last visited May 28, 2024).

[446] 33 U.S.C. § 1251 et seq.

[447] *Id*. 1251(a).

[448] *See generally*, *Arkansas v. Oklahoma*, 503 U.S. 91, 101 (1992) (noting that the 1972 CWA amendments provided for a renewed "partnership between the States and the Federal government").

[449] *Hughey v. JMS Dev. Corp.*, 78 F.3d 1523, 1524 (11th Cir. 1996); *see also Sierra Club, Lone Star Chapter v. Cedar Point Oil Co. Inc.*, 73 F.3d 546, 567 (5th Cir. 1996) (where a person is discharging substances into protected waters without a NPDES permit, "Congress has already set the permit limitation in such cases—zero discharge. A court need only apply the statutory definition to determine if the substance in question is a pollutant. If it determines that the substance is a pollutant, and the defendant is discharging it *at all* without a permit, then there has been a violation of § 1311(a)").

The term "pollutant" is defined broadly in the CWA to mean "dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt and industrial, municipal, and agricultural waste discharged into water."[450] Under the CWA, a "discharge" of pollutants occurs where the pollutants are "add[ed] . . . to navigable waters from any point source."[451] A "point source" is defined as "any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel," or other "conduit . . . from which pollutants are . . . discharged."[452] There is some uncertainty as to how the CWA permitting requirement will apply to AOE projects. On its face, the CWA definition of "pollutants" does not appear to capture iron salts or other materials proposed for use in AOE. Arguably, the materials do not qualify as "wastes," since they are not being disposed of but rather introduced into the environment to help mitigate climate change. Following this reasoning, some scholars have argued that CDR projects that involve "the intentional release of materials into U.S. waters for an express remedial purpose may not constitute a discharge of a "pollutant" [for the purposes of the CWA] because the materials are not being discarded."[453] The same might be said of AOE projects. Additionally, in AOE, materials would be released into the air and not directly to waters. Again, in the CDR context, scholars have argued that "materials released into the ambient air . . . may ultimately precipitate into U.S. waters, but that type of generalized deposition may not constitute a discharge from a 'point source' that would trigger NPDES permitting requirements."[454]

It should be noted, however, that EPA and the courts have previously taken an expansive view of the CWA and required permits for activities that broadly resemble AOE. One example is EPA's approach to the release of pesticides into the air above U.S. waters. Regulations adopted by EPA in 2006 stated that NPDES permits will generally not be required for such releases because pesticides do not qualify as "pollutants" under the CWA.[455] EPA cited a previous court decision holding that pesticides that were applied to a lake to eliminate non-native fish species and did not leave behind any "residues or unintended consequences" were not "pollutants" under the CWA because they were "not chemical wastes."[456] Notably however, EPA reasoned that if the application of pesticides does leave behind residual materials, those materials should be viewed as "wastes" from the

[450] 33 U.S.C. § 1362(6)

[451] *Id*. § 1362(12).

[452] *Id*. § 1362(14).

[453] Tracy D. Hester, *Remaking the World to Save It: Applying U.S. Environmental Laws to Climate Engineering Projects*, 38 ECOLOGY L. QUARTERLY 851, 882 (2011). *See also* Zora F. Franicevic, *Engineering Our Climate: A Comprehensive Legal Framework that Captures the Harmful Effects of Geoengineering Approaches*, 30 CORNELL J.L. & PUB. POL'Y 587, 606 (2021).

[454] Hester, *supra* note 453, at 882; *see also* Franicevic, *supra* note 453, at 606.

[455] Application of Pesticides to Waters of the United States in Compliance with FIFRA, 71 Fed. Reg. 68483 (Nov. 27, 2006).

[456] *Id*. at 68485 (quoting Fairhurst v. Hagener, 422 F.3d 1146 (9th Cir. 2005)).

pesticide application and thus will qualify as "pollutants" under the CWA.[457] EPA's regulations were struck down in a subsequent court decision but, importantly, the court agreed with EPA's reasoning.

In *National Cotton Council of America v. U.S. EPA,* the Sixth Circuit Court of Appeals agreed with EPA that, where a "chemical pesticide is intentionally applied to water to perform a particular useful purpose and leaves no excess portions after performing its intended purpose it is not a chemical waste . . . and does not require a NPDES permit".[458] However, the court held that "excess pesticide and pesticide residue meet the common definition of waste" and thus qualify as "pollutants" under the CWA.[459] The court further stated that, if "a chemical pesticide is initially applied to land or dispersed in the air . . . above or near waterways" and, at some point after the application, "excess pesticide or residual pesticide finds its way into the navigable waters," that could constitute a "discharge of pollutants" requiring a NPDES permit.[460]

Following the court's reasoning in the *National Cotton Council* case, it might be argued that NPDES permits are required for AOE projects involving the release of iron salts or other substances into the air, at least where some of the released substances end up in navigable waters. The substances that reach navigable waters might be viewed as "residues" or "waste materials" from the AOE project and thus fall within the definition of "pollutants" in the CWA. Additionally, where the substances are released from a tower or another fixed structure, that structure would likely qualify as a point source under the CWA and the release as a "discharge" into navigable waters. Based on the court's statements in *National Cotton Council,* the fact that the substances are first released into the air and then fall into the water would not appear to affect the analysis. There is, however, some more recent case law suggesting that such indirect discharges may require closer scrutiny.

In *County of Maui v. Hawaii Wildlife Fund*, the U.S. Supreme Court considered whether a NPDES permit was required for the underground injection of pollutants in circumstances where the pollutants mixed with groundwater, which then seeped through an aquifer and eventually reached the Pacific Ocean.[461] The question for the court was whether this type of indirect introduction of pollutants into navigable waters qualified as a "discharge" under the CWA. The court held that, even if a discharge does not "directly deposit[] pollutants into navigable waters," an NPDES permit will nevertheless be required if "the discharge reaches the same result through roughly similar means" or, stated differently, if it "is the functional equivalent of a direct discharge."[462] According to the court, this must be assessed on a case-by-case basis, taking into account factors such as the distance the pollutants travel before entering navigable waters and the time taken.[463] The court also identified

[457] *Id*. at 68489.

[458] *National Cotton Council of America v. U.S. EPA*, 553 F.3d 927, 936 (6th Cir. 2009) (internal citations omitted).

[459] *Id*.

[460] *Id*. at 936–37.

[461] *County of Maui, Hawaii v. Hawaii Wildlife Fund*, 140 S.Ct. 1462 (2020).

[462] *Id*. at 1476.

[463] *Id*. at 1476-1477.

various other factors that "may prove relevant (depending upon the circumstances of the particular case)," such as "the nature of the material through which the pollutant travels" and "the extent to which the pollutant is diluted or chemically changed as it travels."[464]

It should be noted that the court in *County of Maui* did not specifically opine on situations in which pollutants reach navigable waters after being released into the air. However, such situations are similar to the underground injections at issue in *County of Maui* in that both involve "indirect discharges" to navigable waters, and thus they might be subject to the same "functional equivalence" test. Assuming that test applied, one would need to evaluate the specifics of an AOE project, including the time and distance between the release of substances into the air and their deposition in navigable waters, to determine if a NPDES permit is required.

AOE projects requiring NPDES permits would need to submit a permit application to the relevant EPA regional office or state agency. Applications must generally be submitted at least 180 days before any discharge occurs and include information about the nature and location of the discharge.[465] Before issuing a permit, the applicable EPA office or state agency must notify the public and invite comments.[466] In some cases, an environmental review may also be required under NEPA or a state equivalent.[467] Additionally, where EPA is the permitting agency, the state in which the discharge will occur must certify that it will comply with all applicable water quality requirements or waive certification before a permit can be issued.[468]

(D) Ocean Dumping Permits

AOE projects that involve dispersing materials from offshore platforms may require ocean dumping permits under the MPRSA.[469] Enacted in 1972, the MPRSA implements the London Convention domestically in the U.S. Consistent with the requirements of the London Convention, the MPRSA establishes a domestic regulatory regime governing "the dumping of all types of materials into ocean waters" within 12 nautical miles of the U.S. coast, and further offshore in some circumstances.[470]

Under the MPRSA, a permit from EPA is required to:

- transport material from the U.S., or from another country using a U.S.-registered vessel or aircraft, for the purpose of dumping it into ocean waters (regardless of where the dumping occurs);

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[464] *Id*. at 1476.

[465] 40 C.F.R. § 122.21.

[466] *Id*. § 124.10 - 124.12.

[467] *Id*. §§ 122.29 & 124. 61.

[468] 33 U.S.C. § 1341(a)(1); 40 C.F.R. § 124.53(a).

[469] 33 U.S.C. § 1401 et seq.

[470] *Id*. § 1401(b).

- dump materials transported from a location outside of the U.S. into ocean waters within 12 nautical miles of the U.S. coast.[471]

The MPRSA defines "dumping" broadly to mean any "disposition of material" (with limited exceptions discussed below).[472] The MPRSA definition of "material" is similarly broad, referring to "matter of any kind or description."[473] As EPA has noted, the MPRSA definition of dumping "encompass[es] the disposition of material both for the purpose of disposal and purposes other than disposal," making it somewhat broader than the definition in the London Convention.[474] EPA has concluded that a range of ocean-based CDR and SRM activities might qualify as dumping and thus need to be permitted under the MPRSA. Specifically, EPA has indicated that "authorization under an MPRSA permit" may be required for CDR and SRM activities that involve "transporting alkaline solutions, alkaline minerals, iron solutions or solids, or reflective materials to ocean waters via vessel or aircraft and releasing the materials into those waters."[475]

There is some uncertainty as to whether, when, and how the MPRSA will apply to AOE projects involving the release of aerosols from offshore platforms or other structures. The definition of dumping in the MPRSA expressly excludes "the construction of any fixed structure or artificial island [and] the intentional placement of any decide in ocean waters or on or in the submerged land beneath such waters, for a purpose other than disposal, when such construction or such placement is otherwise regulated by Federal or State law."[476] An MPRSA permit would, thus, not be required to construct an offshore platform or other structure for use in AOE. Such construction would be "for a purpose other than disposal" and would be regulated under other federal and state laws (e.g., the OCSLA and state equivalents discussed above). However, once the structure is constructed, use of it to release substances into the air may trigger the permitting requirements in the MPRSA.

