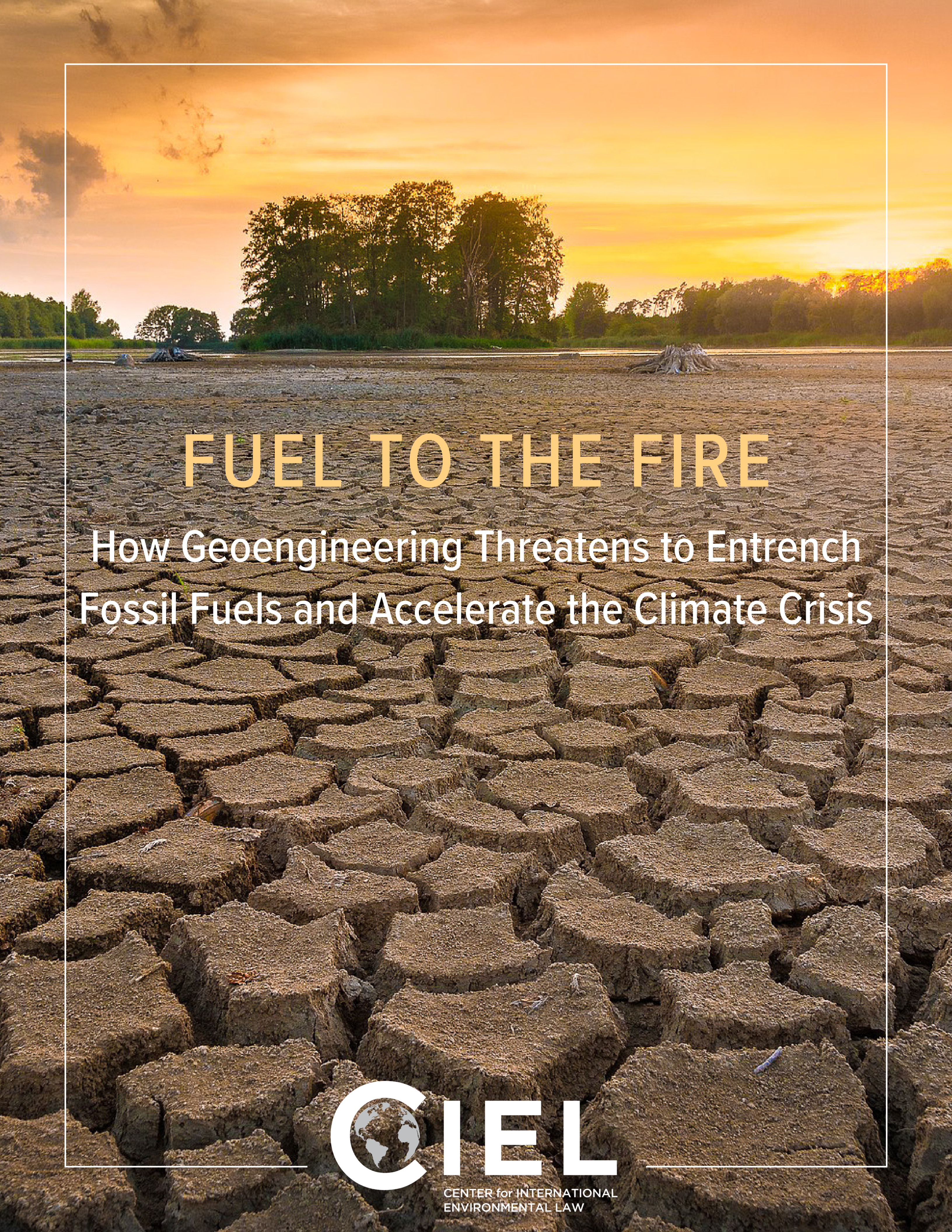

FUEL TO THE FIRE

How Geoengineering Threatens to Entrench Fossil Fuels and Accelerate the Climate Crisis

CIEL
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FUEL TO THE FIRE

HOW GEOENGINEERING THREATENS TO ENTRENCH FOSSIL FUELS AND ACCELERATE THE CLIMATE CRISIS

"It's an engineering problem, and it has engineering solutions... The fear factor that people want to throw out there to say we just have to stop this, I do not accept."

–REX TILLERSON, FORMER CEO, EXXONMOBIL AND US SECRETARY OF STATE (2012)[1]

"When serious proposals for large-scale weather modification are advanced, as they inevitably will be, the full resources of general-circulation knowledge and computational meteorology must be brought to bear in predicting the results so as to avoid the unhappy situation of the cure being worse than the ailment."

–HENRY WEXLER, US WEATHER BUREAU (1958)[2]

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Acronyms and Abbreviations

AEI	American Enterprise Institute	IPCC	United Nations Intergovernmental Panel on Climate Change
BECCS	Bioenergy with carbon capture and storage	IPN	International Policy Network
BPC	Bipartisan Policy Center	LCOE	Levelized cost of energy
CCC	Copenhagen Consensus Center	LNG	Liquefied natural gas
CCS	Carbon capture and storage	MCB	Marine cloud brightening
CCUS	Carbon capture, use, and storage	NAS	National Academy of Sciences
CCW	Coal combustion waste	NCCC	National Carbon Capture Center
CDR	Carbon dioxide removal	NORCE	Norwegian Research Centre AS
CLARA	Climate Land Ambition and Rights Alliance	OGCI	Oil and Gas Climate Initiative
CO2	Carbon dioxide	PV	Photovoltaic
CSLF	Carbon Sequestration Leadership Forum	SAI	Stratospheric aerosol injection
DAC	Direct air capture	SCoPEx	Stratospheric controlled perturbation experiment
DACCCS	Direct air capture with carbon capture and storage	SGRP	Harvard University's Solar Geoengineering Research Program
DOE	US Department of Energy	SO_2	Sulfur dioxide
EPRI	Electric Power Research Institute	SR1.5	Intergovernmental Panel on Climate Change's Special Report on 1.5 degrees
EOR	Enhanced oil recovery	SRM	Solar radiation modification
EV	Electric vehicle	TCM	Technology Centre Mongstad
GHG	Greenhouse gas	TJI	Thomas Jefferson Institute
GW	Gigawatt	WCA	World Coal Association
IEA	International Energy Agency	ZECA	Zero Emission Coal Alliance
IEAGHG	International Energy Agency's Greenhouse Gas R&D Programme		

Executive Summary

The present report investigates the early, ongoing, and often surprising role of the fossil fuel industry in developing, patenting, and promoting key geoengineering technologies. It examines how the most heavily promoted strategies for carbon dioxide removal and solar radiation modification depend on the continued production and combustion of carbon-intensive fuels for their viability. It analyzes how the hypothetical promise of future geoengineering is already being used by major fossil fuel producers to justify the continued production and use of oil, gas, and coal for decades to come. It exposes the stark contrast between the emerging narrative that geoengineering is a morally necessary adjunct to dramatic climate action, and the commercial arguments of key proponents that geoengineering is simply a way of avoiding or reducing the need for true systemic change, even as converging science and technologies demonstrate that shift is both urgently needed and increasingly feasible. Finally, it highlights the growing incoherence of advocating for reliance on speculative and risky geoengineering technologies in the face of mounting evidence that addressing the climate crisis is less about technology than about political will.

Key Findings and Messages

The urgency of the climate crisis is being used to promote geoengineering.

- Models are increasingly including large-scale carbon dioxide removal to account for overshooting (or surpassing 1.5 degrees of warming).
- Proponents are seeking increased funding and incentives for research and development of carbon dioxide removal technologies.
- A growing set of actors are considering or pursuing research into solar radiation modification, including outdoor experiments.

Geoengineering relies heavily on carbon capture and storage.

- Carbon capture and storage (CCS) are separately or jointly required for several forms of carbon dioxide removal.
- Most large-scale CCS projects use captured carbon for enhanced oil recovery or enhanced coal bed methane.
- Proponents of carbon capture and storage estimate that its use for EOR could spur consumption of 40% more coal and up to 923 million additional barrels of oil in the US alone by 2040.

Most direct air capture is only viable if it produces oil or liquid fuels.

- Most current or anticipated commercial applications of direct air capture are for the production of liquid (transport) fuels or enhanced oil recovery, both of which produce significant CO_2 emissions.
- Leading proponents of direct air capture explicitly market the process as a way to preserve existing energy and transportation systems.
- Direct air capture requires large energy inputs, resulting in either associated emissions or the diversion of renewable resources that would otherwise displace fossil fuels.

Carbon mineralization could promote wide dispersal of hazardous combustion wastes.

- Achieving large CO_2 reductions from mineralization would demand new mining at an unprecedented and infeasible scale.
- Coal combustion waste and other industrial wastes have been proposed as alternate feedstocks for mineralization.
- The atmospheric impact of using coal combustion waste would be minimal, and the process would promote coal by monetizing the industry's largest hazardous waste stream.

Reliance on bioenergy with CCS could raise emissions, threaten food security, and justify business as usual.

- Carbon dioxide removal often relies heavily on bioenergy with CCS (BECCS), despite warnings that its potential is overstated.
- BECCS presents the same use and storage problems as fossil CCS and direct air capture.
- Emissions due to land clearance for BECCS could exceed any reduction in atmospheric CO_2.
- Deploying BECCS at the scale suggested in many models would threaten food security and access to land for millions of people.
- Major oil companies rely on massive deployment of BECCS and carbon dioxide removal to justify continued heavy use of oil and gas for the next century.

Solar radiation modification is a dangerous distraction—and is simply dangerous.

- Techniques to modify earth's albedo were among the earliest forms of weather modification and geoengineering research.
- Fossil fuel companies have researched environmental modification for decades as a potential profit stream.
- Global sulfur dioxide emissions from fossil fuel combustion show solar radiation modification can affect the climate, with profound risks.
- Solar radiation modification could cause acid rain and ozone depletion, disrupt storm and rainfall patterns across large regions, and reduce the growth of crops and CO_2-absorbing plants.
- The most widely touted solar radiation modification technologies would use sulfate aerosols, which are clearly linked to ozone depletion and acid rain.

Fossil fuel interests have raised the profile of solar radiation modification.

- Fossil fuel interests played a significant but largely unrecognized role in shaping the research and public debates on solar radiation modification.
- Despite its risks, solar radiation modification has been promoted as a means to delay or minimize other forms of climate action and allow business-as-usual reliance on fossil fuels.
- Despite international moratoria, open-air solar radiation modification experiments are being actively explored.
- Proponents of solar radiation modification recognize that such tests could open the door to wider-scale deployment of geoengineering.

Geoengineering is creating new tools for climate denial—and they are being used.

- Climate denialists have long advocated geoengineering as an excuse for climate inaction.
- Recent years have seen a resurgence in geoengineering interest among opponents of climate action.
- Contrary to claims by geoengineering proponents, the use of geoengineering by climate denialists is neither uncommon nor coincidental.

We must and can stay below 1.5°C without relying on geoengineering.

- Clear and achievable pathways exist for keeping the world below 1.5°C.
- All pathways that avoid overshooting 1.5°C of warming require an early, rapid phase-out of fossil fuels.
- This transition is ambitious, but achievable by accelerating the deployment of existing renewable energy and energy efficiency technologies.
- Low-risk, win-win approaches exist to reduce CO_2 emissions from the land and natural resource sectors while advancing other sustainable development goals.
- Geoengineering deployments pose a high risk of delaying the necessary transition, while creating new threats that compound and exacerbate climate impacts.

Recommendations

Humanity has a limited and rapidly closing window to avoid truly catastrophic climate change. To keep warming below 1.5 degrees, the world must reduce greenhouse gas emissions 45% by 2030 and reach net zero emissions by around 2050. By entrenching fossil fuel interests and promoting continued reliance on fossil *infra*structure, geoengineering distracts from more viable solutions and threatens to exacerbate the climate crisis, while exposing large parts of the world to new and significant risks. The managed decline of fossil fuels is both a necessary and achievable solution to the climate crisis.

Climate policy should:

- Focus at the national and global level on the rapid, managed decline of fossil fuels and the accelerated transition to a new energy economy in a timeframe that will keep the world below 1.5 degrees of warming.
- Ensure that all public *infra*structure investments align with the Paris Agreement and the 1.5-degree goal.
- Avoid policies that promote or subsidize the construction of new fossil *infra*structure or extend the economic life of existing fossil *infra*structure, including through subsidies for carbon capture and storage, direct air capture, or BECCS.
- Prohibit open-air experiments of solar radiation modification techniques.

Introduction: Postcards from the Edge of a Climate Breakdown

It is more than 120 years since Svante Arrhenius published the first calculations of global warming caused by human emissions of carbon dioxide (CO_2), eighty years since Guy Callendar published the first evidence that humans were inadvertently modifying the atmosphere at a global scale, and sixty since Roger Revelle warned that humankind was now conducting "a vast geophysical experiment" on the Earth through its unbridled combustion of fossil fuels.[3]

Through the ensuing decades, and against a backdrop of ever more robust scientific consensus and ever greater levels of certainty, the scientific community has repeatedly called on governments, industry leaders, and the general public to recognize the growing climate threat and to act while there is still time.

Even as the world grappled with "inadvertent" climate change caused by human activity, a smaller cadre of scientists, governments, and corporations continued to publish on, invest in, and occasionally experiment with intentional modification of the climate and the geosphere at a variety of scales—to confront climate change, to advance goals unrelated to climate change, or both. This body of research and practice employs a diverse array of theories, strategies, and technologies, but shares a common objective: "deliberate large-scale intervention in the Earth's climate system."[4] And it shares a common moniker: geoengineering.