The release of substances from a fixed offshore structure as part of an AOE project could be viewed as a "disposition of materials" and thus qualify as dumping under the MPRSA. In this regard, it is notable that EPA has previously concluded that "releasing . . . materials into [ocean] waters" as part of an ocean CDR or SRM activity may qualify as dumping, within the terms of the MPRSA.[477] It could be argued that in AOE there is no direct release of materials "into" ocean waters. Rather, the materials are released into the air, and only reach ocean waters indirectly (i.e., if and when they fall on the surface). In this sense, AOE is different from ocean CDR and many SRM activities, which involve the direct discharge of materials into ocean water. Even so, however,

[471] 33 U.S.C. §§ 1411-1412.

[472] *Id*. § 1402(f).

[473] *Id*. § 1402(c).

[474] EPA, *Permitting for mCDR and mSRM*, https://www.epa.gov/ocean-dumping/permitting-mcdr-and-msrm#permitting (last visited May 28, 2024).

[475] *Id*.

[476] 33 U.S.C. § 1402(f).

[477] EPA, *supra* note 474.

EPA might view AOE similarly to ocean CDR and SRM activities. In all three cases, materials do end up in the ocean, and thus there is arguably a "disposition of materials" subject to the MPRSA. Further supporting this argument, the MPRSA has been applied to regulate the incineration of materials on board vessels which, like AOE, results in the release of substances into the air that eventually end up falling on the ocean.[478]

Assuming the release of aerosols from offshore structures as part of an AOE project is viewed as dumping, an MPRSA permit would be required transport materials to the offshore structure, if transportation occurred on a vessel or aircraft that was registered in the U.S.[479] An MPRSA permit would also be required to discharge the materials if the offshore structure were located within 12 nautical miles of the U.S. coast and the materials were transported from a location outside the U.S. However, AOE projects involving releases from offshore structures would not require permits under the MPRSA if:

1. the structure were located more than 12 nautical miles from the U.S. coast; and

2. materials were delivered to the structure using foreign vessels or aircraft that were loaded outside the U.S.[480]

EPA may only issue permits under the MPRSA if it determines that "dumping will not unreasonably degrade or endanger human health, welfare, or amenities, or the marine environment, ecological systems, or economic potentialities."[481] Before issuing permits, EPA must provide an opportunity for public comment and consult with other government agencies, including at the state and local levels.[482] EPA is not, however, required to conduct an environmental review under NEPA before issuing permits.[483]

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[478] EPA, *Special and Research Permits for Ocean Dumping*, OCEAN DUMPING, https://www.epa.gov/ocean-dumping/special-and-research-permits-ocean-dumping (last visited May 28, 2024).

[479] 33 U.S.C. §§ 1411-1412.

[480] This leaves a gap in coverage since a structure located within the U.S. EEZ, but more than 12 nautical miles from the coast, to which materials were delivered from oversea using a foreign vessel or aircraft, would not be subject to the MPRSA permitting requirements.

[481] 33 U.S.C. § 1412(a).

[482] *Id*.

[483] *Maryland v. Train*, 415 F. Supp. 116 (D. Md. 1976) (holding that EPA is not required to prepare an EIS for actions taken under the MPRSA because, "[w]here federal regulatory action is circumscribed by extensive procedures, including public participation, for evaluating environmental issues and is taken by an agency with recognized environmental expertise, formal adherence to the NEPA requirements is not required unless Congress has specifically so directed"). EPA does, however, voluntarily conduct NEPA reviews when designating dump sites under the MPRSA. *See* Policy and Procedures for Voluntary Preparation of National Environmental Policy Act (NEPA) Documents, 63 Fed. Reg. 58045, 58046 (Oct. 29, 1998)

The MPRSA authorizes EPA to "establish and issue various categories of permits."[484] Pursuant to this authority, EPA has established three permit classes, as follows:

1. research permits are available where dumping occurs as part of a research project and EPA determines that "the scientific merit of a proposed project outweighs the potential environmental or other damage that may result from dumping;"[485]

2. general permits are available for the dumping of materials that "will have only minimal adverse environmental impacts and are generally disposed of in small quantities;"[486] and

3. special permits may be issued for the dumping of other materials that meet EPA-established criteria relating to the effects of dumping on the environment and other ocean uses and available alternatives to dumping.[487]

Given that AOE is still being investigated, it seems likely that early projects could be authorized via research permits. There is, however, some uncertainty as to whether and when different types of activities will qualify for research permits. For example, a previous study by the authors found that many ocean CDR researchers were "confused about whether and when [their] projects might qualify for research permits."[488] As noted in the study:

> The term "research project" is not defined in the [MPRSA or associated] regulations and EPA has not provided any guidance on the factors it will consider in determining whether a particular activity involves research. This has prompted a range of questions including: What counts as research? Are there restrictions on who can undertake research (e.g., only academic or government scientists)? Could an activity undertaken by a commercial entity qualify as a research project? How will a project that has both research and commercial elements be treated? For instance, if a project is designed to answer scientific questions about the impacts of ocean CDR, but is funded through the sale of carbon credits, would it still be treated as a research project?[489]

Similar questions are likely to arise in connection with AOE projects. Additionally, project developers may also question how EPA will assess the scientific merit of a particular research project and whether it outweighs the project's potential harms, such that a research permit can be issued. Given this, as we have previously recommended, "EPA should provide additional guidance on when research permits may be available" and, in

[484] 33 U.S.C. § 1412(b).

[485] 40 C.F.R. § 220.3(e).

[486] *Id*. § 220.3(a).

[487] *Id*. § 220.3(b).

[488] Romany M. Webb & Korey Silverman-Roati, Executive Actions to Ensure Safe and Responsible Ocean Carbon Dioxide Removal Research in the United States 17 (2024), https://scholarship.law.columbia.edu/sabin_climate_change/211/.

[489] *Id*. at 17-18.

particular, "clarify the factors it will consider in determining whether an . . . activity qualifies as a research project [and] how it will evaluate the scientific merit of any such project."[490]

5.3 Domestic Laws Governing the Use of Mobile Facilities for Atmospheric Oxidation Enhancement

This Part discusses the laws governing AOE activities using mobile emissions sources. Several proposals have suggested deploying AOE from mobile sources like ships, airplanes, and balloons. Among the various mobile AOE platforms, ships may be the most promising for several reasons. Some AOE techniques benefit from the marine environment.[491] In addition, global marine fuel consumption is three orders of magnitude higher than global jet fuel consumption, so marine fuel additives may be a logistically attractive option for some AOE techniques, such as iron salt aerosol deployment.[492]

To the extent that mobile sources simply serve as platforms for aerosol dispersal, these sources will generally be governed by the same laws and regulations that govern fixed dispersal mechanisms. For example, pesticides sprayed from trucks and helicopters, coal dust drifting from barges, and ordinance fired from planes and warships are all treated as "point sources" of pollution under the CWA, despite the fact that they originate from mobile facilities.[493] However, AOE projects that propose dispersing aerosol by modifying vehicle fuels or combusting oil-soluble iron additives inside vehicle engines[494] will be subject to a different set of legal and permitting requirements that govern mobile source emissions.

In the United States, emissions from mobile sources are primarily regulated at the federal level, although state and local governments retain broad authority to regulate local pollution, and may exercise significant control over mobile source emissions in certain circumstances discussed throughout this subsection. Under the CAA, mobile source emissions are controlled through two mechanisms: (1) regulation of fuels and fuel additives, and

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[490] *Id*. at 18.

[491] *See generally* Oeste et al., *supra* note 21 (discussing the role of sea spray aerosols in methane destruction techniques).

[492] *See* Ming et al., *supra* note 37 (discussing the relative benefits of deploying iron salt aerosol from jets, ships, and stationary power plants); *see also* Daphne Meidan et al., *Evaluating the Potential of Iron-Based Interventions in Methane Reduction and Climate Mitigation*, 19 ENVIRONMENTAL RESEARCH LETTERS (Apr. 19, 2024), https://doi.org/10.1088/1748-9326/ad3d72 (studying the potential climate impact of incorporating AOE additives into marine fuels).

[493] *See, e.g.*, *Peconic Baykeeper, Inc. v. Suffolk Cnty.*, 600 F.3d 180, 188–89 (2d Cir. 2010) (addressing pesticides sprayed from trucks and helicopters); *Alaska Cmty. Action on Toxics v. Aurora Energy Servs., LLC*, 765 F.3d 1169, 1171 (9th Cir. 2014) (holding that coal dust spilled from barges represented a "point source" of pollutants for the purpose of assessing permits issued under the CWA); *Weinberger v. Romero-Barcelo*, 456 U.S. 305, 309 (1982) (upholding a remedy granted by a District Court that had concluded that, under the CWA, the release of bombs and other "ordinance from aircraft or from ships into navigable waters is a discharge of pollutants, even though the EPA . . . has not promulgated any regulations . . . for this category of pollutants.").

[494] Timothy M. Sturtz et al., *Environmental Impact Modeling for a Small-Scale Field Test of Methane Removal by Iron Salt Aerosols*, SUSTAINABILITY 14(21), 14060 (2022) (discussing the use of fuel exhaust for AOE); Oeste et al., *supra* note 21, at 12 (discussing "[t]he generation of [iron salt aerosol] by combusting fuel oil with ferrocene or other oil-soluble iron additives in ship engines"); Ming et al., *supra* note 37, at 5 (discussing the use of fuel additives as an AOE delivery mechanism).

(2) regulation of vehicle systems (particularly engines). However, these mechanisms are applied differently to different types of mobile sources. Emissions from vehicles that travel on roads, like trucks and cars, are controlled through regulations governing vehicle manufacturers, along with detailed laws and regulations at the federal, state, and even local level governing the use of fuels and fuel additives.[495] In contrast, emissions from aircraft are regulated almost entirely at the federal level, and governed through a permitting process known as a "type certificate" that approves entire categories of aircraft, including their fuels and engines, as a single functional system.[496] Finally, emissions from marine vessels are regulated in a similar manner to on-road vehicles, but certain standards governing emissions, fuel use, and other operating requirements are established at the international level under MARPOL Annex VI.[497]

5.3.1 Regulation of Motor Vehicle Emissions

Under the CAA, EPA regulates emissions from on-road motor vehicles (e.g., cars and trucks) through two channels: (1) emissions standards for new makes and models of motor vehicles, and (2) standards for fuels and fuel additives. The first channel is largely targeted toward vehicle manufacturers, so AOE distribution via on-road motor vehicles like cars and trucks will primarily be regulated by federal laws governing fuel and fuel additives.