Since at least the 1980s, proposals that humanity attempt to geo-engineer its way out of the climate crisis have been generally relegated to the fringes of climate science and policy. This fringe status reflected not only the profound uncertainties and potentially staggering costs of tinkering with planetary systems, but also the profound risks of doing so.

Over the last decade, however, and with increasing speed, geoengineering strategies, technologies, and risks have moved from the fringes of climate discourse toward its center. In significant part, this

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shift reflects a growing alarm among scientists, decision-makers, and concerned observers that a substantial amount of global climate change is already locked in; that humanity has yet to act on the climate crisis at anything approaching the ambition, scale, or urgency required; and that, accordingly, dangerous ideas once considered unthinkable must now be examined. As others have documented at length, however, the growing focus on geoengineering also reflects the persistent, intensive, and well-resourced efforts of a relatively small group of scientists and industries to push geoengineering technologies into climate debates and policies.[5]

Many and perhaps most proponents of geoengineering are acting in good faith. The scientists, policy experts, activists, and citizens who look to geoengineering as a potential solution are rightly concerned about the severity of the climate crisis, the extent of warming to which the world is already committed, and the dwindling number of paths available to avert worst-case scenarios. However, any consideration of geoengineering must begin with a thorough examination of its risks. One such risk is that rather than provide a solution, geoengineering will further entrench the fossil fuel economy and make the transition from fossil fuels more difficult.

In light of their history, capacity, and fundamental commercial interests, it should come as little surprise that fossil fuel companies have been among the most active and sustained players in the geoengineering space. To date, however, the nature and extent of the fossil industry's role in geoengineering has received inadequate attention and scrutiny.

The present report represents a first step toward filling that gap. It investigates the early, ongoing, and often surprising role of the fossil fuel industry in developing, patenting, and promoting key geoengineering technologies. It examines how the most heavily promoted strategies for carbon dioxide removal and solar radiation management depend on the continued production and combustion of carbon-intensive fuels for their viability. It analyzes how the hypothetical promise of future geoengineering is already being used by major fossil fuel producers to justify the continued production and use of oil, gas, and coal for decades to come. And it exposes the stark contrast between the emerging narrative that geoengineering is a morally necessary adjunct to climate action and the commercial arguments that geoengineering is simply a way of avoiding or reducing the need for true systemic change, even as converging science and technologies demonstrate that shift is both urgently needed and increasingly feasible. Finally, it highlights the growing incoherence of advocating for speculative and risky geoengineering technologies as critical to human rights while at the same time ignoring the pervasive and disastrous risks to human rights these same technologies present for both present and future generations.

Many proponents of geoengineering testing and deployment have downplayed or dismissed these "excuse for delay" and "moral hazard" critiques of geoengineering as overblown and largely theoretical. To the contrary, our analysis demonstrates those risks are both underestimated and—for many geoengineering technologies—potentially unavoidable.

BOX 1

A Note on Coverage

Given the wide array of geoengineering technologies that have been proposed and the decades-long history of geoengineering research, this report does not address every geoengineering idea that has been proposed, or even all of those that have been seriously considered. It focuses instead on those technologies that figure most heavily in current, ongoing debates about geoengineering testing and deployment. Similarly, and in light of the global nature of the fossil fuel industries, this report could not and does not purport to cover the panoply of fossil fuel industry research into or promotion of geoengineering worldwide. For example, the role of US oil and coal companies is discussed more extensively than that of the European coal industry, fossil fuel interests in China and India receive less attention still, and the vast majority of other countries are not addressed at all. CIEL has prepared this report in the hope and expectation that it will spur future research to close such gaps.

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PART 1

The Scientific Basis and Moral Imperative for Urgent Climate Action

In October 2018, the United Nations Intergovernmental Panel on Climate Change (IPCC) released its starkest warning yet on the growing impacts of climate change, the urgent need for accelerated climate action, and the dire consequences of further delay. Against a growing backdrop of intense storms, floods, and wildfires worldwide, the report synthesizes and summarizes what has long been evident to scientists and informed observers alike: The 1.0 degree Celsius of warming the planet has already experienced is putting human lives, human rights, and ecosystems at risk around the world.

In its Special Report on 1.5 degrees (SR1.5),[6] the IPCC recognized that these risks will be increasingly severe and widespread in a world projected to be at least 1.5 degrees warmer. More importantly, in an update to the well-known "Burning Embers" diagram, the IPCC confirmed the growing scientific consensus that warming near or above 2.0 degrees would push human and biological systems well into the danger zone across multiple "Reasons for Concern." Critically, the IPCC concluded that limiting warming to 1.5 degrees is still possible, but demands immediate, dramatic reductions in greenhouse emissions and a rapid transformation of our global energy system.[7] Specifically, the IPCC concluded that keeping warming within 1.5 degrees requires the world to reduce global carbon dioxide emissions 45% by 2030 and achieve net zero CO_2 emissions by 2050.[8]

The IPCC modeled four illustrative pathways to achieving those goals. A unifying factor in all of the pathways was the "virtually full decarbonization of the power sector by mid-century,"[9] with rapid reductions by 2030 providing the greatest likelihood of avoiding overshoot (or surpassing 1.5 degrees of warming). The IPCC recognized that every scenario requires tradeoffs between near-term ambition, the risk of overshoot, transitional challenges between 2030 and 2050, and the amount of carbon dioxide removal (CDR) that would eventually be required. But it concluded that the risk of overshoot, transitional challenges, and the utilization of CDR—with all its attendant risks and impacts—are all *significantly reduced* if ambitious action is taken in the near term.[10] It cautioned that strategies that prioritize taking concerted action only *after 2030* "face significant risks of carbon *infra*structure lock-in and overshoot, with the risk that a return to 1.5 degrees could not be achieved."[11]

> *"The available literature indicates that 1.5°C-consistent pathways would require robust, stringent and urgent transformative policy interventions targeting the decarbonization of energy supply, electrification, fuel switching, energy efficiency, land-use change, and lifestyles."*
>
> — IPCC SR1.5[14]

Accordingly, the first, most ambitious, and safest of IPCC's illustrative pathways (Pathway 1) models an immediate and rapid transformation of our energy system to reduce CO_2 emissions 58% by 2030 and 97% by 2050. To achieve this, it couples widespread adoption of energy efficiency and renewable energy technologies with the near elimination of coal (-97%), oil (-87%), and gas (-74%) by the year 2050. It closes the remaining gap through a limited deployment of forest, agriculture, and land-use measures, including afforestation and reforestation.[12] This approach is consistent with the IPCC's finding that "1.5°C-consistent pathways would require robust, stringent and urgent transformative policy interventions targeting the decarbonization of energy supply, electrification, fuel switching, energy efficiency, land-use change, and lifestyles."[13]

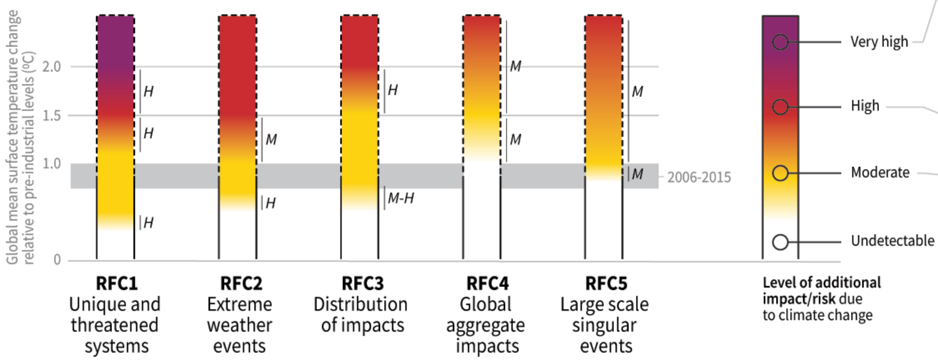
In each of the three remaining illustrative pathways, the IPCC modeled the continued use of forest and land-use measures, but also incorporated progressively escalating deployments of carbon capture and storage (CCS) and bioenergy with CCS (BECCS).[15] The IPCC highlighted the potential value of forest and land use measures in accelerating early action on climate change and noted the particular benefits of increased conservation and restoration efforts in natural areas for their rapid deployability, lower risk of social and environmental impacts, and potential for positive co-benefits.[16] It observed that, as additional information has emerged in recent years on the viability, scale requirements, and potential negative impacts of BECCS, projections of its potential contributions to global emission reductions have been declining. The IPCC observed that few reliable models for meeting 1.5 targets incorporated direct air capture with CCS (DACCCS) or other proposed carbon dioxide removal technologies. It cautioned, however, in the Summary and throughout the report,

FIGURE 1
Reasons for Concern

How the level of global warming affects impacts and/or risks associated with the Reasons for Concern (RFCs) and selected natural, managed and human systems

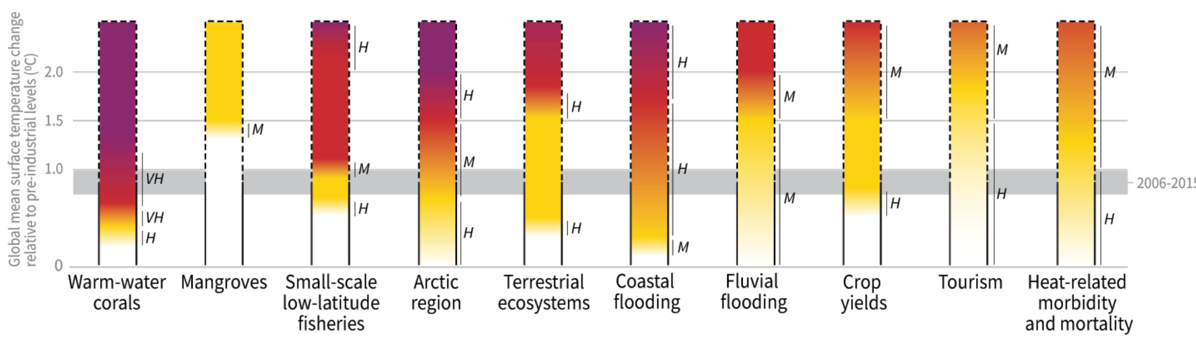
Five Reasons For Concern (RFCs) illustrate the impacts and risks of different levels of global warming for people, economies and ecosystems across sectors and regions.

Impacts and risks associated with the Reasons for Concern (RFCs)



Purple indicates very high risks of severe impacts/risks and the presence of significant irreversibility or the persistence of climate-related hazards, combined with limited ability to adapt due to the nature of the hazard or impacts/risks.
Red indicates severe and widespread impacts/risks.
Yellow indicates that impacts/risks are detectable and attributable to climate change with at least medium confidence.
White indicates that no impacts are detectable and attributable to climate change.

Impacts and risks for selected natural, managed and human systems



Confidence level for transition: *L*=Low, *M*=Medium, *H*=High and *VH*=Very high

IPCC, *Summary for Policymakers*, in GLOBAL WARMING OF 1.5°C: AN IPCC SPECIA`L REPORT ON THE IMPACTS OF GLOBAL WARMING OF 1.5°C 13 (V. Masson-Delmotte et al. eds., 2018), https://www.ipcc.ch/site/assets/uploads/sites/2/2018/07/SR15_SPM_version_stand_alone_LR.pdf.

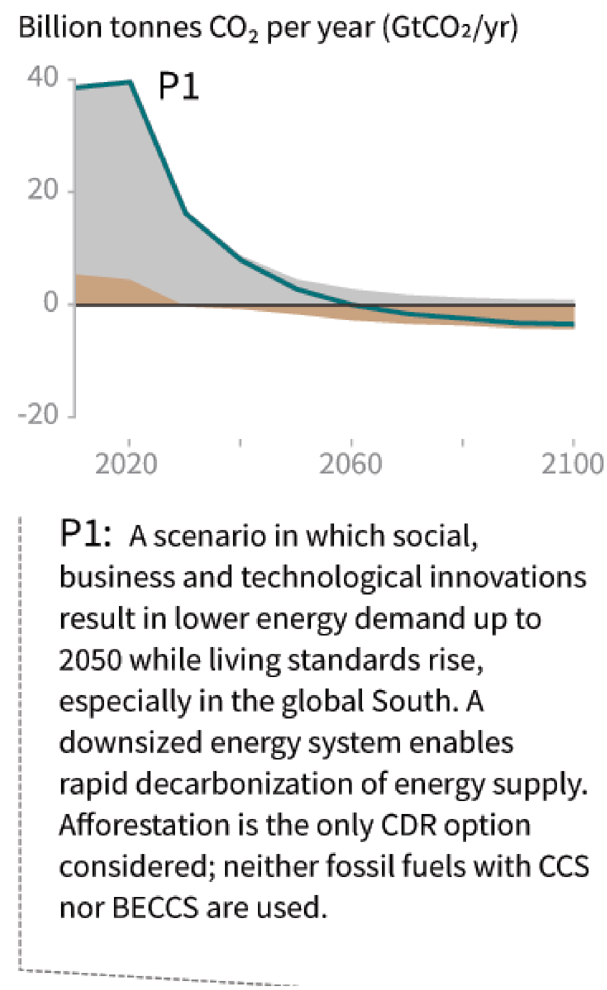
that the economic and technological uncertainties associated with these approaches, the long projected timelines for their deployment at any meaningful scale, and the moderate to high likelihood of negative social and environmental impacts made reliance on these technologies risky and inherently speculative.[17]

The IPCC expressly declined to incorporate any form of solar radiation modification (SRM) into its model, citing the pervasive and profound uncertainties, significant questions about the feasibility of most SRM approaches, and the high risk of negative impacts.[18]

Remarkably, and in stark contrast to the cautious language and clear warnings of the IPCC itself, the release of the SR1.5 report has triggered a barrage of stories in the global media arguing that geoengineering—whether through large-scale CDR, SRM, or both—may be the only way to save the climate, the planet, and humanity.[19] A growing drumbeat of activists, public officials, and concerned citizens are calling for accelerated public support for development and deployment of these technologies. While these demands are sincere, the call for diverting public attention and resources to these geoengineering technologies—and the companies that control or stand to benefit from them—is not a backup plan or an insurance policy. Instead, it risks further entrenching the fossil fuel economy and making it even harder to combat the climate crisis.

FIGURE 2

IPCC Pathway 1 to 1.5ºC



IPCC, *Summary for Policymakers*, in GLOBAL WARMING OF 1.5°C: AN IPCC SPECIAL REPORT ON THE IMPACTS OF GLOBAL WARMING OF 1.5°C 13 (V. Masson-Delmotte et al. eds., 2018), https://www.ipcc.ch/site/assets/uploads/sites/2/2018/07/SR15_SPM_version_stand_alone_LR.pdf.

PART 2

Geoengineering: Carbon Dioxide Removal, Solar Radiation Management, and Beyond

As noted in the introduction, geoengineering has been succinctly described as the "deliberate large-scale intervention in the Earth's climate system."[20] The array of techniques and technologies potentially encompassed within this definition is vast and diverse—ranging from restoring forests and agricultural soils to spraying aerosols into the atmosphere to deploying giant mirrors in space.

There is ongoing debate about what should and should not be considered geoengineering and the categories into which various geoengineering approaches can be divided. The IPCC's SR1.5 Report expressly avoids the term "geoengineering" and instead divides the approaches and technologies involved into two broad and distinct classes: those which purport to remove carbon dioxide from the atmosphere (carbon dioxide removal), and those which alter the Earth's balance of solar radiation (solar radiation modification).[21] Within CDR, the United Nations Environment Program further distinguishes between approaches that are based on natural processes (such as reforestation or soil restoration), those involving a mix of nature and technology (such as bioenergy with carbon capture and storage), and approaches that are primarily technological (such as direct air capture with carbon capture and storage).[22]

- **Carbon dioxide removal** technologies seek to remove emitted CO_2 from the atmosphere. Also known as *negative emission technologies*, CDR proposes to "draw down" atmospheric levels of CO_2, whether through enhancement of natural processes or through the deployment of complex—and often unproven—technologies. Among the most widely discussed (or heavily touted) CDR approaches are:
  - Afforestation and reforestation,
  - Soil sequestration,
  - Bioenergy with carbon capture and storage,
  - Direct air capture with carbon capture and storage,
  - Enhanced weathering,
  - Ocean alkalinization, and
  - Ocean fertilization.
- **Solar radiation modification**—also called **solar radiation management**—does not attempt to reduce greenhouse gases (GHGs) in the atmosphere, but proposes to modify the earth's radiation balance in ways that alter heat absorption at regional or global levels and temporarily mask the effects of anthropogenic warming. The most widely discussed technologies for SRM include:
  - Atmospheric aerosol injection,
  - Marine cloud brightening,
  - Marine sea surface brightening, and
  - Modifying the albedo, or reflectivity, of polar ice or promoting polar ice growth.

The CDR/SRM dichotomy does not capture the full spectrum of geoengineering proposals and technologies. For example, it does not account for techniques that seek to manage the flow of energy within and among earth systems. Such proposals include transferring hotter surface ocean water to lower depths or building giant pipes to push low-atmosphere air into the upper atmosphere. To date, these earth system modification proposals have received considerably less public attention than CDR and SRM, and this report will not discuss them at length.

"...with Carbon Capture & Storage": Why CCS is Vital to the Geoengineering Debate

The ways in which geoengineering techniques are categorized, and what is and is not considered geoengineering, will affect law, scientific research, private and public capital flows, and the sociopolitical context in which critical public decisions about geoengineering are made. For that reason, this report applies an expansive definition of geoengineering, viewing all technological CDR methods and all forms of SRM as within the geoengineering umbrella. This comprehensive approach is vital to any realistic evaluation of CDR and SRM methods because of the critical ways in which the various technologies and strategies intersect and interrelate.

While individual CDR projects may not appear to be global in scale, the wide-scale deployment of CDR methods would reshape the planet. CDR at the scale suggested by its proponents would lead to massive geological storage of carbon dioxide, land-use change over enormous parcels of land for use in minerals mining or bioenergy production, and potentially dramatic changes to marine ecosystems across large regions.

Further, CDR methods—like SRM methods and geoengineering generally—pose the same risks that are at the heart of this report. The wide adoption of CDR techniques risks entrenching fossil fuel interests and making mitigation efforts considerably more difficult. This is especially true as core CDR technologies are disproportionately owned or funded by fossil fuel companies.

Most significantly, this report considers the pervasive role of carbon capture and storage within geoengineering and the role of the fossil fuel industry in promoting CCS. As is readily evident from their titles, and as discussed more fully herein, BECCS, the most widely discussed technological approach to CDR, expressly relies on effective use of CCS. Similarly, the most widely discussed technologies for direct air capture (DAC) would require the operation of large-scale carbon storage to dispose of captured carbon unless, as is frequently proposed, the captured carbon were simply processed into carbon-based fuels, to be combusted and re-emitted into the atmosphere. Moreover, DAC approaches frequently rely on CCS as a source of low-carbon fuel to power their own energy-intensive processes. Less obviously, but no less significantly, CDR techniques such as enhanced weatherization, mineralization, and ocean alkalinization may draw heavily on carbon capture technologies in their processes and feedstocks, or may require coal combustion wastes or similar residuals to operate at scale. Accordingly, many of the financial and policy incentives which could apply to one of these technologies would (or do) apply to others.

Geoengineering May Entrench Fossil Fuel Interests

The IPCC makes clear in SR1.5 that the key to limiting warming to 1.5 degrees is *transition*. The path out of a world with runaway global warming is not simply a matter of emissions adding and subtracting up to a certain amount. Entire *systems* of energy, land use, urban design, *infrastructure*, and industrial production need to shift from a reliance on fossil fuels to more sustainable paradigms.

Geoengineering threatens this transition by entrenching the exact systems that need redesigning. Proponents and experts of CDR techniques acknowledge that the "main advantage of sequestration is its compatibility with existing fossil fuel *infra*structure."[23] SRM, in addition to posing enormous unknown risks, is acknowledged even by its supporters as a perfect excuse for inaction.[24]

Finally, and critically, the fossil fuel industry controls huge swaths of the technologies necessary to pursue CDR and SRM at scale. These companies have been involved in geoengineering research and debates from their earliest days and are not separate from—but rather inextricably linked to—any real-world execution of geoengineering.

It is not surprising that the fossil fuel industry has invested and is investing heavily in the technologies that would render a transition from fossil fuels less urgent. But it is important to acknowledge the depth of those connections. The debate around geoengineering will in part determine the trajectory of the global response to climate change. To limit warming to 1.5 degrees, the global community will need to mobilize massive public and private resources. It will need to redesign systems and restructure vast sectors of the global economy. A focus on geoengineering risks slowing that transition, diverting investments from other more realistic and more workable solutions, while enriching and entrenching the very interests at the heart of the crisis itself.

Geoengineering proponents are right to be concerned. The situation is dire, and we as a global community should test out and invest in a diverse suite of technologies and techniques to combat this crisis. But the core challenge remains known: We need to transition away from reliance on fossil fuels. Anything that moves us toward greater reliance will not be a solution, and the push for geoengineering is likely to do exactly that.

PART 3

Asphalt Fields and Black Carbon Skies: A Brief History of Fossil Fuels and Weather Modification

While widespread public and scientific debate about geoengineering has only recently emerged from a long period of quiescence and relative obscurity, neither the basic principles underlying geoengineering technologies nor the fantasy of applying them at ever larger scales are recent developments. Governments, scientific institutions, and private companies, including many fossil fuel companies, were conducting research into weather modification and albedo enhancement more than sixty years ago.

Experimentation with weather modification at local and regional scales began in the 1930s and began to accelerate and diversify in the 1940s. Governments, including their militaries, were interested in using weather modification for a variety of purposes—to make rains more predictable, to dissipate fog or redirect storms, to convert ice-covered areas into habitable zones, and to use as tools of war. Academic institutions sought greater understanding, and oil companies sought to protect their financial interests. Industry groups saw weather modification as a means to protect their existing investments and to open new product lines and profit streams.

Early science on climate change was frequently discussed and reported in parallel with this research, as an "inadvertent" form of weather modification. Guy Calllender, whose work in 1938 brought climate change back into active scientific debate, spent much of World War II working with the UK's Petroleum Warfare Department and British and US oil companies to develop pioneering techniques for clearing fog-bound airstrips by massive flaring of fossil fuels.[25] By the 1950s and into the 1960s, rising signs that the Arctic was warming[26] spurred a flurry of research and discussion within the US and Russian military and scientific communities as to how that warming might be accelerated to produce a permanently ice-free Arctic Ocean, whether through blocking rivers, "blackening polar ice caps," or using coal plant emissions or nuclear blasts to generate persistent ice fogs and melt the Arctic sea ice.[27] In a 1958 report reviewing and critiquing these various projects, Henry Wexler of the US National Weather Bureau proffered a warning that remains prescient and relevant six decades later:

"When serious proposals for large-scale weather modification are advanced, as they inevitably will be, the full resources of general-circulation knowledge and computational meteorology must be brought to bear in predicting the results so as to avoid the unhappy situation of the cure being worse than the ailment."[28]

Yet, by as early as 1965, a landmark climate report to US President Lyndon Johnson, led by Roger Revelle of the Scripps Institute, included a suggestion that increasing the albedo, or reflectivity, of the Earth could combat atmospheric warming.[29] While the prospect of using such technological fixes may have retreated into the background, it retained a recurring interest for some of the world's most powerful and well-resourced corporate actors.

Early Oil Industry Interest in Weather Modification

The oil industry began studying hurricane formation no later than the 1940s.[30] This research was necessary to protect the industry's investments in a rapidly expanding fleet of offshore oil rigs, which were often damaged or disabled by hurricanes in the Gulf of Mexico. But by no later than the 1960s, some in the oil industry were actively exploring techniques to control or modify the weather, not just understand it. In some cases, the concern was related to hurricanes—how to divert their course or dissipate their energy. In other cases, the purpose was to seed clouds and increase precipitation, specifically through the use of petroleum byproducts.

Esso (now ExxonMobil (Exxon)) spent considerable time and money researching weather modification techniques. As Exxon's chief scientist, James F. Black played a key role in Exxon's internal research on carbon dioxide and climate change in the 1970s and 1980s.[31] Before this, Black was an active contributor to Exxon's research into intentional weather modification.

In 1963, Black published two studies describing Exxon's experiments in coating large areas of land with asphalt, with the goal of lowering albedo, raising surface temperatures, and increasing rainfall in nearby areas.[32] In this paper, Black describes how spreading asphalt, which absorbs sunlight and emanates heat, could alter meteorological conditions at a local to regional scale to produce rainfall over arid areas.[33] Experiments of this technique were covered in a 1963 edition of *Popular Mechanics*,[34] and Black later patented the process on behalf of Exxon.[35] While the initial experiments were limited in scope, Exxon envisioned deploying the technique over tens to hundreds of square miles.

In 1964, the National Academy of Sciences convened a Panel on Weather and Climate Modification. In 1966, the Panel published the outcomes of its work in *Weather and Climate Modification: Problems and Prospects*,[36] which summarized the state of knowledge and research needs in the field of meteorological control. Black participated in two of the twelve meetings that contributed to the final report.[37] Notably, this report also included a long discussion on then-emerging climate science and the risk that accumulating carbon dioxide in the atmosphere could lead to global warming.[38]

In 1974, Colorado State University published a book-length report entitled *Weather Modification by Carbon Dust Absorption of Solar Energy*.[39] Two of the four authors of this report, M.L. Corrin and C.A. Stokes, had deep fossil fuel industry connections, working for Philips Petroleum and Citgo, respectively.[40] This report evaluated the idea of spraying large amounts of carbon black, or soot, in different ways to absorb solar energy and modify the weather or climate.

This report is significant for several reasons. First, the authors both identify the industry's clear financial incentive in modifying weather to diffuse tornadoes and hurricanes, among other applications, and note the utility of using fossil fuels—in this case, petroleum to make carbon black—for these applications. Second, the report identifies a meso level of weather and climate modification, whereby local effects become regional, and above which regional effects become global. This understanding—that weather modification and climate engineering exist on a spectrum and are not isolated or independent activities—was therefore clear to experts on the subject no later than 1974.

These reports from the National Academies of Science and Colorado State University document the oil industry and fossil fuel companies' significant interest in weather modification and climate control at its earliest stages. Critically, it also exemplifies the ways in which these interests were aligned with or reflected in research by academic institutions and scholars. Fossil fuel companies frequently hired academics (e.g., Colorado State University's M.L. Cornin) as consultants or funded university research programs.

One example of the latter is the University of California San Diego Center for Energy Research,[41] created in 1974 via a grant from the Gulf Oil Foundation.[42] In addition to several studies relating to climate change generally,[43] the Center also investigated options for modulating solar radiation balance to combat the effects of increased carbon dioxide accumulating in the atmosphere.[44] One of the authors of this paper was directly funded by Shell's graduate funding program.[45]

The Importance of Acknowledging this Early Fossil Fuel Interest

The purpose of identifying this connection is not to claim that all academic interest in weather modification or climate control stems from fossil fuel industry funding. As mentioned in the introduction, there are and always have been well-intentioned, fully independent people pursuing research and deployment of these technologies. It is simply to demonstrate that the extent to which the fossil fuel industry was (and still is) researching and supporting various forms of geoengineering—especially the more controversial solar radiation management techniques—remains unknown.