(A) EPA Regulation of Motor Vehicle Fuels

As a general matter, the CAA bars the commercial use[498] of new fuel additives for any make and model of vehicle if they were not used and tested in EPA's engine certification process for that make and model of vehicle.[499] However, EPA may allow the use of new additives in a vehicle system if it determines that the use of such additives, and emissions from them, will not damage the vehicle's emissions control system or otherwise cause it to violate emissions standards.[500] To implement this authority, EPA regulates motor vehicle fuels and fuel additives through three different processes: (1) fuel registration requirements, (2) prohibitions on fuel manufacturing, and (3) fuel quality standards.

EPA requires manufacturers and importers to register all fuels and fuel additives that they propose to sell, offer for sale, or introduced into commerce.[501] EPA defines fuel additives broadly to include any substance "other than one composed solely of carbon and/or hydrogen, that is intentionally added" to a motor vehicle fuel or

[495] *See infra* Part 5.3.1.

[496] *See infra* Part 5.3.2.

[497] *See infra* Part 5.3.3.

[498] Specifically, the CAA bars "any manufacturer of any fuel or fuel additive" from introducing new fuels or fuel additives "into commerce." 42 U.S.C. § 7545(f).

[499] 42 U.S.C. § 7545(f).

[500] *Id*. § 7545(f)(4).

[501] 40 C.F.R. § 79.4(a)(1).

fuel system, which "is not intentionally removed prior to sale or use."[502] That definition would encompass any AOE-related additive. EPA defines a "fuel manufacturer" to include "any person who, for sale or introduction into commerce . . . causes or directs the alteration of the chemical composition of a bulk fuel, or the mixture of chemical compounds in a bulk fuel, by adding to it an additive."[503] This definition would likely encompass those introducing AOE-related additives into fuels.

As part of the registration process, manufacturers of fuels and fuel additives must conduct extensive testing "to determine potential public health and environmental effects of the fuel or additive (including carcinogenic, teratogenic, or mutagenic effects),"[504] and must provide a broad range of information about the composition, intended use, and effects of the additive.[505] EPA regulations outline detailed testing requirements and procedures,[506] which require manufacturers to study both the evaporative emissions from fuels and fuel additives, and the emissions produced by the use of those products in common vehicle/engine configurations.[507] Importantly, these regulations exempt from registration any fuel additives that are "in research, development, or test status" and are not commercially available.[508]

Separately, EPA has broad authority to ban the manufacture, sale, or "introduction into commerce" of any fuel additive if the additive "causes, or contributes to, air pollution or water pollution . . . that may reasonably be anticipated to endanger the public health or welfare," or if the use of such additive will impair any commonly used emissions control system.[509] This provision is broader than the registration requirements, and it allows EPA to proactively prohibit the manufacture of harmful fuel additives, not just regulate their registration and sale.[510]

Finally, EPA has issued fuel quality standards that apply to gasoline, diesel, and marine fuels "introduced into commerce" in the United States.[511] These standards are cumulative with EPA's fuel additive registration requirements;[512] the registration requirements regulate fuels and fuel additives on a per-product basis, while EPA's fuel quality standards ensure that the blends of products ultimately used do not negatively impact vehicle

[502] *Id*. § 79.2(e).

[503] *Id*. § 79.2(d).

[504] 42 U.S.C. § 7545(b)(2)(A).

[505] *Id*. § 7545(b)(2)(B).

[506] 40 C.F.R. § 79.50–79.68.

[507] *Id*. § 79.57(a).

[508] *Id*. § 79.4(a)(3)(i).

[509] 42 U.S.C. § 7545(c)(1).

[510] *See Fuels and Fuel Additives—Statutory Framework*, § 12:183 *in* 2 L. OF ENVTL. PROT. (Envtl. L. Inst. 2024). (noting that 42 U.S.C. § 7545(c) "provides EPA with general authority to control or prohibit a fuel or fuel additive").

[511] 40 C.F.R. § 1090.1(a).

[512] *Id*. § 1090.1(c).

emissions, air quality, or public health.[513] EPA's fuel quality standards differ for each type of regulated fuel, but generally limit the sulfur content and treatment volume of each additive.[514] These standards also require the manufacturers of fuel and fuel additives to keep records of,[515] certify to,[516] and perform tests to monitor[517] the composition of their products.

Any person may apply for a temporary exemption from EPA's fuel quality standards for "fuel used for research, development, or testing."[518] Applicants seeking an exemption must demonstrate that their proposed research and development program accomplishes an appropriate research and development purpose, cannot "be achieved in a practicable manner" while meeting the fuel quality standards, is reasonable in scope, and "affords EPA a monitoring capability" over the research program.[519] Each temporary exemption expires "at the completion of the test program or 1 year from the date of approval, whichever occurs first," but may be extended by re-application.[520] This exemption process could offer a regulatory path for AOE proponents seeking to conduct AOE experiments that involve the modification of vehicle fuels.

(B) State and Local Regulation of Motor Vehicle Fuels

The CAA broadly preempts state regulation of emissions from motor vehicles,[521] and generally prohibits states from prescribing or enforcing regulations on fuel or fuel additives already regulated by EPA "for purposes of motor vehicle emission control."[522] However, states can regulate fuel additives under four circumstances, three of which are set out in the CAA and one of which has been repeatedly upheld by federal courts.

1. States may regulate fuel additives if state regulations are identical to those prescribed by EPA.[523]

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[513] *Id*. § 1090.1(a)(1).

[514] *Id*. § 1090.155 (outlining general requirements for fuel additive manufacturers); 40 C.F.R. § 1090.265 (outlining standards for gasoline additives); 40 C.F.R. § 1090.310 (outlining standards for diesel additives).

[515] *Id*. § 1090.1200 et seq.

[516] *Id*. § 1090.1000 et seq.

[517] *Id*. § 1090.1300 et seq.

[518] *Id*. § 1090.610(a)(1).

[519] *Id*. § 1090.610(c).

[520] *Id*. § 1090.610(e)(2).

[521] 42 U.S.C. § 7543(a).

[522] *Id*. § 7545(c)(4)(A).

[523] *Id*. § 7545(c)(4)(A)(ii).

2. States may regulate fuel additives if EPA allows them to do so in their SIPs (see Part 5.2.3(B) above).[524] Individual SIPs may allow states or localities to regulate the types of fuel and fuel additives that can be sold in those jurisdictions.[525]

3. The CAA allows states which were regulating motor vehicle emissions before 1966 to issue regulations that the state determines are at "least as protective of public health and welfare" as those set by EPA, so long as those standards address "compelling and extraordinary conditions," the state's determination is not deemed arbitrary or capricious, and the state regulations are compatible with Federal enforcement.[526] In practice, California is the only state that falls into this carve-out, but the CAA allows other states to adopt California's standards with two years notice.[527] This carve-out allows California to adopt its own regulations and prohibitions for fuel and fuel additives.[528]

4. Multiple federal courts have held that, while states cannot regulate fuel and fuel additives "for purposes of motor vehicle emission control,"[529] they may regulate these products for other purposes so long as that regulation does not conflict with the goals of the CAA. For example, one fuel additive, methyl tertiary-butyl ether (MTBE), was formerly used as an oxygenate in gasoline to reduce vehicle emissions by ensuring that fuels "burn[ed] more completely."[530] However, MTBE easily dissolves into groundwater, and in the early 2000s, several states enacted laws banning the use of gasoline containing MTBE. These laws were generally upheld, even though they prohibited a fuel additive already regulated by EPA, because the states were deemed to be exercising their authority over groundwater pollution, not regulating vehicle emissions.[531]

5.3.2 Regulation of Aircraft Emissions

Emissions produced by aircraft are regulated almost entirely at the federal level, where regulatory authority is split between EPA and the FAA. Under the CAA, EPA is required to propose emission standards for pollutants emitted by aircraft engines that "may reasonably be anticipated to endanger public health or welfare,"[532] and

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[524] *Id*. § 7545(c)(4)(C).

[525] *See Exxon Mobil Corp. v. U.S. E.P.A.*, 217 F.3d 1246, 1248 (9th Cir. 2000) (upholding fuel regulations set by Clark County, Nevada, under a SIP that were designed to reduce carbon monoxide in the Las Vegas Valley).

[526] 42 U.S.C. § 7543(b).

[527] *Id*. § 7507.

[528] *Id*. § 7545(c)(4)(B).

[529] *Id*. § 7545(c)(4)(A).

[530] *Methyl Tertiary Butyl Ether (MTBE)*, EPA ARCHIVE ((Feb. 20, 2016), https://archive.epa.gov/mtbe/web/html/gas.html.

[531] *See Oxygenated Fuels Ass'n, Inc. v. Pataki*, 158 F. Supp. 2d 248 (N.D.N.Y. 2001); *see also Oxygenated Fuels Ass'n Inc. v. Davis*, 331 F.3d 665, 670 (9th Cir. 2003).

[532] 42 U.S.C. § 7571(a)(2)(A).

the FAA regulates aircraft engines,[533] fuels, and fuel additives[534] to ensure that they comply with EPA's emissions standards. In some circumstances, the use of aircraft in AOE projects may also trigger application of the MPRSA which, as noted above, applies to the transport of materials from the U.S., or from an overseas location using a U.S.-registered aircraft, for the purpose of dumping them into ocean waters. For a fuller discussion of the MPRSA, see Part 5.2.3(D) above.

(A) EPA Aircraft Emissions Standards

EPA has broad authority to regulate aircraft emissions that might be hazardous to human health or the environment,[535] but in practice EPA has only regulated a small subset of potential pollutants. Different engine systems are subject to different emissions standards, which generally vary based on the design and construction date of the engine in question.[536] EPA regulates PM emissions from all new aircraft engines, and many in-use engines, through either set "smoke numbers" that define the maximum allowed opacity of engine emissions or by direct regulation of PM emitted from engine systems.[537] EPA regulates aircraft PM emissions based on three different thresholds: (1) a PM mass standard in milligrams per kilonewton of force produced by an engine, (2) a PM number standard in number of particles per kilonewton of force, and (3) a PM mass concentration standard in micrograms per cubic meter. For regulatory purposes, PM is divided into two categories: (1) non-volatile PM ("nvPM"), emitted from the engine itself, and (2) volatile PM, "formed from transformation of an engine's gaseous emissions."[538] "Because of the difficulty in measuring volatile PM, which is formed in the engine's exhaust plume and is significantly influenced by ambient conditions," EPA has only adopted emissions standards for nvPM.[539] Any AOE fuel additive will need to be assessed to ensure that its use in a specific engine type does not cause that engine to breach its regulatory PM emissions threshold.