The foregoing is far from a comprehensive overview of the history of weather modification, or even the history of fossil fuel company involvement with it. Rather, it serves to demonstrate three critical points.

First, as was the case in the history of the climate debate, oil companies were there from the beginning. These companies had a strong business interest in understanding and controlling the weather to protect high-value assets and their core markets, and they used their well-resourced and sophisticated research apparatuses to explore their options.

Second, these companies saw opportunities to use waste or by-products of their production processes—such as carbon black and asphalt—as new profit centers, much as they did after 1950 with chemicals now used for plastics.

Finally, these companies developed a deep expertise and understanding of wind and rain patterns and the manipulation of incoming solar radiation. Though these preliminary studies may not have been conducted to combat climate change or provide potential alternatives to emissions reduction, once the debate over how to adapt to climate change and the subsequent debate over whether or not to engage in geoengineering began in earnest, these companies were better positioned than almost any other institutions to understand the parameters of that debate.

PART 4

Carbon Dioxide Removal and Negative Emissions: The Pervasive Role of Carbon Capture, Use, and Storage

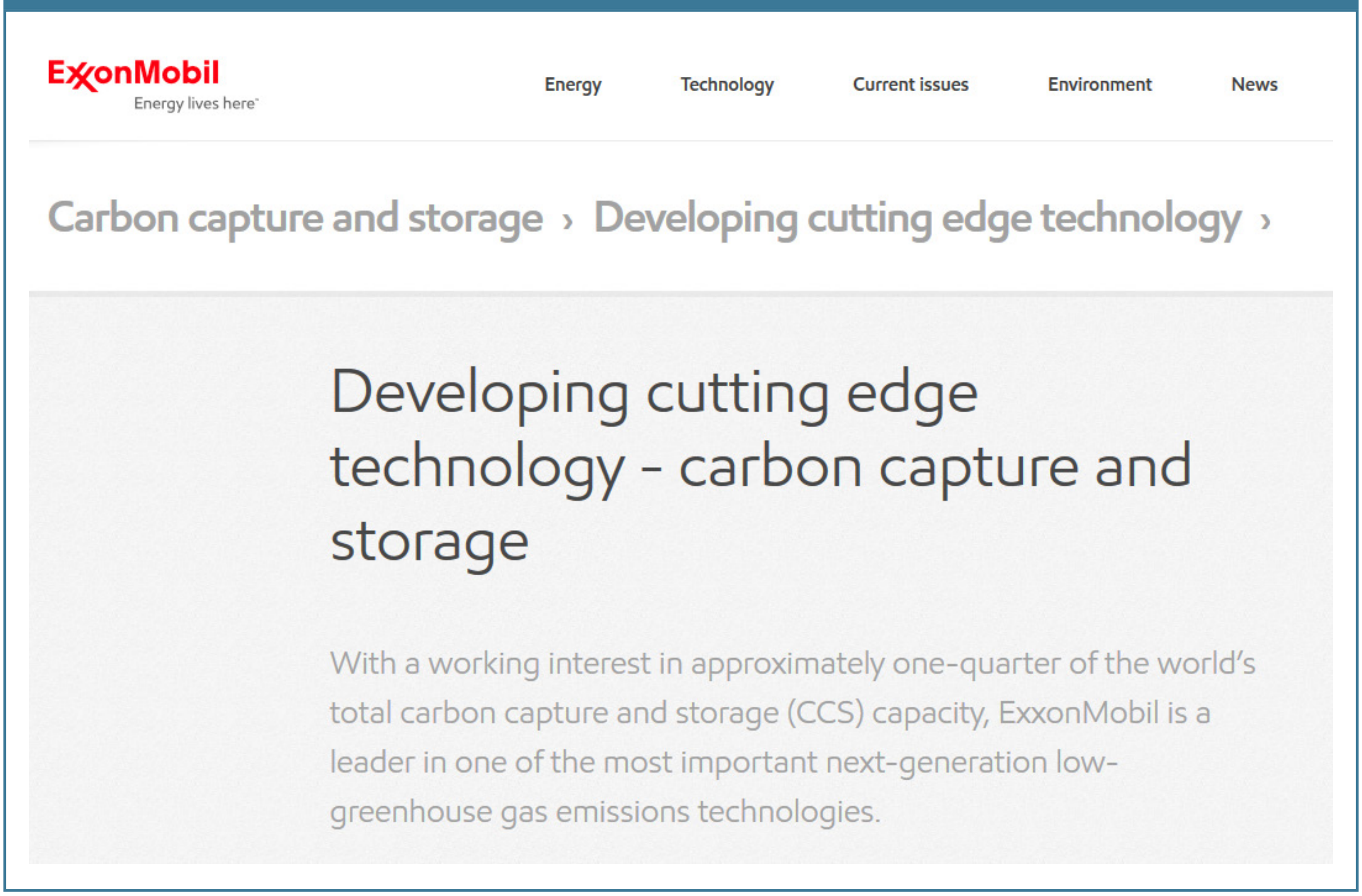
Most geoengineering approaches being actively explored rely on the effective and widespread deployment of some form of carbon capture and storage or carbon capture, use, and storage (CCUS).

For example, most debate on bioenergy with carbon capture and storage has rightly focused on the lifecycle greenhouse gas and pollutant emissions of biofuel or bioenergy production and use, as well as on the social, environmental, and food security impacts of producing biofuels at the scales required to create meaningful emissions reductions. As its name implies, however, BECCS will also require the deployment and operation of CCS *infra*structure at an unprecedented scale and in a manner that is economically viable.

Direct air capture, although distinct from carbon capture from flue gases, would require the deployment of even more energy-intensive technologies and would still require the storage or productive use of enormous quantities of harvested CO_2.

Many proposals for enhanced weathering or carbon mineralization rely on concentrated streams of carbon dioxide generally

FIGURE 3
ExxonMobil Webpage on Carbon Capture and Storage



Developing Cutting Edge Technology – Carbon Capture and Storage, EXXONMOBIL, https://corporate.exxonmobil.com/en/technology/carbon-capture-and-storage/carbon-capture-and-storage/developing-cutting-edge-technology-carbon-capture-and-storage (last visited Jan. 3, 2019).

operating at industrial point sources, or would arguably constitute forms of waste management and storage for coal fly ash (a residual from coal combustion) and other industrial wastes.

As discussed more fully herein, CCUS technology has been disproportionately funded, promoted, and controlled by fossil fuel companies. CCUS is valuable to the fossil fuel industry in three key ways: it expands oil production, provides a lifeline to a declining coal industry, and further entrenches the overall fossil fuel economy.

For oil companies, CCS presents an opportunity for additional oil production because the primary uses of captured carbon thus far identified are the production of more oil or other petrochemical products. Exxon proudly declares that it has "a working interest in approximately one-quarter of the world's total carbon capture and storage (CCS) capacity[.]"[46] Chevron "has invested more than $75 million in CCS research and development over the last decade."[47] BP, in addition to its seventeen-year sponsorship of the Carbon Mitigation Initiative, is a current sponsor of the CO_2 Capture Project.[48] And Shell has a working interest in four CCS projects, discussed in greater detail below.[49]

For coal producers and power generators, especially coal-fired power plants, CCS provides a lifeline to keep the industry operational in a carbon-constrained world. Finally, for all fossil fuels, the promise of technologies that purport to ameliorate the climate crisis while leaving the fossil-based global energy system fundamentally unchanged provide social, political, and economic cover for companies to advocate for and assume the continued economic viability of that system.

As a result, incentivizing CCUS through policy and relying on it in planning will likely slow the transition away from fossil fuel investments and undermine broader efforts to mitigate climate change.

This centrality is made explicit in one proposed two-degree pathway published by Shell in 2018, called its Sky Scenario.[50] The Sky Scenario purports to present a potential pathway for the world energy transition to achieve the goals of the Paris Agreement. The scenario, however, relies extraordinarily heavily on deployment of CCS, both to capture fossil fuel emissions and for use with bioenergy. The scenario requires that at least 10,000 major CCS facilities be constructed, despite acknowledging that fewer than 50 are in operation today.[51] Significantly, positing CCS deployment at this scale permits Shell to project continued heavy reliance on fossil fuels, particularly oil and natural gas, until 2100.

The relationship between CCUS and geoengineering strategies based on solar radiation modification is more complex. Even proponents of solar geoengineering acknowledge the risks of termination shock—that once SRM begins, any reduction in SRM intensity would lead to catastrophically rapid atmospheric warming unless and until atmospheric greenhouse gas concentrations have been returned to lower levels.[52] Accordingly, many proposed SRM strategies explicitly presuppose the widespread deployment of CCS.[53] In the absence of CCUS, however, SRM proponents must assume that mitigation efforts will move so slowly that sustained SRM deployments may be necessary, but just rapidly enough that excess GHG concentrations can nonetheless be brought down to safe levels without recourse to CDR technologies.

Carbon In, Carbon Out: Captured Carbon and Enhanced Oil Recovery

The technology required to remove carbon dioxide from gas streams has been around for over 70 years.[54] While companies such as Exxon have recognized the potential value of these technologies in addressing climate change since at least 1980,[55] the historic development of CO_2 capture has been primarily driven by commercial purposes unrelated to climate mitigation.

The most widespread and commercially important of these purposes is enhanced oil recovery (EOR). EOR is a technique for extracting new oil from a depleted well—that is, from a once-productive well that can no longer be commercially exploited through other economic means.

FIGURE 4
Type of CO_2 utilization patents

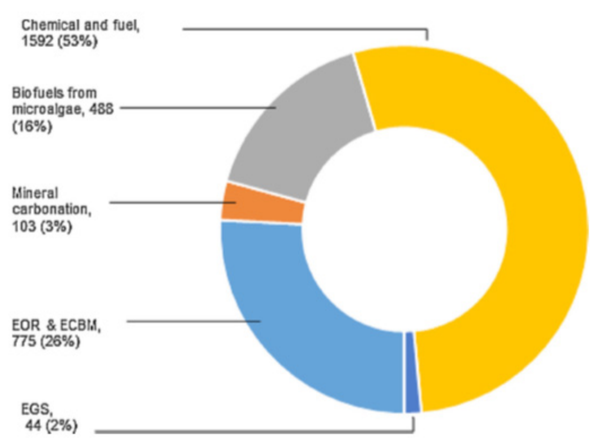


Fig. 3. Type of CO_2 utilization patents.

Rahmad Norhasyima & T.M. Indra Mahila, *Advances in CO_2 Utilization Technology: A Patent Landscape Review*, 26 J. OF CO2 UTILIZATION 323 (2018), https://www.sciencedirect.com/science/article/pii/S2212982018301616.

By injecting highly-pressurized CO_2 and water into a depleted well, oil companies can force remaining oil to the surface and extract it for sale and use.[56] Put more simply, EOR is a means of oil production, and its critical input is condensed CO_2. Anything that makes that CO_2 cheaper will enable oil companies to extract ever more oil from depleted wells, whereupon it will be burned—and emitted to the atmosphere—just like any other fossil fuel.

The first patent for EOR with carbon dioxide was granted in 1952;[57] and by 1984, the industry was explicitly touting the technology's importance to long-term oil production.[58] Today, the vast majority of carbon dioxide used in industrial processes is used for EOR, and EOR is expected to remain the dominant use of industrial CO_2 for the foreseeable future.[59]

The role of CO_2 in EOR is critical to understanding the viability and value of CCS and geoengineering strategies that encourage CCS because EOR remains the key driver of profitable CCS deployment. Despite decades of research into the process, fossil energy with carbon capture and storage, especially coal-fired power with CCS, cannot compete with the ever-falling cost of renewable energy.[60] The ability to sell the carbon dioxide to an EOR operator is the primary avenue through which this expensive process can become profitable.

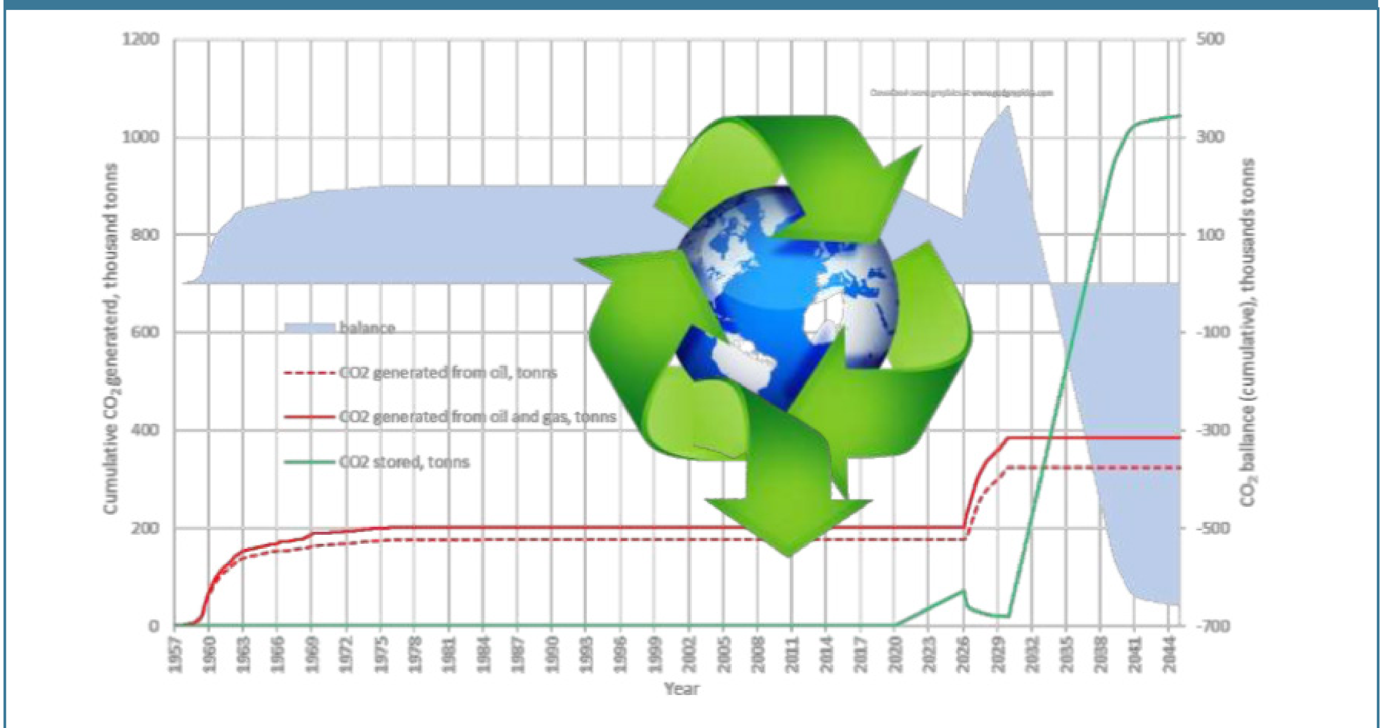
As a case in point, even with government incentives,[61] as of December 2018 there were only two large-scale fossil energy power plants with carbon capture units operating: the Boundary Dam project in Canada and the Petra Nova plant in the United States.[62] Both are coal-fired, and both use the captured carbon dioxide for EOR.[63]

Increasingly, proponents of carbon capture claim that captured CO_2 can be used in the production of other products, including plastics, petrochemicals, synthetic fuels, and cements.[64] As noted by the Global CCS Institute, however, "the market for products derived from non-EOR use of CO_2 is small relative to what is needed to be stored."[65] The Norway-based research group NORCE, which actively advocates for CCUS, echoed this view in a presentation at the 2018 climate negotiations in Katowice, Poland, observing that EOR is "currently the only commercially ready process allowing for simultaneous utilization and storage (CCUS) of industrial-scale volumes[.]"[66] Thus, even if one ignores the environmental and climate impacts of their production and use, these non-EOR products (other than transportation fuels) are likely to account for only a small fraction of CO_2 use for the foreseeable future.

This reality is reflected in a 2018 landscape review of patents in the CCUS space. Patents for EOR and enhanced coal bed methane production accounted for more than a quarter (26%) of the

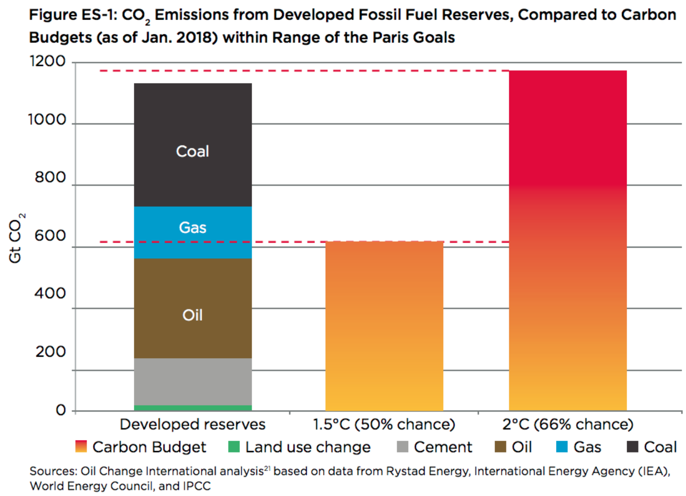
FIGURE 5

CO_2 Emissions/Storage Balance from Simulated CO_2-EOR Case Study



Presentation, Roman Berenblyum, NORCE, Regional business case for CO2-EOR and storage – the subsurface solution toolbox, at 4, http://cop24.co2geonet.com/media/10127/5_regional-business-case-for-co2eor.pdf (last visited Feb. 6, 2019).

FIGURE 6
CO^2 Emissions from Developed Fossil Fuel Reserves, Compared to Carbon Budgets within Range of the Paris Goals



OIL CHANGE INTERNATIONAL, DRILLING TOWARDS DISASTER: WHY U.S. OIL AND GAS EXPANSION IS INCOMPATIBLE WITH CLIMATE LIMITS 5 (2019), http://priceofoil.org/content/uploads/2019/01/Drilling-Towards-Disaster-Web-v2.pdf.

3000 patents identified. An additional 53% of patents covered the use of CO_2 in chemicals or as fuels.[67]

Accordingly, calls for additional CCS or CCUS—or for geoengineering techniques reliant thereon—should primarily be understood to drive the expansion of enhanced oil recovery or the production of combustible fuels. This EOR, in turn, will necessarily lead to the increased production and consumption of oil, the increased GHG emissions that arise from its combustion, and increased investments in the *infra*structure for producing, distributing, and using fossil fuels.

A "Simulated Case Study" of a 20-year CCS-EOR project presented by NORCE demonstrates one common explanation for how CCS-EOR would reduce emissions, as well as the manifest problems with that theory.[68] (See Figure 5.) In the simulation, a CCS project begins injecting CO_2 into a depleted well in 2026, leading to a massive increase in the oil production from the well. Over the ensuing three years, from 2026-2029, the relatively modest amount of CO_2 stored by injection is dwarfed by an additional 200,000 tons of CO_2 emitted by the produced oil until the well is fully depleted. To reverse these resulting emissions, a further 200,000 tons of CO_2 must be injected into the now fully depleted well long after the economic incentives for doing so have ceased to exist. Yet it is only after these emissions from the produced oil have been fully offset, and the energy penalties that arise from carbon capture itself have been accounted for, that a CO_2-EOR project could begin having any measurable positive impact on emissions.

Even were this not the case, EOR faces two further and fundamental limitations when viewed in the context of the global climate crisis. First, and fundamentally, both the climate crisis and sources of fossil fuel emissions are global in nature. Accordingly, to contribute to meaningful GHG reductions on a global basis, EOR would need to be available and economically viable in the areas where the most intensive emissions occur. In reality, however, there is a substantial disconnect between the areas where large emissions sources are concentrated and areas in which EOR is technically and economically feasible. Moreover, even in those countries where EOR capacity is substantial, proponents of large-scale CCS deployment acknowledge that EOR wells are not a sufficiently large reservoir for stored carbon dioxide.[69] Despite the industry's extensive research into carbon storage,[70] as well as research from institutions such as the International Energy Agency,[71] underground carbon dioxide storage has not been demonstrated to work at the scale needed for the global deployment of CCS some advocates support.

More fundamentally, the oil and gas in existing developed wells already exceeds the total remaining carbon budget needed to give the world even a 50% chance of keeping total temperature rise below 1.5 degrees Celsius. Adding developed coal reserves and cement brings the cumulative emissions embedded in the existing fossil fuel resources perilously close to 2.0 degrees even if no new fossil resources were developed.[72]

In view of the IPCC's clear warnings that a rapid and dramatic transition away from fossil fuels provides the best hope for keeping warming below 1.5 degrees, any policy that would promote fossil fuel production in the name of climate mitigation faces a heavy—and likely insurmountable—burden of proof.

A recent change in US law serves as a case in point.

Promoting CCS, DAC, and EOR in the US Tax Code

In mid-2018, the US Congress passed the Furthering carbon capture, Utilization, Technology, Underground storage, and Reduced Emissions (FUTURE) Act, which altered a tax credit under Section 45Q of the US Internal Revenue Code.[73] Prior to the changes, the provision provided a tax credit for the underground storage of CO_2. The credit was worth \$20 per metric ton for CO_2 stored in geologic formations, and \$10 per ton for CO_2 used as an injectant for enhanced oil recovery.

The FUTURE Act modified Section 45Q in several critical respects. First, it dramatically expanded the size of the credit: up to $35 per metric ton of CO_2 used for EOR or otherwise utilized, and up to $50 per metric ton of CO_2 stored in geological formations.[74] Significantly, the FUTURE Act also extended these credits to the use of CO_2 in chemicals or in any product for which a commercial market exists. It made direct air capture projects eligible for the credit for the first time. It also lowered the thresholds for the amount of carbon a facility must capture to qualify for the credit. CO_2 capture facilities that begin construction before January 1, 2024, are eligible for such credits for twelve years.

As the NORCE presentation above demonstrates, even proponents of EOR acknowledge that the process of producing, refining, and combusting oil results in net carbon emissions, even when carbon dioxide is stored in the wells used for EOR.[75]

Some EOR proponents argue that the emissions from the produced oil can be ignored because oil from EOR will displace other, purportedly more carbon-intense oil from the markets. [76] In the US context, however, the Department of Energy's analysis did not assert EOR would reduce US domestic oil production. Indeed, DOE argued that "increasing domestic oil production" would be an "important co-benefit" of promoting CO_2-EOR.[77]

Claims that oil from CO_2-EOR would displace more carbon-intensive oil on global markets, instead of adding to the abundant supplies of government-subsidized oil on those markets, rely heavily on assumptions and forecasts that are, at best, highly disputed. While optimistic supporters claim that over 80%[78] of the oil produced via new EOR will displace oil that would have been produced anyway, other projections suggest a much lower displacement value, closer to 50%.[79] In that case, the proposed emissions benefits of EOR disappear.[80]

Accepting, for the sake of argument, the optimistic replacement value claim, the structure of the incentive serves to benefit fossil fuel-based power generation and make it more difficult to take meaningful climate action. Because the expanded tax credit applies to new carbon capture facilities, the effect of the tax credit—and its clear intention—will ultimately be to subsidize the deployment of CCS units on power plants where they did not exist before, and therefore subsidize those facilities themselves. Not only does this risk extending the life of fossil fuel-powered facilities already in existence, but some analysts have suggested that it may even spur new coal or gas plant construction.[81]

The vast majority of EOR projects (and CCS projects generally) have been initiated in or proposed for the United States, which has the second largest coal fleet in the world after China, as well as one of the oldest fleets. Yet a 2012 global assessment of the viability and potential for retrofitting existing coal-fired power stations found only 4-25% of installed coal capacity in the US was potentially suitable for CCS retrofit, and that at most 6% of installed capacity at least moderately suitable for retrofit.[82] Indeed, even a contrary study of coal-fired power plants in Texas—suggesting that CCS retrofits might be economic, particularly if the CO_2 was used for EOR—acknowledged that new solar power plants would be more cost effective in most circumstances.[83] This study highlights that, for many advocates, CCS is viewed less as a necessary step to meeting energy demand in a carbon-constrained world than as a means of keeping coal economically viable in a world of declining carbon budgets and rapidly falling renewable energy prices.

Missing from the calculation of the carbon intensity of oil produced via CO_2-EOR is the fact that the carbon dioxide used must have come from an emissions source such as a coal or gas power plant—or, for that matter, a biofuel or direct air capture facility—for it to be considered a carbon emissions reduction. This gives rise to a significant risk of double-counting reductions. For example, the "simulated case study" of CO_2-EOR discussed in the preceding section does not appear to account for the actual CO_2 emissions source in calculating the emissions balance for the project. Similarly, one group supporting the changes to 45Q notes in

their fact sheet that the new tax credits both reduce emissions from the US power sector *and* reduce the carbon intensity of oil produced via CO_2-EOR.[84] This double-counting—of treating both fossil-energy CCS and CO_2-EOR as independently valuable for emissions reduction, when in actuality they are linked—allows proponents to gloss over the way in which this change in US federal tax policy amounts to a subsidy further entrenching the fossil fuel industry.

Moreover, were more ambitious climate policies put in place, carbon-emitting entities would be insulated twofold by these subsidies: The emissions would be lower, due to the carbon capture, and their ability to absorb costs would be greater due to the subsidization of their activity.

This is the risk of policy options like the new Section 45Q tax credit. It purports to be climate policy, and it may lead to marginal emissions reductions in limited circumstances. But the tax credit functions as a subsidy to the fossil fuel industry, prolonging and expanding a business model that needs to be radically phased down.