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[533] *Id*. § 7572(a).

[534] 49 U.S.C. § 44714.

[535] 42 U.S.C. § 7571(a)(2)(A).

[536] *See* 40 C.F.R. §§ 1031.30–1031.140.

[537] *Id*. § 1031.30. Emissions standards vary based on the type of engine used by an aircraft, and many standards apply only to aircraft engines manufactured after a certain compliance date. For example, EPA requires "turboprop engines with rated output at or above 1,000 kW" manufactured "on or after August 9, 1985" to operate below a designated "smoke number" threshold. (40 C.F.R. § 1031.40(a)). In contrast, EPA requires supersonic engines manufactured "on or after January 1, 1984" to comply with "smoke number" thresholds, as well as thresholds for carbon monoxide, hydrocarbon, and nitrous oxide emissions. (40 C.F.R. § 1031.90). Compliance dates vary significantly, and higher emissions standards may be set for new engine models without displacing emissions standards for older models. *See, e.g.*, 40 C.F.R. § 1031.60(e) (outlining different nitrous oxide emissions thresholds for engines manufactured before 1995, after 1995, after 2012, and after 2014).

[538] *See* Control of Air Pollution From Aircraft Engines: Emission Standards and Test Procedures, 87 FED. REG. 72312, 72319 (Dec. 23, 2022).

[539] *Id*.

Some classes of engines are also subject to emissions standards for hydrocarbon emissions from unburnt fuel, carbon monoxide emissions, and nitrogen oxide emissions.[540] These standards may affect the use of AOE fuel additives, because some AOE processes can lead to the formation of carbon monoxide when in the presence of nitrogen oxides.[541] EPA has also adopted standards for GHG emissions from certain classes of aircraft.[542] These standards are tied to fuel efficiency standards,[543] and so AOE fuel additives that impact fuel efficiency might affect compliance with GHG emissions standards.

(B) FAA Regulation of Aircraft Emissions

The FAA regulates aircraft operations to ensure that they comply with EPA's emissions standards, as well as rigorous standards for safety and noise control. As a general matter, the FAA meets these regulatory goals through a unified permitting process called a "type certificate." Type certificates are system-level permits that regulate the aircraft as an entire functional system, rather than separately certifying individual components.[544] Fuels and fuel additives are regulated as part of this process; applicants for type certificates must "identify the fuel and oil grade, designation, and/or specifications that are used in their products during certification," and those specifications are then integrated into the operating limitations of the certified aircraft system.[545]

Before issuing a type certificate for most categories of aircraft or manned balloons, the FAA must determine that the aircraft system as a whole "meets the applicable airworthiness, aircraft noise, fuel venting, exhaust emission, and fuel efficiency requirements."[546] If the FAA determines that a system contains "novel or unusual design feature[s]" that render existing regulations inadequate or inappropriate to guarantee the system's compliance with regulatory safety standards, the FAA has the authority to attach special conditions to type certificates to ensure that the system meets such standards.[547]

The FAA separately issues type certificates for "restricted category aircraft," meaning non-passenger aircraft designated for "special purpose operations."[548] These "special purpose operations" generally encompass industrial and agricultural uses, such as "aerial surveying," agricultural uses like "spraying, dusting, and seeding"

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[540] 40 C.F.R. § 1031.30(a).

[541] *See supra* note 537 and accompanying text.

[542] *See generally* 40 C.F.R. § 1030.1 (outlining classes of aircraft subject to GHG emissions standards).

[543] *See* 40 C.F.R. § 1030.30.

[544] *See Certification*, FAA (n.d.), https://www.faa.gov/uas/advanced_operations/certification.

[545] Federal Aviation Administration, Approval of Propulsion Fuels, Additives, and Lubricating Oils, Advisory Circular 20-24D (June 30, 2014), https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_20-24D.pdf.

[546] 14 C.F.R. § 21.21(b)(1); *see also* 14 C.F.R. § 21.29 (applying a similar review standard to products manufactured outside of the United States).

[547] *Id*. § 21.16.

[548] *Id*. § 21.25.

and "weather control (cloud seeding)."[549] Restricted category civil aircraft may be exempted from some regulatory requirements "that the FAA finds inappropriate for the special purpose for which the aircraft is to be used," although they are subject to FAA's regulations governing aircraft noise.[550] The FAA has the discretion to identify new categories of special purpose operation,[551] and AOE projects using non-passenger aircraft could seek designation as a "special purpose operation." It may be easier for early-stage AOE research projects to receive approval to use AOE-modified fuels under restricted category type certificates than it would be for them to seek standard category certificates. While restricted category aircraft must still demonstrate that they are safe for their "intended use," the "level of safety for restricted category aircraft may be lower than the level of safety for standard category aircraft."[552]

The FAA has issued detailed regulatory guidance for parties seeking a new or modified type certificate that authorizes the use of new aircraft fuel additives.[553] Any proposed fuel additive must be specifically identified, either as part of a broader class of additives incorporated into existing industry or regulatory standards, or "identified and controlled to a single compositional definition."[554] The FAA may require additives to be approved for each specific aircraft configuration, or may approve additives on a broad basis for "an identifiable population of engines or aircraft."[555] Broad approval is particularly likely for additives for which there is a great deal of data available, particularly those which are similar to existing, approved additives.[556] In any event, those seeking the approval of an additive must demonstrate:

(1) "that the additive does not have any adverse effects on the operation, performance, durability, or materials of the products intended for use;"

(2) "that the additive does not have any adverse effects on the performance of the base fuel or oil that it is intended for use with;" and

[549] *Id*. § 21.25(b).

[550] *Id*. § 21.25 (a)(1).

[551] *Id*. § 21.25(b)(7).

[552] *See* Federal Aviation Administration, Restricted Category Type Certification, Order 8110.56B (July 19, 2017), https://www.faa.gov/documentLibrary/media/Order/FAA_Order_8110_56B.pdf.

[553] *See* Federal Aviation Administration, Approval of Propulsion Fuels, Additives, and Lubricating Oils, Advisory Circular 20-24D (June 30, 2014), https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_20-24D.pdf.

[554] *Id*.

[555] *Id*.

[556] *Id*.

(3) "that the additive is compatible with all other additives, or combination of all other additives, permitted for use in the base fuel or oil."[557]

If a fuel additive has any "appreciable effect on the weight, balance, structural strength, reliability, operational characteristics, or other characteristics affecting the airworthiness of" a system regulated by a type certificate,[558] the use of that product may require a supplemental type certificate.[559] This categorization includes changes that impact system emissions.[560] An application to use AOE additives will generally require the applicant to show that the additive does not undermine the system's compliance with fuel efficiency, fuel venting, and exhaust emissions requirements,[561] and will need to show that the AOE additive does not undermine other regulated characteristics of the aircraft like airworthiness or noise emissions.[562]

(C) State and Local Regulation of Aircraft Emissions

Existing federal regulations almost entirely preempt state and local regulation of emissions from aircraft systems.[563] However, state and local governments have narrow authority to issue regulations that "can be met without affecting the design, structure, operation, or performance of the aircraft engine."[564] Under this authority, states and localities may regulate emissions from ground-based test and maintenance facilities for aircraft fuels and engines.[565]

(D) Other Relevant Requirements

In addition to regulating aircraft emissions in cooperation with EPA, FAA more broadly regulates the use and safety of U.S. airspace. AOE projects that propose to use tethered balloons will need to comply with certain

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[557] *Id*.

[558] 14 C.F.R. § 21.93 (a).

[559] *Id*. § 21.113. Applicants must seek an entirely new type certificate "if the FAA finds that the proposed change in design, power, thrust, or weight is so extensive that a substantially complete investigation of compliance with the applicable regulations is required." *Id.* § 21.19.

[560] *Id.* § 21.93(c)

[561] *Id.* § 21.115(a)

[562] *Id.* § 21.33(b).

[563] 42 U.S.C. § 7573 (expressly preempting state and local emissions standards for "any air pollutant from any aircraft or engine thereof" unless those standards are identical to federal standards).

[564] Barbara J. Van Arsdale et al., *Enforcement of Aircraft Emission Standards*, *in* 61B AM. JUR. 2D POLLUTION CONTROL § 619 (Nov. 2024 ed.).

[565] *People of State of Cal. ex rel. State Air Res. Bd. v. Dep't of Navy*, 431 F. Supp. 1271, 1289 (N.D. Cal. 1977), *aff'd sub nom. People of State of Cal. v. Dep't of the Navy*, 624 F.2d 885 (9th Cir. 1980) (holding that, while the Clean Air Act preempted state regulation of pollution from aircraft engines, that preemption did not prevent state regulation of pollution from stationary "test cells" that housed aircraft engines during testing, repair, and maintenance).

notice and permitting requirements.[566] To operate a moored balloon between 150 and 500 feet, operators must provide at least 24 hours' notice to the nearest FAA air traffic control facility.[567] Generally, no moored balloon may be flown more than 500 feet above ground level, less than 500 feet below the bottom of cloud cover, or within five miles of any airport[568] without a "certificate of waiver" issued by the FAA.[569] Any moored balloon must comply with FAA requirements for lighting and signage to ensure that the balloon and its mooring lines are sufficiently visible.[570] Balloons operating in certain "restricted areas" designated by the FAA, other federal agencies, or the military[571] will be subject to separate requirements and permitting procedures depending on the nature of the restriction.[572]

5.3.3 Regulation of Marine Emissions

In the United States, maritime emissions are primarily controlled through the CAA, which authorizes EPA to regulate emissions from a wide variety of "non-vehicle engines," including those used in ships. EPA is also authorized to regulate emissions from ocean-going vessels under a second statute—the Act to Prevent Pollution from Ships ("APPS")—which incorporates the requirements of MARPOL into U.S. law.[573] The line between these two statutes is not precise,[574] but as a general matter, the APPS assigns regulatory and enforcement authority between EPA and the Coast Guard to achieve MARPOL's emissions standards, while the CAA provides EPA with the regulatory authority to enact broader emissions regulations that may also impact ocean-going vessels.[575] Importantly, as discussed in this Section, the CAA allows coastal states to implement stricter regulations to control near-shore marine emissions.

As with aircraft, the use of vessels in AOE projects may also trigger application of the MPRSA in some circumstances. Under the MPRSA, a permit is required to transport materials from the U.S., or from an overseas

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[566] These requirements apply to balloons with diameters of more than 6 feet or gas capacities of more than 115 cubic feet. 14 C.F.R. § 101.1(a)(1).

[567] *Id*. § 101.15.

[568] *Id.* § 101.13.

[569] *Id.* § 101.3

[570] *Id.* § 101.17.

[571] *Id.* § 73.13.

[572] *Id.* § 101.11.

[573] For a discussion of MARPOL, see *supra* Part 4.1.2(D).

[574] For example, in 2008 Congress amended both the CAA and APPS to ratify and implement MARPOL Annex VI. *See* Xiaoxin Shi, *Making Ends Meet: Using A Market-Based Approach to Incentivize Foreign Vessels to Comply with the Air Emission Standards of MARPOL Annex VI*, 4 PENN ST. J.L. & INT'L AFF. 556, 562 (2015).

[575] *See generally* Sandra Y. Snyder, E*PA's Category 3 Marine Emissions Standards Mimicking MARPOL Annex VI or Mocking the Clean Air Act?*, 71 BROOK. L. REV. 1065 (2005) (discussing the relationship between MARPOL and the CAA, and arguing that EPA has an obligation under CAA to enact more stringent emissions regulations on international shipping than it had enacted in 2005).

location using a U.S.-registered vessel, for the purpose of dumping them into ocean waters. An MPRSA permit is also required to dump materials within 12 nautical miles of the U.S. coast, if those materials were transported from a location outside the United States. The MPRSA definition of dumping is broad and may encompass airborne releases from vessels for the purposes of AOE. Indeed, the MPRSA has previously been applied to regulate the incineration of materials on board vessels which, like AOE, results in the release of substances into the air that eventually end up falling on the ocean. For a fuller discussion of the MPRSA and its potential application to AOE projects, see Part 5.2.3(D) above.

(A) Federal Regulations of Marine Emissions

EPA's marine emissions regulations follow the same general structure as EPA's regulations governing motor vehicle emissions (see Part 5.3.1 above). As with motor vehicle emissions, EPA's regulation of marine emissions occurs through two channels: (1) emissions standards for marine engines targeted toward engine manufacturers,[576] and (2) a set of standards and registration requirements for fuels and fuel additives. These requirements are supplemented by regulations targeted toward the manufacturers, operators, and owners of vessels subject to MARPOL—primarily, ocean-going vessels "operating in U.S. navigable waters or the U.S. EEZ" under non-U.S. flags and U.S. flagged ocean-going vessels "wherever they are located."[577] U.S.-flagged vessels that "do not enter waters subject to the jurisdiction or control of any foreign country," or U.S.- or Canada-flagged vessels operating in the Great Lakes, are subject to separate fuel operating standards.[578]

At the federal level, additives to marine fuels are regulated through essentially the same process as additives to motor vehicle emissions (see Part 5.3.1 above), and subject to the same registration process[579] and fuel quality standards.[580] While the standards for marine fuels differ for each product, they generally limit the sulfur content and treatment volume of each additive.[581] Like the standards for motor vehicle fuels, marine fuel standards similarly require the manufacturers of fuel and fuel additives to keep records of,[582] certify to,[583] and perform tests to monitor[584] the composition of their products. Marine fuel additive manufacturers are not required to

[576] 40 C.F.R. §§ 1042.2, 1045.2.

[577] *Id*. § 1043.10(a), (b).

[578] *Id.* § 1043.10(a), (b).

[579] *See generally id*. § 79.

[580] *Id*. § 1090.1(a).

[581] *See id.* § 1090.155 (outlining general requirements for fuel additive manufacturers); § 1090.325 (outlining standards for ECA marine fuel additives); § 1090.310 (outlining standards for diesel additives).

[582] *See id*. § 1090.1200 et seq.

[583] *See Id.* § 1090.1000 et seq.

[584] *See id*. § 1090.1300 et seq.

register their products during research and development, and may apply for a temporary research exemption from the CAA's marine fuel quality standards through the same process that applies to vehicle fuel additives.[585]

The owners and operators of marine vessels are subject to a second set of emissions standards under MARPOL Annex VI, as implemented through the APPS. These requirements are broadly designed to control three categories of pollutants: (1) nitrous oxides, (2) sulfur oxide, and (3) PM.[586] To this end, vessels are subject to operating requirements that limit the volume of nitrous oxides that they may emit and the sulfur content of the fuels that they may use.[587] However, the United States allows vessels to use noncompliant fuels, "provided the vessel applies a method that results in equivalent emissions reductions."[588] In practice, this offers vessels "three primary alternatives" for compliance with fuel sulfur standards: (1) "adding 'scrubbers' to the vessel" that remove sulfur emissions from exhaust systems, (2) "using low-sulfur fuel oil," or (3) modifying the vessel to use liquefied natural gas.[589]

Regulation 3.2 to MARPOL Annex VI allows countries to exempt individual ships from MARPOL's relevant pollution controls "to conduct trials for the development of ship emission reduction and control technology."[590] Under the APPS, such exemptions are processed by the U.S. Coast Guard in consultation with EPA. The Coast Guard has issued guidance for submitting such requests, but has not established a detailed application process for such exemptions.[591]

(B) State Coastal Zone Regulations

States have some authority to enact stricter marine air pollution controls than those prescribed at the federal level. The CAA allows these emissions standards to be set by state or local governments, acting under an EPA-approved SIP or under the special regulatory status provided to California.[592] As with motor vehicle emissions, EPA may authorize California to set emissions standards for "nonroad engines," including those used in marine

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[585] *Id*. § 1090.610(a)(1).

[586] *See generally id*. Part 1043 – Control of NOx, SOx, and PM Emissions from Marine Engines and Vessels Subject to the MARPOL Protocol.

[587] *See id*. § 1043.60.

[588] *See Id*. § 1043.55 (implementing MARPOL Annex VI).

[589] Shelby E. Brown, *IMO 2020: Industry Conditions and Readiness*, 44 TUL. MAR. L.J. 145, 152 (2019).

[590] *See* 16711/CG-CVC Policy Letter 12-04 CH-1, United States Coast Guard (Nov. 7, 2019), https://www.dco.uscg.mil/Portals/9/DCO%20Documents/5p/CG-5PC/CG-CVC/Policy%20Letters/2019/CG%20CVC%20Policy%20Ltr%2012-04%20MARPOL%20Annex%20VI%20CHANGE%201%20signed.pdf

[591] *See id*.

[592] *See Ports Primer: 7.2 Air Emissions*, EPA (July 17, 2023), https://www.epa.gov/community-port-collaboration/ports-primer-72-air-emissions.

vessels, as long as those standards are "in the aggregate[] at least as protective of public health and welfare as applicable Federal standards."[593] Other states may adopt California's standards on notice to EPA.[594]

California has long attempted to control marine pollution at the state level. Since 2007, the California Air Resources Board ("CARB") has attempted to regulate emissions of "diesel particulate matter (PM), nitrogen oxides, and sulfur oxides"[595] from vessels operating with 24 nautical miles of California's coast. These early regulations were not authorized by EPA, and in 2008 a federal appellate court halted their enforcement after determining that they represented impermissible engine pollution standards.[596] Today, CARB regulates the fuels that may be used within 24 nautical miles of California's coast, and broadly requires vessels to use specifically formulated fuels "with a maximum of 0.1% sulfur by weight."[597] Unlike the standards set under MARPOL, CARB does not exempt ships using emissions "scrubbers" from CARB's fuel regulations.[598] California's coastal zone fuel emissions regulations contain a clear process for authorizing research and experiments around new fuels and fuel additives. CARB may issue temporary three-year permits to vessels conducting such experiments, following "a clear and convincing demonstration that the use of the proposed non-compliant fuel will generate data as part of research that advances the state of knowledge of exhaust control technology or characterization of emissions."[599]

In addition, California law broadly prohibits oceangoing ships from conducting "onboard incineration" within three miles of California's coast.[600] For the purpose of this regulation, "'[o]nboard incineration' means the combustion or burning of any materials or wastes for the purpose of volume reduction, destruction, sanitation, or sterilization."[601] Based on this narrow definition, it is unclear whether this requirement would limit incinerator-based AOE projects, but additional regulatory clarity would be helpful.

(C) Port Emissions Regulations

[593] 42 U.S.C. 7543(e)(2)(A).

[594] *Id.* § 7543(e)(2)(B).

[595] Cal. Code Regs. tit. 13, § 2299.1 (a).

[596] *See Pac. Merch. Shipping Ass'n v. Goldstene*, 517 F.3d 1108, 1115 (9th Cir. 2008).

[597] *See* Cal. Code Regs. tit. 17, § 93118.2(e). While some scholars have argued that California's coastal zone fuel regulations are overly broad and may be preempted by the CAA or other elements of federal law, they remain in effect. *See* Bradley D. Easterbrooks, *Overreach on the High Seas?: Whether Federal Maritime Law Preempts California's Vessel Fuel Rules*, 39 PEPP. L. REV. 645, 675–79 (2012).

[598] *See* Marine Notice 2020-1: Reminder of Requirements for Complying with the California Ocean-Going Vessel Fuel Regulation, CARB (Jan. 2020) https://ww2.arb.ca.gov/sites/default/files/2020-01/Marine%20Notice%202020-1_final_rev_ADA.pdf.

[599] Cal. Code Regs. tit. 17, § 93118.2(c)(6)(A)(3)(b).

[600] *Id.*, § 93119.

[601] *Id.*, § 93119(c)(6).