ClearPath, a nonprofit established to "accelerate conservative energy solutions," makes this case explicit in addressing *What Carbon Capture Means for Natural Gas*:

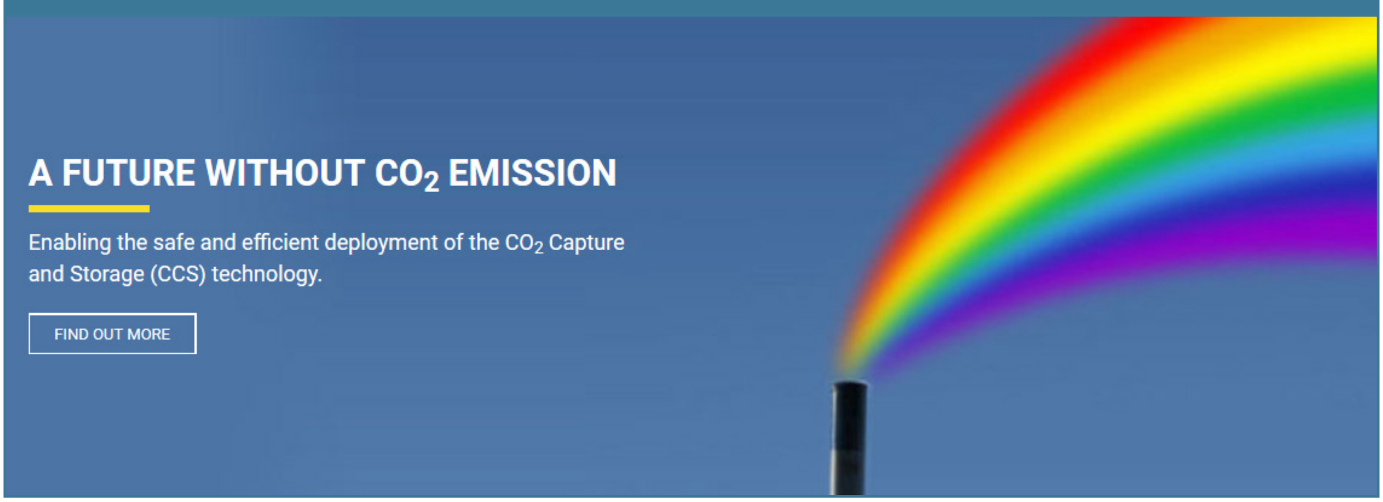
> "Carbon capture is not just crucial to the future of coal, it's a valuable insurance policy for our booming natural gas industry. This technology protects our gas industry from whatever supercharged Clean Power Plan a future Democratic White House will inevitably throw at the power sector, while reducing emissions affordably now. But without a targeted policy lever (such as the 45Q tax credit extension currently being considered by Congress) to advance the technology before environmental regulations hit, the industry will be vulnerable."[85]

A 2018 report funded jointly by Clear Path and the coal industry's Carbon Utilization Research Council quantified how the coal, oil, and natural gas industries all stand to benefit from the push for CCS. The report concluded that, in the United States alone, active promotion of CCS could drive "up to a 40% increase in coal production for power from 2020 to 2040" and generate up to "923 million *additional* barrels of oil produced annually by 2040."[86]

To transform this vision to reality, ClearPath's founder created the ClearPath Action Fund, a political SuperPAC ostensibly designed to support Republican clean energy champions in the United States Congress. As noted by the League of Conservation Voters, recipients of ClearPath's largesse, like Republican Representative Fred Upton, have a demonstrated record of supporting the fossil fuel industry, but an altogether weaker record when it comes to supporting climate action and promoting the deployment of renewable energy.[87]

Some advocates of the changes to the tax credit assert that even if EOR increases oil production and emissions in the near term, the credit is necessary to spur the development of direct air capture technologies which will eventually be deployed at greater scale. Observers have noted that the evidence is limited that the new tax credits will accomplish the DAC-promotion goals proponents wish to see,[88] a risk fundamental to policies like this and those that would promote DAC generally. For reasons discussed in the section on DAC, however, this argument appears equally at odds with the systemic changes necessary to transition to a low-carbon economy.

FIGURE 7
Coal Industry's Vision for CCS: Smokestacks and Rainbows



CO2GEONET, http://www.co2geonet.com/home/ (last visited Feb. 6, 2019).

How Carbon Dioxide Removal will "Save" the Coal Industry

Carbon capture and storage is commercially valuable for oil producers because of carbon dioxide's usefulness in enhanced oil recovery. It is valuable for large point-source producers of carbon dioxide as a way to keep current business models intact and resilient to additional climate policies. For coal-fired power generation specifically, it is becoming ever clearer that policy support for CCS, and therefore for coal-fired power, is necessary for the long-term viability of the industry.

While awareness of the GHG impacts of fossil gas continues to expand, coal remains widely recognized as the most carbon intense of the fossil fuels and the most vulnerable to climate policies in the near term. Moreover, because coal is primarily used for large-scale power generation, it competes with ever-cheaper renewables, as well as other forms of power generation (including natural gas).

Much of the advocacy for development and deployment of CCS or CCUS is premised on the assumption that coal will be a necessary part of the energy mix for decades to come and, specifically, that developing countries will continue to massively expand their coal fleets. Therefore, proponents argue, the global community must deploy CCS or CCUS units around the world to account for this growth while meeting the goals of the Paris Agreement.[89] Yet not even the most optimistic projections for coal with CCS suggest the CO_2 emissions in flue gases could be fully captured,[90] and actual rates of capture can be much, much lower. Even with CCS, therefore, fossil energy still emits carbon dioxide into the atmosphere. And, as concluded by a recent report from the Institute for Energy Economics and Financial Analysis, despite decades of research into CCS for coal, the process remains "unworkable and too expensive for fast-changing electricity-generation markets[.]"[91]

Viewed in light of rapidly changing trends in the industry, CCUS appears more necessary for the preservation of coal than the reduction of emissions from the energy sector. The International Energy Agency (IEA) noted in a 2017 special report that global demand for coal had fallen precipitously for two years straight.[92] Moreover, IEA noted that the decline in coal consumption was not limited to Western Europe and North America, but included a decline in China as well.[93] Consistent with this trend, a recent ClimateScope report from Bloomberg observed that in 2017, for the first time ever, "renewables accounted for the majority of all new power-generating capacity added" and "the large majority of the world's new zero-carbon power capacity was built in developing countries."[94] As IEA acknowledges in its special report, "without CCUS, coal use will be seriously constrained in the future."[95]

"CCUS appears more necessary for the preservation of coal than the reduction of emissions from the energy sector."

IEA's Greenhouse Gas R&D Programme (IEAGHG), whose members include several major fossil fuel companies and utility operators, made this case more explicitly in a presentation at the 2018 UN climate negotiations in Katowice, Poland. As they note, "CCS enables access to significantly higher quantities of fossil fuels in a 2°C world." Put more bluntly by the IEA's representative, "CCS unlocks 'Unburnable Carbon.'"[96]

The limited deployment of CCS in China once again demonstrates the centrality of EOR to the operation of carbon capture. China contains the world's largest coal fleet. As noted by the IEA, China has added significant coal capacity in recent years, and "[r]educing greenhouse gas emissions while expanding electricity use in China's growing economy is likely not achievable without the early retirement of many coal plants or carbon capture and storage (CCS) retrofits."[97]

In stark contrast to aging coal plants in the US and Europe, most of China's coal fleet is relatively new and constructed at the very large scales considered necessary for efficient carbon capture. As detailed by IEA, the potential for CCS retrofits for China's coal fleet is enormous.[98] These investments, however, are not materializing. Instead, the bulk of CCS projects in China are planned for use in conjunction with enhanced oil recovery, *not* as part of a fleet-wide strategy to reduce emissions from coal combustion. China's CCS program is not only extremely limited, but also heavily dependent on EOR.[99] China currently has one large-scale CCS facility operating, which uses the carbon dioxide for EOR.[100] Of the eight additional planned or proposed large-scale projects, five plan to use the captured carbon dioxide for EOR, with the other three still investigating potential uses.[101] Both the deployment of CCS and the use of the captured carbon for EOR are positioned as ways to preserve the existing coal fleet rather than as means of reducing emissions.

Industry's Pervasive Role in CCS Research and Policy

In addition to their direct investments in commercial CCS, CDR, and EOR ventures, fossil fuel companies have been instrumental in the funding, communication, and advocacy of CCS research and CCS policies through a wide array of corporate consortia and industry groups, joint industry-government working groups, and funding partnerships with universities, non-profits, and individual researchers.

Given its importance to their interests and their future, it is not surprising that fossil fuel companies and industry groups would be active in the development and promotion of CCS. At the same time, the central commercial incentive underlying their engagement—the perpetuation and continued expansion of the fossil fuel industry—cannot and should not be ignored. From coal plant to oil well, fossil fuel companies directly and indirectly benefit from the promotion of CCS and EOR. Payments for capturing or storing carbon dioxide, such as those in the Section 45Q tax credit, present a subsidy to both fossil-based power producers and EOR operations. Moreover, payments to reduce the carbon intensity of coal or gas power plants make such plants more resilient to carbon pricing or other forms of climate action, despite failing to eliminate emissions of carbon dioxide. Finally, because public resources and political capital are finite, action on or even debate over CCS promotion serves to distract from, rather than reinforce, more productive action on climate change.

Major oil, gas, and coal companies have created numerous institutes at universities to study and promote CCS. For example:

- In 1998, BP and Kinder Morgan spurred the creation of the Gulf Coast Carbon Center at the University of Texas,[102] which is now additionally sponsored by Chevron, Exxon, Shell, and other fossil fuel companies.[103]
- Since funding its creation in 2000,[104] BP has been the primary sponsor[105] of the Carbon Mitigation Initiative (CMI) at Princeton University, which "aims to identify the most credible methods of capturing and sequestering a large fraction of carbon emissions from fossil fuels[.]"[106]
- The same year, fossil fuel companies also funded the Carbon Sequestration Initiative at MIT, "an industrial consortium formed to investigate carbon capture and storage technologies," which ran from 2000 until 2016.[107]
- In 2002, Exxon, among others, launched the Global Climate and Energy Project at Stanford University.[108]
- In 2008, Peabody and Arch Coal launched the Consortium for Clean Coal Utilization at Washington University in St. Louis.[109]

In addition to funding these university programs—most of which still participate in climate debates today—fossil fuel companies also funded the creation or operation of industry consortia to pursue CCS, often in conjunction with governments.

Among the earliest and most influential of the latter is the International Energy Agency's Greenhouse Gas R&D group.[110] Established in 1991, IEAGHG's membership includes major fossil fuel producers (Exxon, Chevron, Shell, Total, RWE, and PetroBras), utility operators and industry groups (Southern Company, J-Power, EPRI, and Coal Industry Advisory Board), and government parties. Among the governments, several are actually represented by state-owned enterprises in the fossil fuel or energy sector (Equinor (formerly Statoil)). IEAGHG "stud-

FIGURE 8
Membership of IEA's Greenhouse Gas R&D Programme

Guide to Membership, IEAGHG, https://ieaghg.org/ (last visited Feb. 6, 2019).

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ies and evaluates technologies that can reduce greenhouse gas emissions derived from the use of fossil fuels,"[111] with a focus on CCS.[112] IEAGHG purports to offer only expert opinion rather than policy recommendations. As an IEA implementing agreement, however, IEAGHG has a substantial impact on IEA assessments of the feasibility and value of CCS technologies.

In 2000, fossil fuel companies formed the Carbon Capture Project as an industry collaboration to advance CCS technology.[113] The project has been funded or sponsored by individual corporate members, the United States and Norwegian governments, and the European Union.[114]

In 2009, the US Department of Energy (DOE) created the National Carbon Capture Center (NCCC).[115] The NCCC is funded through a cost-sharing agreement between DOE and several corporate partners, including Southern Company (which manages and runs the center), Duke Energy, Peabody, Cloud Peak Energy, American Electric Power, and Exxon.[116] According to a press release, Arch Coal was a corporate sponsor as well.[117]

Finally, a collection of major oil and gas companies participate in the Oil and Gas Climate Initiative (OGCI).[118] This initiative, announced in 2014, directs investment into CCUS research, among other things.[119] In 2018, Exxon, Chevron, and Occidental Petroleum joined the OGCI, which was cast in media coverage as a major breakthrough, despite the fact that the commitment only raised research funding to $1 billion in total.[120] As some observers noted, "The $100 million each member commits is a tiny fraction of their overall expenditure and the group has been criticized for a lack of ambition, and because part of its rationale is to expand the use of gas."[121]

In addition to these institutions pursuing CCS directly, fossil fuel companies also fund a variety of industry bodies and front groups to promote CCS to governments and the public. One of the primary organizations advocating the widespread deployment of CCS is the Global CCS Institute.[122] The Institute lists its goals as building knowledge of CCS, shifting the narrative surrounding CCS, and enabling investment into CCS. Members include a wide array of coal, oil, and gas companies, as well as utilities, energy companies, and others.[123] Among other activities, the Institute is active at the UNFCCC climate negotiations.[124]

The coal industry separately operates the World Coal Association (WCA), "the only organization that works on a global basis on behalf of the coal industry."[125] This includes advocating for significant (additional) public incentives for CCUS and asserting that zero-emission coal is not only possible but should be a critical part of the solution to climate change.[126] Membership for the WCA includes over thirty coal companies, associations, and research groups.[127]

Finally, in the United States, the Carbon Capture Coalition promotes CCS research and deployment. Participants in the coalition include coal, oil, and gas companies, as well as other industrial actors.[128] After the passage of the reformed Section 45Q tax credit, the Coalition declared that it had "achieved its top federal priority."[129] This should not be surprising, given that when the group was formed in 2011, it was originally called the National Enhanced Oil Recovery Initiative.[130]

This key understanding is especially important when evaluating policy options in response to the climate crisis. Significant public funds have already been invested in the development of CCS. In Europe, the European Union and European states have been funding research into underground storage of carbon dioxide since 1990,[131] and in 2009, the EU allocated one billion euros to CCS projects specifically.[132] As described above, the governments of the United States, European Union, and Norway have contributed to the Carbon Capture Project, and the US DOE founded and continues to fund the National Carbon Capture Center. Overall, the US government has been funding CCS research since 1997,[133] with over $5 billion appropriated since 2010.[134] These public expenditures, especially in the United States, continue today. Without a radical shift in public understanding, they are likely to increase.

Carbon Dioxide Removal and Oil's Plans for the Next Petroleum Century

The lack of significant progress in CCS deployment over the past several decades has not stopped the major fossil fuel companies from including it in their outlooks and projections. Many of the largest oil and gas companies rely on the promise of CCS or CCUS in their long-term forecasts and marketing materials to square the continued expansion of fossil fuel production with a rhetorical commitment to a low-carbon future.

It is critical to examine what integrated oil and gas companies say about the role of carbon capture: CCS and CCUS are not a solution to climate change in any meaningful way, but rather a means of averting material regulation of their products or, in the case of EOR, expanding production.