Marine vessels may be subject to stricter emissions controls when they are near or in ports. For example, CARB has long issued special "At-Berth" regulations that limit emissions from ships in or near ports. The latest version of these regulations was issued by CARB on September 27, 2022, and approved by EPA on October 20, 2023.[602] Collectively, these regulations require ships to use more rigorous "CARB-approved emissions control strategies" while in port, and set limits on all visible vessel emissions,[603] as well as specific emissions thresholds for nitrogen oxides, reactive organic gasses, PM, diesel PM, and GHGs.[604] The definition of particulate matter contained in California's At-Berth regulations is broad, and would likely encompass all AOE distribution mechanisms.[605] By default, ships are required to comply with CARB's At-Berth regulations by connecting their main operations to on-shore power sources and limiting use of auxiliary engines.[606] However, CARB may authorize alternative emissions control strategies based on "sound principles of science" that would meet CARB's emissions thresholds.[607]

6. Conclusion and Key Takeaways

Despite scientists' dire warnings about the impacts of climate change, progress in reducing the GHG emissions that cause it continues to lag.[608] The IPCC has made clear that, in order to achieve the Paris Agreement's goal of limiting the increase in global average temperatures to "well below 2 degrees Celsius," global GHG emissions must reach net zero in the second half of the century.[609] The need to get to net zero and the practical impossibility of completely eliminating all emissions has prompted growing interest in the possibility of removing GHGs from the atmosphere. While GHG removal cannot substitute for rapid and deep emissions cuts, it could be an important complement thereto, helping to offset residual emissions from hard-to-abate sectors and potentially even delivering net negative emissions and thereby reduce the total atmospheric GHG load.

To date, efforts to advance GHG removal have primarily focused on developing CDR techniques, but the possibility of AMR is now also beginning to receive attention. One often-discussed AMR technique is AOE, which aims to accelerate the natural oxidation process whereby hydroxyl and chlorine radicals react with atmospheric methane, converting it into carbon dioxide and other by-products. AOE is still in the very early stages of development but, if proven effective and able to be safely deployed at scale, it could deliver significant climate

[602] *See* California State Nonroad Engine Pollution Control Standards; Ocean-Going Vessels At-Berth; Notice of Decision, 88 Fed. Reg. 72461 (Oct. 20, 2023).

[603] Cal. Code Regs. tit. 17, § 93130.6.

[604] *See generally id*., § 93130.1 *et seq*.

[605] California defines regulated particulate matter emissions as "any airborne finely divided material, except uncombined water, which exists as a liquid or solid at standard conditions (e.g., dust, smoke, mist, fumes, or smog)." *Id*., § 93130.2.

[606] *Id.*, § 93130.5(c).

[607] *See id.*, § 93130.5(d)-(j) (detailing the requirements for any alternative CARB-approved emissions control strategy).

[608] UNITED NATIONS ENVIRONMENT PROGRAMME, *supra* note 3.

[609] Intergovernmental Panel on Climate Change, *supra* note 2, at 50.

benefits. One recent study found that, due to the high GWP of methane, "oxidizing it to [carbon dioxide could] reduce[] its 20-year warming impact by 99% or, if considered on a 100-year warming impact timescale, by 97%."[610] Significantly more research is, however, required to fully evaluate the efficacy and impacts (both positive and negative) of AOE. Field testing and (if ultimately deemed appropriate) deployment of AOE would involve the dispersal of iron salt or other aerosols from either fixed structures or mobile facilities (e.g., ships or aircraft) over land or the ocean.

There are currently no international or domestic (U.S.) laws dealing specifically with aerosol dispersal for AOE. That does not, however, mean that AOE projects are unregulated. As explained in this paper, depending on where they occur and the precise activities involved, AOE projects may be subject to a variety of general environmental and other laws. Those laws were not designed with AOE in mind, but might still apply to AOE projects because they involve activities or have impacts regulated under the laws.

At the international level, a number of international agreements and treaties could impact whether, when, where, and how AOE projects take place.[611] One notable example is the CBD, which has near universal global participation, with 196 parties.[612] Those parties have recently adopted a number of decisions addressing geoengineering, the definition of which is arguably broad enough to encompass AOE.[613] Generally speaking, the decisions seek to prevent deployment, but provide limited exceptions for research activities.[614] A similar approach has been taken by parties to the London Convention and Protocol, which have adopted several instruments dealing specifically with geoengineering activities in the ocean.[615] Again, those instruments prevent deployment, but allow research in certain circumstances.[616] The instruments could influence where and how AOE projects in or affecting the ocean are conducted. Additionally, ocean-based projects could also be impacted by UNCLOS, MARPOL, and the Basel Convention (among others).[617]

Also potentially relevant to AOE are international agreements and rules of customary international law aimed at preventing, mitigating, and managing transboundary environmental harms.[618] One example is LRTAP which specifically targets transboundary air pollution resulting from the release of PM and other designated pollutants.[619] The pollution controls established under LRTAP could influence the conduct of, and in some cases

[610] Nisbet-Jones et al., *supra* note 5, at 3.

[611] *See supra* Part 4.

[612] S*ee supra* Part 4.1.1(B) (discussing the CBD).

[613] *Id*.

[614] *Id*.

[615] See supra Parts 4.1.2(B)–(C).

[616] *Id*.

[617] *See supra* Parts 4.1.2(A) & (D).

[618] *See supra* Part 4.1.3.

[619] *See supra* Part 4.1.3(A).

even bar, AOE projects involving the dispersal of ultrafine particles into the air. To the extent that substances released in AOE projects impact the ozone layer, the Vienna Convention and associated Montreal Protocol could also apply.[620]

A similarly broad range of domestic (U.S.) laws could apply to AOE projects conducted within the land territory of the United States or in offshore areas under its jurisdiction.[621] Arguably the most important category of domestic law applicable to AOE projects is federal environmental law, but project proponents will also need to be cognizant of relevant tribal, state, and local law. Some AOE projects may end up being subject to multiple layers of law—arising at the federal, tribal, state, and local levels—which may impose overlapping or even duplicative permit or other requirements.

Similar to the situation under international law, the suite of domestic laws applicable to any AOE project will depend on the precise activities involved and where they take place. One important distinction, from a legal perspective, is whether an AOE project is conducted using a fixed structure or a mobile facility, such as a ship or aircraft. Generally speaking, AOE projects involving the dispersal of materials from towers or other fixed structures will often raise more significant legal issues, including because they require the use of land (either on or offshore) which must be legally authorized and are likely to need multiple environmental and other permits, for example under the CAA, CWA, and/or MPRSA.[622] In comparison, AOE dispersals from mobile sources, such as vessels, may be subject to fewer legal requirements, and early AOE research projects may benefit from special regulatory carve-outs and permitting processes designed to facilitate research and development activities.[623] However, as noted above, precisely what legal requirements apply will depend on the specifics of each project.

Notwithstanding the above, there are some domestic (U.S.) laws that are likely to apply to most, if not all, AOE projects.[624] These include NEPA and equivalent state and local laws that mandate *ex-ante* review of, and public participation in decision-making about, environmentally-risky projects.[625] Other laws, such as the WMRA, would require AOE project proponents to provide advance notice to the government or other interested parties.[626] These are primarily procedural requirements, however. With few exceptions, the laws do not establish substantive requirements that dictate how AOE projects must be conducted, or prevent projects that pose significant environmental or other risks.

Overall, it is clear that the legal framework for AOE activities is highly complex. Multiple laws could apply but none of them were, at the time they were adopted, intended to regulate AOE. As a result, there is often

[620] *See supra* Part 4.1.3(B).

[621] *See supra* Part 5.

[622] *See supra* Part 5.2.

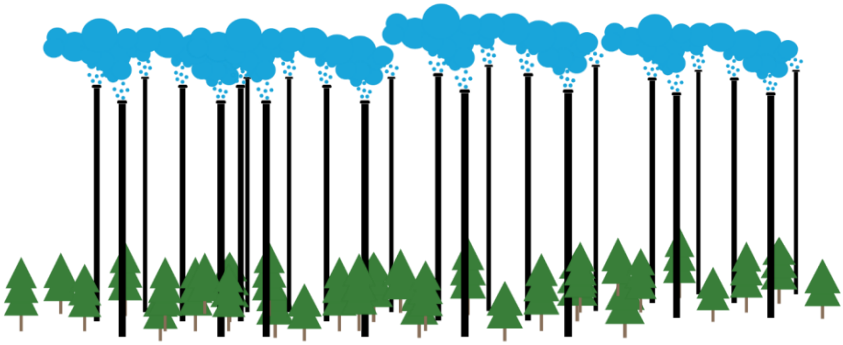
[623] *See supra* Part 5.3.

[624] *See supra* Part 5.1.

[625] *See supra* Part 5.1.1.

[626] *See supra* Part 5.1.2.

significant uncertainty as to when and how the laws will be applied in practice, and whether they will ensure safe, responsible, and just AOE development. There is a need for further research into these issues and, more generally, into the laws governing different AMR techniques. Future papers by the authors will delve into these questions.



AOE CASE STUDY 1: LAND-BASED NEAR-COASTAL TOWERS

AOE Delivery Mechanism: Land-Based Near-Coastal Towers

Early studies have suggested that AOE projects might in the future be conducted from fixed towers that directly disperse AOE-enhancing aerosols into the atmosphere. These dispersal towers might be located either on land or in the ocean. On land, coastal areas may be preferred sites for AOE towers, particularly those dispersing iron salt aerosol, given the important role that sea spray plays in the methane oxidation process.

This case study highlights governance regimes, permitting processes, and legal reporting obligations in the United States that are likely to impact AOE projects conducted using land-based towers. For the purposes of this hypothetical case study, iron salt aerosol (assumed to be fine particulate matter with diameters that are generally 2.5 micrometers or smaller) are directly dispersed from fixed towers located near the coast within the territorial United States.

NOTE: This case study is intended for illustrative academic purposes only, and the laws, regulations, and permitting rules highlighted in this document are not exhaustive. Additional legal requirements are likely to apply to individual AOE projects, depending on the location and nature of the proposed AOE activities. In particular, land-based AOE projects will likely be subject to detailed laws, regulations, and permitting processes at the state and local levels that may vary significantly between jurisdictions. The depth of treatment in this case study does not necessarily correlate with the relative importance of an identified legal regime. This document is not an indication that any approaches that might be covered by this category should be tested or deployed, or are ready to be tested or deployed.

For more information on this possible approach, see Franz Dietrich Oeste et al., *Climate Engineering by Mimicking Natural Dust Climate Control: The Iron Salt Aerosol Method*, 8 EARTH SYSTEM DYNAMICS 1, 31 (Jan. 13, 2017), https://doi.org/10.5194/esd-8-1-2017; Daphne Meidan et al., *Evaluating the Potential of Iron-Based Interventions in Methane Reduction and Climate Mitigation*, 19 ENVIRONMENTAL RESEARCH LETTERS (Apr. 19, 2024), https://doi.org/10.1088/1748-9326/ad3d72, *see also Iron Salt Aerosol: Brief Summary*, CLIMATE GAME CHANGERS (n.d.), https://climategamechangers.org/game-changers/climate-restoration/iron-salt-aerosol-brief-summary/ (last visited May 28, 2024).

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Preparation of this case study was generously supported by ClimateWorks Foundation and Spark Climate Solutions.

Key International Governance Regimes

- **CBD:** Calls for strict controls on ocean fertilization and climate-related geoengineering activities.
- **UNCLOS:** Restricts when, where, and how substances can be introduced into marine environments.
- **London Convention and Protocol:** Establishes rules governing the "dumping" of material at sea and calls for restrictions on ocean fertilization activities.
- **LRTAP:** Governs transboundary air pollution, including pollution from particulate matter like AOE aerosols.

Key U.S. Federal Laws

- **CAA:** Grants EPA the power to regulate emissions of air pollutants from stationary sources.
- **CWA:** Establishes a federal permitting regime for "point source discharges" of pollution into navigable waterways.
- **ESA:** Prohibits the unauthorized taking (including harming, injuring, and killing) of protected species.
- **Marine Mammal Protection Act:** Prohibits the unauthorized taking of marine mammals.
- **NEPA and Magnuson-Stevens Fisheries Conservation Act (*potentially*):** Require environmental review of certain Federal permitting and other actions.
- **FAA Air Hazard Permits:** Sets standards for tall structures that may interfere with air travel.
- **FLPMA (*potentially*) or NFMA (*potentially*):** Govern the private use of most federally owned land.
- **WMRA:** Governs "weather modification" activities.

Key U.S. State and Local Laws

- **State and Local Land Use Laws:** Will usually govern the siting and construction of AOE dispersal towers.
- **State Air and Water Pollution Laws:** May set stricter requirements than those set by the CAA and CWA, although any state requirements must be compatible with federal law.
- **State Endangered Species Protections (*potentially*):** May prohibit activities with negative effects on protected species or habitats.

Pre-Deployment Review Processes and Notice Requirements

General Environmental Review:

- NEPA requires any federal agency permitting, funding, or otherwise approving an AOE project to review its environmental risks.
  - Smaller projects may qualify for a simpler "environmental assessment."
  - Environmental review will require public participation in decision-making.
- Depending on a project's location, it may be subject to similar review requirements under state and local NEPA-equivalents, or under the federal Magnuson-Stevens Fisheries Conservation Act.

Weather Modification Reporting:

- WMRA imposes reporting requirements for "weather modification" projects that would apply to all AOE projects. Under WMRA, NOAA must be given (1) an initial report at least 10 days before commencement; (2) interim annual reports; and (3) a final report within 45 days of completion.
- Activities in state jurisdictions may be subject to review and reporting requirements under state-level weather modification laws.

Species Protection Permits

Additional research is needed to understand if, and when, AOE projects might impacts species or their habitats. However, if an AOE project might have a negative impact on any protected species or habitat, it would need to obtain permits under various species protection laws.

"Incidental Take Permits" under the ESA:

- Needed if a project may harm, kill, or otherwise take any listed endangered or threatened species.
- FWS and NMFS can authorize take resulting from acts undertaken "for scientific purposes" or if the take "is incidental to" an otherwise lawful activity.
  - Permit applications must include conservation and harm minimization plans.
  - FWS/NMFS must be satisfied that "the taking will not appreciably reduce the likelihood of the survival and recovery of the species in the wild," among other things.

Other Programs:

- The Marine Mammal Protection Act requires permits for activities that may harm, kill, or otherwise take marine mammals. This may be relevant to AOE aerosol towers operating near the coast.
- Activities may be subject to state-level species and habitat protection laws and review processes, particularly if they require state permits or funding.

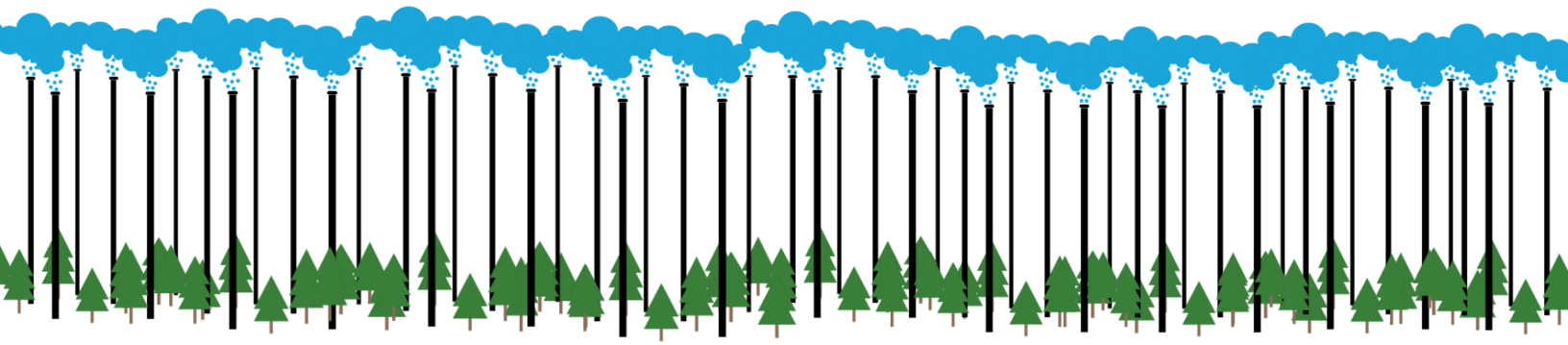
Water Pollution Permits

CWA:

- CWA prohibits "the discharge of *any* pollutant by any person" into navigable waters without a NPDES permit issued by EPA or an authorized state agency. There is no minimum threshold for liability.
- CWA likely requires AOE dispersal towers to obtain NPDES permits, because AOE activities could discharge "pollutants" into navigable waters.
  - Applications must be submitted at least 180 days before any discharge occurs.
  - Before issuing a permit, the relevant EPA office or state agency must invite public comments.
  - Where EPA is the permitting agency and a discharge will impact a state, the impacted state must certify that the discharge complies with all applicable water quality requirements or waive certification before a permit can be issued.
- NPDES permits may be administered by the siting state or by EPA directly.

State Water Pollution Laws:

- States and localities may have water pollution laws that set stricter standards than those set by federal laws, and AOE projects may need to seek separate authorization from state regulators.



Land Use and Air Navigation Hazard Issues

Building or Altering Structures on Public Land:

- In the United States, a large amount of land is owned or controlled by government entities. The federal government owns roughly 28 percent of the total U.S. land area, while an additional eight percent of the total land area is under state and local government ownership.
  - FLPMA governs the use of land managed by the federal BLM. Under FLPMA, BLM may authorize use of the land for any activity that is not governed by another law or specifically forbidden.
  - The U.S. Forest Service manages designated forest land under NFMA. These lands are subject to established land use plans, and (barring some designated categories) the Forest Service may authorize activities consistent with these plans.
  - These laws, and equivalent state laws, contain detailed provisions governing private use of public lands. Neither federal statute specifically authorizes or forbids AOE.

Building or Altering Structures on Private Land:

- AOE structures on private land will be subject to state and local laws governing land use and nuisance.
  - These laws, regulations, and permitting processes should be carefully considered; land use rules vary significantly from jurisdiction to jurisdiction, and can be quite detailed and onerous.
- Many state and local laws specifically restrict development near the coast.

FAA Navigation Hazard Requirements:

- FAA regulations affect the construction of structures that may interfere with air traffic.
  - Any person building or modifying an AOE tower above FAA thresholds must provide notice of their activities to the FAA and will be subject to several regulatory requirements.
    - Notice is generally required for structures over 200 feet tall.
    - FAA has set shorter thresholds near airports and heliports.
  - Notice must be provided to the FAA by the earlier of 45 days before beginning construction, or 45 days before filing for construction permits.[1]
  - FAA will review proposed construction to determine if it will cause a hazard to air navigation.
- An FAA "hazard determination" may weigh heavily against a project in state and local permitting processes, and will likely be a barrier to insuring or financing structures.

Treatment of AOE Aerosols as Air Pollutants

AOE Aerosols are Regulated "Criteria Pollutants" under the CAA:

- Iron salt aerosol smaller than 10 nanometers are a form of PM, which is regulated as a "criteria pollutant" under the CAA.
- AOE towers that emit more than 100 tons per year of PM (or 70 tons in some sensitive areas) will be regulated as "major sources" of air pollution, and subject to a permitting process discussed below.

Some AOE Aerosols may be "Hazardous Air Pollutants" under the CAA:

- EPA also regulates the emission of 188 "hazardous air pollutants."
  - If AOE projects use aerosols that are categorized as "hazardous air pollutants," AOE towers will be subject to separate regulations and emissions thresholds.
- Sources of hazardous air pollutants are subject to different regulatory standards depending on their emissions.
  - Major sources are facilities with the potential to emit 10 tons of any one hazardous air pollutant or 25 tons of any combination of air pollutants in a year.
  - Sources that are not "major sources" of hazardous air pollutants may still be regulated by EPA or state authorities, but are subject to less rigorous requirements.
- Sources of hazardous air pollutants are subject to a separate permitting and review process.

CAA Stationary Source Permits

New Source Permitting for Major Sources of Particulate Matter:

- Projects categorized as "major sources" of PM must receive permits from EPA before they can begin construction of new polluting facilities or modify existing ones.
- AOE towers that emit more than 100 tons per year of PM (or 70 tons in some sensitive areas) will be regulated as "major sources" of air pollution, and subject to a permitting process discussed below.

Standards for Review:

- Permitting standards for new "major sources" of pollution vary by location.
- In areas that already meet national air quality standards for criteria pollutants, new major sources of pollution must satisfy the PSD standard.
    - The PSD standard requires the owners or operators of new or modified major sources to show that they plan to implement the best available emissions control technology.
    - "Best available control technology" is determined on a case-by-case basis, taking into account cost, energy efficiency, and overall environmental impacts, among other things.
    - Applicants must also assess their impact on air quality, visibility, and flora, among other analyses.
- In areas that fail to meet national air quality standards for criteria pollutants, new or modified sources of air pollution are subject to more rigorous requirements. Project sponsors must have a history of compliance with air pollution standards, and demonstrate that a project:
    - Will reduce existing pollution that offsets pollution from the new source,
    - Will use the most stringent possible pollution controls for all criteria pollutants, and
    - The state in which it will be sited is implementing its air quality improvement plan.