The most striking example of this is Shell's Sky Scenario.[135] Shell proposes an ostensibly "net-zero emissions" world that still relies on fossil fuels for 30% of energy production through at least the end of this century, with the continued high combustion of fossil fuels theoretically offset by CCS and BECCS.[136] Other companies, including Exxon,[137] BP,[138] and Total[139] similarly assert the need to include significant deployment of carbon capture to meet emissions reduction targets. Critically, in all projections, the production and consumption of oil and gas remain robust through the window of the projection, as far out as 2100 in Shell's Sky Scenario.

There is a massive difference between positive incentives (like those in Section 45Q) and negative incentives (like carbon taxes). While both can theoretically stimulate the deployment of CCS, positive incentives do so by providing additional income to fossil fuel companies, whereas negative incentives internalize those costs to companies.

This distinction was recently put in stark relief in the United States. BP claimed in the 2018 edition of its energy outlook that "we continue to believe that carbon pricing must be a key element of any such approach as it provides incentives for everyone—producers and consumers alike—to play their part."[140] Nonetheless, the company spent $13 million last year to oppose a carbon tax proposal in the US state of Washington.[141]

Fossil fuel companies similarly have a long history of funding opposition to action on climate change, much of it concurrent with their investments in carbon capture and storage.[142] Even staunch proponents of CCS acknowledge that it must be combined with a larger set of climate policies to achieve the Paris goals. Promotion of CCS, in the absence of robust climate policy, must be understood as something quite different—a form of technological and economic entrenchment that serves the interests of the industry, not the climate. This understanding should inform debates over the role of CCS in climate policy and illuminate the current state of fossil fuel industry investment in and advocacy for CCS.

Fossil fuel companies have invested and continue to invest extensively in developing and, critically, promoting carbon capture and storage. The claim that carbon capture will be a critical part of the solution to climate change is valuable to the industry because of both the windfall it stands to gain from incentives and the built-in assumption that CCS is necessary because fossil fuels remain central to global energy production. The acceptance of this assumption thus provides the delay in transition that is the very justification for the rush to geoengineering in the first place.

Shell's Role in Carbon Capture and Storage: A Case Study

Four CCS projects by Shell provide a useful illustration of the inherent problems with pursuing CCS as a front-line strategy to combat climate change.[143]

- Boundary Dam is a CCS project at a coal-fired power plant in Saskatchewan, Canada. The carbon sequestered from this plant will be primarily used for EOR.[144]
- Quest is a CCS operation in conjunction with the Athabasca Oil Sands Project in Alberta, Canada.[145] Captured CO_2 is intended solely for storage, not for use. However, the project is only operational because of government funding. As noted on the Shell website, Quest "was made possible through funding for CCS from the governments of Alberta and Canada, which provided C$745 million and C$120 million of funding respectively."[146]
- Shell co-owns with Gassnova SF, A/S Norske Shell, Sasol, and Statoil ASA, a CCS research center in Norway. The Technology Centre Mongstad (TCM) is not commercial, but rather a test facility to improve CCS methods, and has been operational since 2012.[147]
- The Gorgon liquefied natural gas (LNG) project is a partnership among Shell, Chevron, Exxon, and others at Australia's Gorgon LNG field. The Gorgon gas field contains 14% naturally occurring CO_2, and so would be a massive point source if that carbon dioxide were not managed.[148] As a result, the project will include a carbon dioxide injection unit. The overall Gorgon project cost is estimated at $55 billion, with the CCS unit adding another $2 billion.[149] Sponsor companies claim that, once completed, it will be "the world's largest commercial-scale carbon dioxide injection project."[150] Notably, project sponsors are not planning to sell the carbon dioxide for use in EOR or other applications. Rather, the CCS unit is being added because Australian law requires that at least 80% of carbon dioxide produced from the gas field be captured and stored, or that the company pay for offsets if it fails to do so. The expectation of additional carbon taxes

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may provide another motivation for the project.[151] The Gorgon CCS unit does not reduce emissions from the combustion of gas, but rather prevents emissions of CO_2 in the gas well that would have otherwise been vented into the atmosphere. Due to delays in construction of the CCS unit, however, carbon dioxide is being vented anyway, leading to a massive increase in Australia's greenhouse gas emissions.[152]

These four projects demonstrate the range of CCS financing options. The test facility operates as industrial research for the companies involved, and is paid for primarily by them. Boundary Dam produces carbon dioxide for use in EOR, and intends to profit from the process. The Quest facility produces carbon dioxide directly for storage, but is being subsidized by the governments of Canada and Alberta with nearly 900 million CAD for doing so. Finally, Gorgon's carbon injection program is a response to government policy, existing and expected, and is designed to internalize the cost of carbon emissions to the companies producing them.

This framework demonstrates why government resources should not be diverted to promote CCS. As evidenced by the operation of TCM (and decades of fossil fuel industry investment in CCS research and development), research costs can and will be borne by the industry, appropriately internalizing the cost of pollution abatement to polluting industries. For commercial applications, whether as a response to climate policy or positive incentives promoting CCS, companies will install CCS units at their facilities if it makes economic sense to do so. Where climate policy is in place, they may do so as a business decision, internalizing the costs of their carbon emissions, as at the Gorgon site. In those rare instances where capturing carbon dioxide for use is economical, the industry may deploy CCS as well, as at the Boundary Dam power plant (although that project is facing financial challenges).[153] However, to the extent that they require EOR to be viable, such projects will have little, if any, benefit for the climate. The alternative is providing an additional profit center for fossil fuel operations, as in the case of the Quest facility, which then also insulates those operations from effective climate policies. Instead of fossil fuel companies paying for the carbon they produce, they would be getting paid to reduce what they are already producing.

Direct Air Capture: Turning Renewable Energy into New Carbon Emissions

Direct air capture is the process of pulling carbon dioxide molecules from ambient air as opposed to removing them from waste streams, where they exist in considerably greater concentrations. Because it must collect CO_2 from the ambient air, where carbon dioxide exists in extremely low concentrations relative to industrial point sources, DAC is much more expensive per ton of carbon dioxide removed than CCS and is far more energy intensive.

Because DAC does not (directly) rely on the combustion of a fuel to operate, however, it is widely promoted as a negative emissions technology and hailed by some proponents as the holy grail of CDR technologies.[154] In a 2015 review of research and patent filings in geoengineering, patents for CDR related to direct air removal technologies comprised nearly one-third of all patent families and more than 44% of total patents filed worldwide.[155]

The idea of scrubbing carbon dioxide directly out of the air is not new, with demonstrations dating at least as far back as 1946.[156] It wasn't until 1999, however, that "[s]crubbing ambient air as a means of reducing greenhouse gas emissions was first suggested[.]"[157]

This suggestion came from Klaus Lackner, Patrick Grimes, and Hans-Joachim Ziock in a paper submitted to the 24th Annual Technical Conference on Coal Utilization & Fuel Systems.[158] This report, entitled *Carbon Dioxide Extraction From Air: Is It An Option?*, laid out the case for direct air capture as a means of dealing with the problem of accumulating carbon dioxide in the atmosphere. Lackner and his co-authors argued that the primary advantage of DAC is that it specifically does not require a shift away from fossil-based fuel sources.[159] They note that successful deployment of DAC "completely avoids a restructuring of today's *infra*structure, it uses the atmosphere to transport the carbon dioxide from its source to the disposal site and it would make it even possible to lower the atmospheric levels of carbon dioxide, *if this turns out to be necessary or desirable*" (emphasis added).[160]

The following year, Lackner founded the Zero Emission Coal Alliance (ZECA), whose express purpose was to develop a new technology for generating zero-emission energy from coal. This alliance was funded by a consortium of US and Canadian coal companies, including Arch Coal.[161] It was led by Alan Johnson, a Canadian coal executive, until 2004.[162]

There is very little public information about ZECA, and according to Stephen Rackley's comprehensive book *Carbon Capture and Storage*, ZECA "disappeared without trace shortly after it was recognized by Scientific American as the 'Business Leader in Environmental Science' for 2003."[163] Lackner now runs the Center for Negative Carbon Emissions at Arizona State University.[164] The Center advances "carbon management technologies that can capture carbon dioxide directly from ambient air in an outdoor operating environment."[165] While funding for the Center is difficult to determine, the position of a postdoctoral researcher on direct air capture is funded by Shell.[166]

FIGURE 9

Patent Drawing of Direct Air Capture Technology

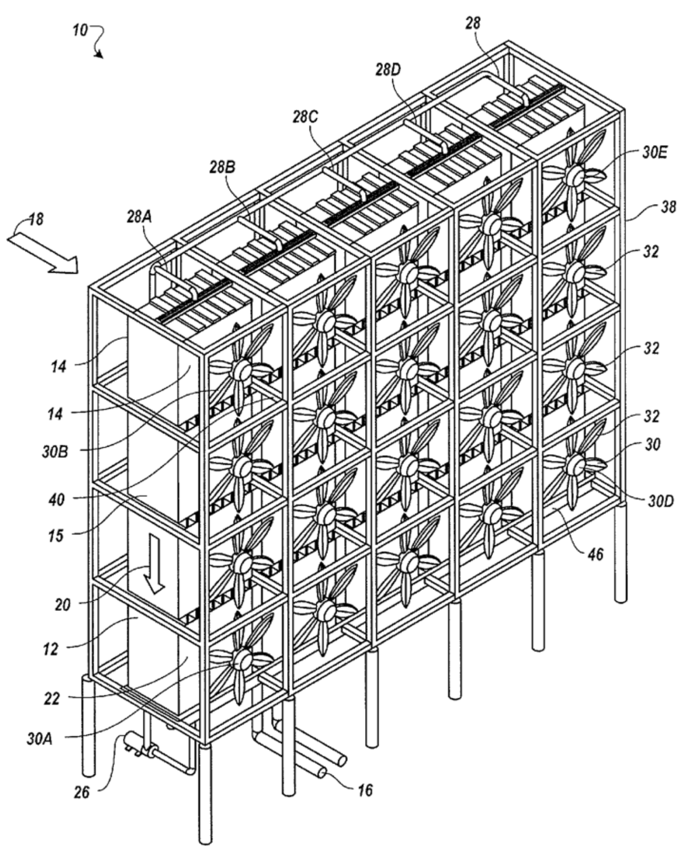


FIG. 1

Carbon Dioxide Capture and Facility, U.S. Patent No. 9,095,813 (filed Aug. 21, 2009).

In their 2015 review of geoengineering patents, Paul Oldham and his co-authors found that two companies owned or partly owned by Lackner—Global Research Technologies[167] and Kilimanjaro Energy[168]—dominated patent filings in the field.[169] Together, the two companies accounted for 21 initial filings for patent families representing 329 patent family members—more than a third of the 910 patents identified for the period.[170] Kilimanjaro secured its first major investment from Arch Venture Partners in August 2010.[171] Commenting on the investment, Arch Ventures explained that Kilamanjaro Energy hoped to make "trillions" from the deployment of its DAC technologies in enhanced oil recovery.[172] Notwithstanding these early hopes, Kilimanjaro subsequently closed shop due to lack of funding.[173]

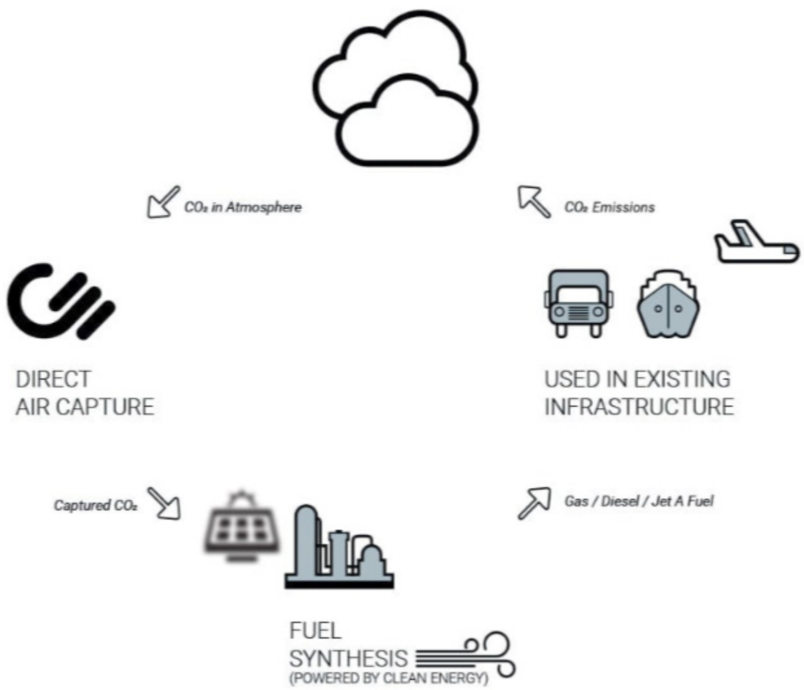
Yet the commercial dreams of Kilimanjaro's backers demonstrate that, as in other forms of CCUS, building and operating DAC technology presumes—and depends upon—the existence of adequate commercial markets for the captured carbon. Unsurprisingly, Kilimanjaro saw that market in EOR. Other proponents envision a distinct but no less direct path between their DAC technologies and the fossil economy.

Powering DAC facilities at any significant scale would demand massive amounts of energy, which must come from one of three sources:

- Unabated and high-emitting power plants fueled by coal or natural gas;
- Fossil-fuel-burning power plants equipped with CCS and subject to the numerous limitations and risks described in the preceding sections; or
- Renewable energy sources that would otherwise be directed to other uses that more directly reduce or replace fossil energy demand and use.

In either of the first two scenarios, the emissions generated to provide power (and sequester the associated carbon) for

FIGURE 10
Carbon Engineering Air-to-Fuels Diagram



Above: The AIR TO FUELS™ process involves capturing CO2 from the atmosphere, producing green hydrogen with low-carbon electricity, and reacting the two to form liquid transportation fuels such as gasoline, diesel, or Jet-A. Such fuels can be closed carbon cycle and can displace the need for crude oil.