New Source Pollution Control Review Process:

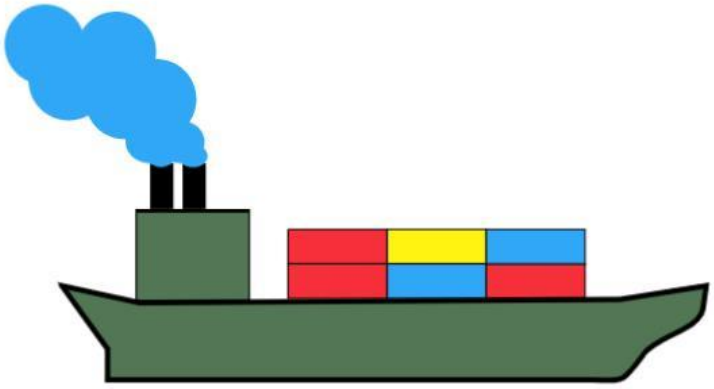
- Determining whether a source is using adequate pollution controls is a two-step process:
    - First, the permit applicant proposes a project design and emissions control plan that "defines the proposed facility's end, object, aim or purpose."
    - Second, EPA takes a "hard look" at the proposal, and tries to identify emissions reductions that can be achieved without undermining the fundamental purpose of a proposed project.
        - EPA does not generally require applicants to change the underlying nature of their projects – for example, EPA would not require a steel mill to produce plastic instead.
- AOE projects may attempt to offset emissions by reducing PM emission from other sources, like decommissioning existing sources of PM pollution.

Offsets and Operating Restrictions:

- If a pre-construction application is approved, AOE facilities will need to abide by the emission limits, monitoring requirements, and other conditions of their permits.

Requirements for Non-Major Sources:

- AOE facilities that emit criteria air pollutants like PM but do not qualify as "major sources" may be subject to similar, but substantially less rigorous, review and permitting programs.
    - The intensity of such regulation and permitting can vary significantly from state to state.
    - There are relatively few federal requirements for such programs, and states may vary significantly in the extent to which they regulate non-major sources.



AOE CASE STUDY 2: MARINE FUEL ADDITIVES

AOE Delivery Mechanism: Marine Fuel Additives

Early studies have suggested that AOE might be possible by adding iron-bearing additives to fuel, which would then be combusted and dispersed from the exhaust systems of mobile platforms like ships, airplanes, and balloons. Several studies have pointed to ships as a possible platform for this type of AOE, both because several AOE techniques benefit from the marine environment and because the high volume of marine fuel makes marine fuel additives a logistically attractive option for some AOE techniques, such as iron salt aerosol deployment.

This case study highlights governance regimes, permitting processes, and legal reporting obligations in the United States that are likely to impact AOE projects conducted using marine fuel additives. For the purposes of this hypothetical case study, we assume that formulated additives are added to the fuel of large, ocean-going vessels and combusted through the ordinary operation of the vessels' engines, dispersing iron salt aerosol (assumed to be fine particulate matter with diameters that are generally 2.5 micrometers or smaller) through the vessels' exhaust plumes. The case study focuses on potentially applicable U.S. federal and state laws and, as such, is most relevant to AOE activities that are conducted by U.S. citizens, conducted using U.S.-flagged vessels, conducted in the territorial waters or EEZ of the U.S., or otherwise subject to the jurisdiction of the United States.

NOTE: This case study is intended for illustrative academic purposes only, and the laws, regulations, and permitting rules highlighted in this document are not exhaustive. Additional legal requirements are likely to apply to individual AOE projects, depending on the location and nature of the proposed AOE activities. In particular, land-based AOE projects will likely be subject to detailed laws, regulations, and permitting processes at the state and local levels that may vary significantly between jurisdictions. The depth of treatment in this case study does not necessarily correlate with the relative importance of an identified legal regime. This document is not an indication that any approaches that might be covered by this category should be tested or deployed, or are ready to be tested or deployed.

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Key International Governance Regimes

- **CBD:** Calls for strict controls on ocean fertilization and climate-related geoengineering activities.
- **UNCLOS:** Restricts when, where, and how marine scientific research is conducted.
- **London Convention and Protocol:** Establishes rules governing the "dumping" of material at sea and calls for restrictions on ocean fertilization activities.
- **MARPOL Annex VI:** Establishes international air pollution standards for ocean-going vessels.

Key U.S. Federal Laws

- **CAA:** Grants EPA the power to regulate emissions from ship engines, and to regulate and ban marine fuel additives.
- **Act to Prevent Pollution from Ships:** Implements MARPOL Annex VI into U.S. law.
- **CWA (*potentially*):** Establishes a federal permitting regime for "point source discharges" of pollution into navigable waterways.
- **MPRSA (*potentially*):** Establishes a permitting regime for the transportation and discharge of materials into the ocean.
- **ESA:** Prohibits the unauthorized taking (including harming, injuring, and killing) of protected species.
- **Marine Mammal Protection Act:** Prohibits the unauthorized taking of marine mammals.
- **NEPA and Magnuson-Stevens Fisheries Conservation Act (*potentially*):** Require environmental review of certain Federal permitting and other actions.

Key U.S. State and Local Laws

Port Emissions Regulations and State Coastal Zone Regulations (*potentially*):

- May place strict operating requirements or emissions controls on vessels in or near ports or near-shore coastal waters.

State Endangered Species Protections (*potentially*):

- May prohibit near-shore coastal activities with negative effects on protected species or habitats.

Species Protection Permits

Additional research is needed to understand if, and when, AOE projects might impacts species or their habitats. However, if an AOE project might have a negative impact on any protected species or habitat, it would need to obtain permits under various species protection laws.

"Incidental Take Permits" under the ESA:

- Needed if a project may harm, kill, or otherwise take any listed endangered or threatened species.
- FWS and NMFS can authorize take resulting from acts undertaken "for scientific purposes" or if the take "is incidental to" an otherwise lawful activity.
  - Permit applications must include conservation and harm minimization plans.
  - FWS / NMFS must be satisfied that "the taking will not appreciably reduce the likelihood of the survival and recovery of the species in the wild," among other things.

Other Programs:

- The Marine Mammal Protection Act requires permits for activities that may harm, kill, otherwise take marine mammals.
- Activities in state jurisdictions, or that require state permits or funding, may be subject to state-level consultation and other requirements to protect species and habitats.

Water Pollution Permits

CWA:

- CWA prohibits "the discharge of *any* pollutant by any person" into navigable waters without a NPDES permit issued by EPA or an authorized state agency. There is no minimum threshold for liability.
- CWA likely requires AOE dispersal towers to obtain NPDES permits, because AOE activities could discharge "pollutants" into navigable waters.
  - Applications must be submitted at least 180 days before any discharge occurs.
  - Before issuing a permit, the relevant EPA office or state agency must invite public comments.
  - Where EPA is the permitting agency and a discharge will impact a state, the impacted state must certify that the discharge complies with all applicable water quality requirements or waive certification before a permit can be issued.
- NPDES permits may be administered by the siting state or by EPA directly.

MPRSA:

- The MPRSA governs, and broadly prohibits, any unpermitted transport and dumping of materials in certain ocean areas. Marine fuel AOE projects may involve regulated "ocean dumping" under MPRSA.
- A permit would need to be obtained under the MPRSA if an AOE project involved:
  - the transport of materials from within the U.S. or, if transportation is performed using a vessel or aircraft registered in the U.S., from an oversea location for the purpose of dumping it into ocean waters; and
  - the dumping of materials that were transported from overseas into ocean waters within 12 nautical miles of the U.S. coast.
- EPA may only issue permits under the MPRSA if it determines that "dumping will not unreasonably degrade or endanger human health, welfare, or amenities, or the marine environment, ecological systems, or economic potentialities."
  - EPA may grant "research permits" for AOE research projects if EPA determines that "the scientific merit of a proposed project outweighs the potential environmental or other damage that may result from dumping."
  - Other categories of permit are available, but may require a more significant environmental review and permitting criteria.
  - Before issuing permits, EPA must provide an opportunity for public comment and engage with other

Pre-Deployment Review Processes and Notice Requirements

General Environmental Review:

- NEPA requires any federal agency approving or funding an AOE project to review its environmental risks.
    - Smaller projects may qualify for a simpler "environmental assessment."
    - Environmental review will require public participation in decision-making.
- Depending on a project's location, it may be subject to similar review requirements under state and local NEPA-equivalents, or under the federal Magnuson-Stevens Fisheries Conservation Act.

Weather Modification Reporting:

- WMRA imposes reporting requirements for "weather modification" projects that would apply to any AOE project. NOAA must be given (1) an initial report at least 10 days before commencement; (2) interim annual reports; and (3) a final report within 45 days of completion.
- Activities in state jurisdictions may be subject to review and reporting requirements under state-level weather modification laws.

Marine Fuel Regulations and Registration

Marine Fuel Additive Registration:

- Under the CAA, manufacturers must register all fuels and fuel additives that they propose to sell, offer for sale, or introduced into commerce.
    - Additives are all fuel substances that are not "composed solely of carbon and/or hydrogen."
    - Registration requires extensive public health and environmental testing.
- Additives are subject to fuel quality standards, which generally limit the sulfur content and treatment volume of each additive.
- Fuel additive regulations contain significant research exemptions.
    - Marine fuel additive manufacturers are not required to register their products during R&D.
    - Manufacturers may receive 1-year research exemptions from fuel quality standards.
    - Research exemption applicants must demonstrate that their proposed R&D program is an appropriate research project, reasonable in scope, cannot "be achieved in a practicable manner" while meeting the fuel quality standards, and allows effective EPA monitoring.

MARPOL Annex VI Emissions Limits (codified in the AAPS):

- Ocean-going vessels are subject to operating requirements that limit the volume of nitrous oxides that they may emit and the sulfur content of the fuels that they may use.
    - Countries may exempt individual ships "to conduct trials for the development of ship emission reduction and control technology."
    - Parties seeking to conduct research into marine fuel AOE processes may seek an exemption permit from the United States Coast Guard (in consultation with EPA).

State Coastal Zone and Port Emissions Permits:

- Marine fuel AOE projects may need state or local permits if they want to engage in AOE activities in ports or near-coastal waters under state jurisdiction.
    - This is particularly important for California, which regulates the fuels that may be used within 24 nautical miles of California's coast, but permits research projects that "advance[] the state of knowledge of exhaust control technology or characterization of emissions."
- Stricter requirements may limit vessel emissions in ports.