Air to Fuels, CARBON ENGINEERING, http://carbonengineering.com/about-a2f/ (last visited Feb. 4, 2019).

a DAC facility would have to be fully offset by the CO_2 it captures before the facility generates any net CO_2 benefit to the atmosphere. In the third scenario, the climate benefit derived from operation of the DAC facility would need to outweigh the benefits of putting the substantial renewable energy it requires to alternate uses.

Proponents of DAC argue that, even with its significant energy penalties, DAC may be necessary to draw down emissions from CO_2 sources that are not readily amenable to CCS, such as vehicle exhaust, and to address emissions in sectors where a transition to cleaner energy sources is difficult, such as aircraft emissions. Ironically, however, the business models for the three DAC companies currently in operation envision the use of captured carbon either for EOR or as a competing source of combustion fuel for existing fossil-fuel-based technologies.

Carbon Engineering

Canadian company Carbon Engineering is emblematic of this approach. Founded in 2009 by Harvard professor[174] and prominent geoengineering advocate[175] David Keith, Carbon Engineering holds multiple patents for technologies to capture CO_2 from the air and convert captured CO_2 to synthetic fuels or other uses.[176] The company is privately funded, although known investors include Bill Gates and Canadian tar sands magnate Murray Edwards.[177] Notably, Bill Gates is also a direct funder of Keith's work at Harvard, sponsoring the Harvard Solar Geoengineering Research Program and, as will be discussed below, funding several workshops and reports on the pursuit of a geoengineering research agenda.

Carbon Engineering has been capturing carbon dioxide since 2015 and has been producing fuels since 2017.[178] According to the company, its technology "has several intrinsic advantages to offer in eliminating fossil carbon dioxide emissions from the transportation sector."[179] Climate Engineering claims that its facility could capture one million tons of CO_2 per year, "equivalent to the annual emissions of 250,000 average passenger cars."[180] Applying the average vehicle emission rate of 4.6 metric tons per year calculated by the US Environmental Protection Agency[181] produces a more realistic estimate of 217,000 car-equivalent emissions. At the same time, however, the facility would produce 320,000 liters of synthetic fuel a day. When the emissions from these produced fuels are considered, the climate benefits of the operation are, at minimum, overstated, even before the source of energy inputs and fate of any waste carbon are considered. Assuming full-time operation and applying the same EPA emissions factors for vehicles, the fuels produced by the facility would produce 313 million kilograms of emissions per year, equivalent to the emissions of 68,000 average passenger vehicles. The climate benefits would be lower still, and likely negative, if the captured carbon were used to produce jet fuels rather than synthetic diesel.[182]

In January 2019, Chevron and Occidental Petroleum announced major investments into Carbon Engineering.[183] A press release from Carbon Engineering notes this added capitalization as the "first significant collaboration between a DAC developer and the energy industry."[184] Notably, the announcement also makes clear that Occidental's interest in direct air capture is the use of carbon dioxide in enhanced oil recovery.[185]

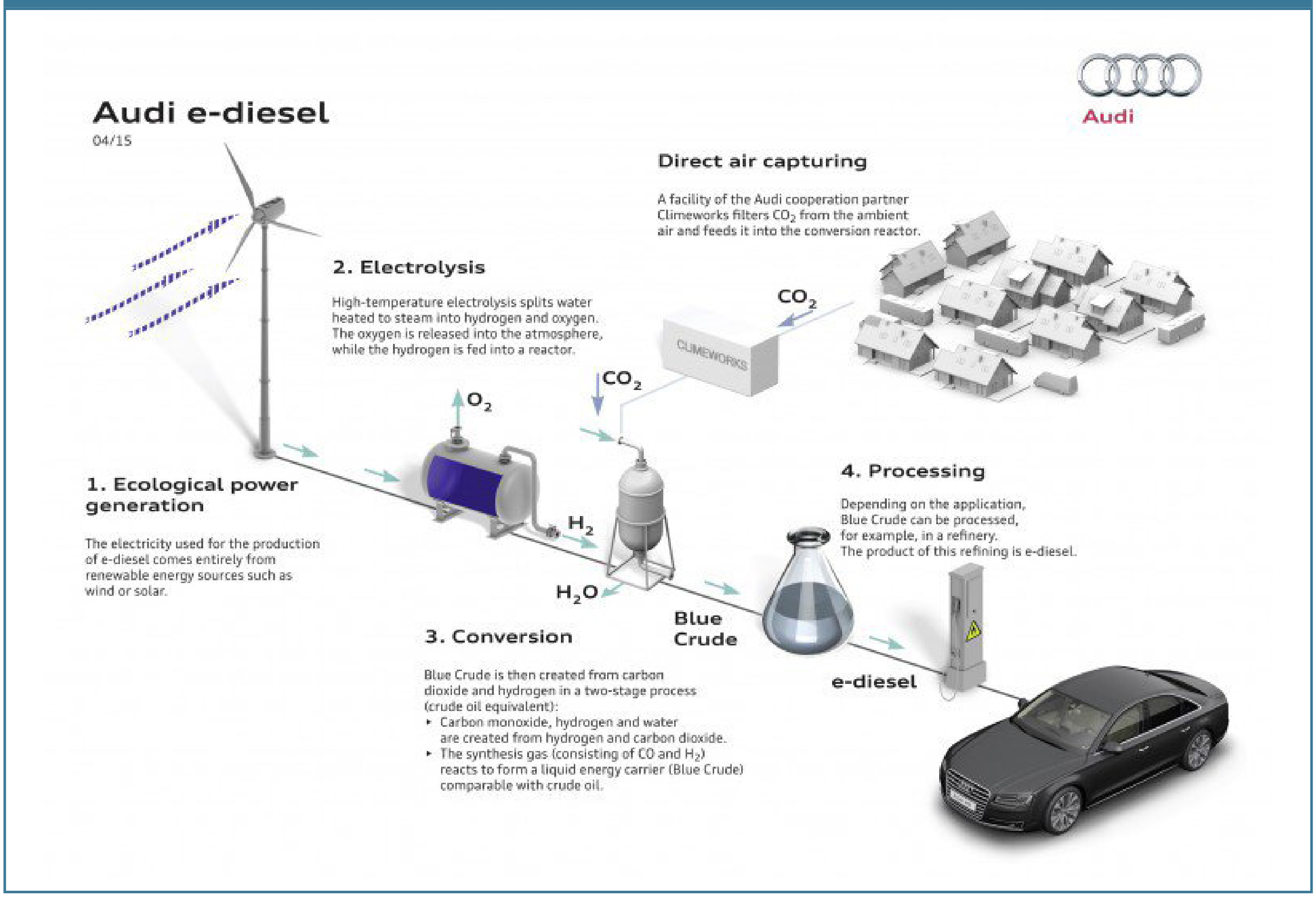
Global Thermostat

Direct air capture company Global Thermostat was founded in 2010 by Graciela Chichilnisky and Peter Eisenberger.[186] While most funding for Global Thermostat is private and therefore unknown to the public—a recent presentation indicates that energy company NRG was an early investor[187]—the company maintains significant connections to the fossil fuel industry. Moreover, the business model as proposed serves the same functions as carbon capture and storage described above, entrenching fossil fuel interests and expanding oil production.

Eisenberger is a former Exxon engineer, and two of the company's chief advisors, Ronald Chance and Rocco Fiato, are former Exxon executives as well. In 2009, Chichilnisky and Eisenberger authored a paper, *Global Warming and Carbon-Negative Technology: Prospects for a Lower-Cost Route to a Lower-Risk Atmosphere*, which argued for "expanded R&D efforts aimed at advancing air extraction technology."[188] This paper was co-authored by Chance and Roger W. Cohen, another former Exxon scientist turned climate skeptic, who was at the time also affiliated with Global Thermostat.[189] In 2014, Eisenberg published another paper, entitled Chaos Control, arguing for the necessity of closing the global carbon cycle by pulling carbon dioxide out of the atmosphere.[190] In the paper, Eisenberger thanks both Cohen and Klaus Lackner for their contributions.[191]

These connections do not suggest undue fossil fuel company influence over the operation of the company, but rather expose the intimate relationship between fossil fuel interests and the business of direct air capture. Global Thermostat promotes a carbon capture technique that uses process heat from power plants or other industrial sources, and which can be used to capture carbon dioxide directly from the air, or from flue gases like conventional CCS.[192] While a flagship project to produce carbon dioxide for carbonated beverages has received a great deal of attention, and while Global Thermostat identifies both plastics and petrochemicals as potential mid-term markets, company statements appear to recognize that the major large-scale markets for captured

FIGURE 11
Audi Graphic Showing Use of Direct Air Capture to Produce Diesel Fuels



Fiona MacDonald, *Audi Has Successfully Made Diesel Fuel From Carbon Dioxide And Water*, SCIENCE ALERT (Apr. 27, 2015), https://www.sciencealert.com/audi-have-successfully-made-diesel-fuel-from-air-and-water.

CO_2 continue to lie in EOR and liquid fuels.[193]

Like proponents of CCS, Global Thermostat claims to offer a solution to the carbon emissions problem of fossil fuels, ostensibly obviating the need to phase fossil fuels out of the energy mix. In both an article from 2011 and a 2018 presentation, Chichilnisky explicitly frames Global Thermostat's technology as a way to protect the $55 trillion in global energy *infra*structure.[194]

Climeworks

Climeworks, the third DAC company currently operating, similarly promotes the carbon dioxide it captures as a product for sale to food and beverage companies, for use in materials, or for use in fuels.[195] In partnership with automaker Audi, Climeworks has been developing e-fuels made from captured carbon dioxide since 2014. These fuels are made with carbon dioxide captured from the air, water, and electricity. The "e-diesel" created from this process, as noted in an Audi press release, is a drop-in fuel, meaning it can be used with current fuel mixes and in modern combustion engines.[196]

This is emblematic of the risks of DAC. As with CCS, the largest and most commercially viable markets for CO_2 lie in the production of new fossil fuels through EOR or enhanced coalbed methane recovery[197] and in the direct production of transport fuels and, to a lesser extent, plastics and other petrochemicals. Proponents of DAC argue that these new products—be they plastics, synthetic fuels, or other materials—would substantially replace those produced by fossil fuels, reducing emissions via substitution. This argument, however, has several major deficiencies.

First, on a basic level, DAC requires enormous energy inputs to operate. As such, DAC can't be considered in isolation from the energy it requires and their related emissions. If DAC is powered by renewable energy, as long as that energy could be used in place of fossil energy sources, it must be understood to enable fossil energy sources to exist as it competes for energy inputs. It is, essentially, the opposite calculation of increasing energy efficiency.

Second, the seeming advantage that DAC carbon-based fuels and materials have is that they can substitute for traditionally produced materials and fuels. But as discussed above, and as outlined in the IPCC's SR1.5, the solutions that will drive emissions reductions and limit atmospheric warming involve entire paradigm shifts and changes in systems of transportation, electricity production and distribution, industry and manufacturing, and others. That a fuel can drop in might be advantageous for its own use and adoption, but it further entrenches, rather than dislodges, the systems and *infrastructure* upon which the fossil economy is built.

Enhanced Weathering and Carbon Mineralization

Direct air capture typically refers to the use of machines to separate carbon dioxide molecules from the ambient air. There are, however, other techniques. One of the most widely discussed is enhanced weathering, alternatively called carbon mineralization.

FIGURE 12
Pathways for Fly Ash Application in Carbon Capture, Use, and Storage

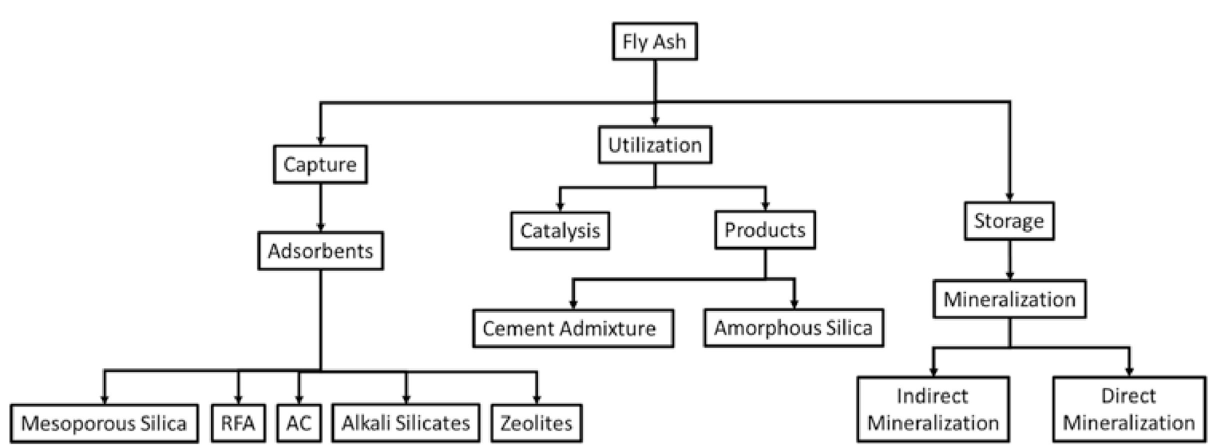


Fig. 2. Pathways for fly ash application in CCUS.

Abdallah Dindi et al., *Applications of Fly Ash for CO2 Capture, Utilization, and Storage*, 29 J. OF CO2 UTILIZATION 82 (2019), https://www.sciencedirect.com/science/article/pii/S221298201830492X.

FIGURE 13
Fly Ash Contamination Pathways

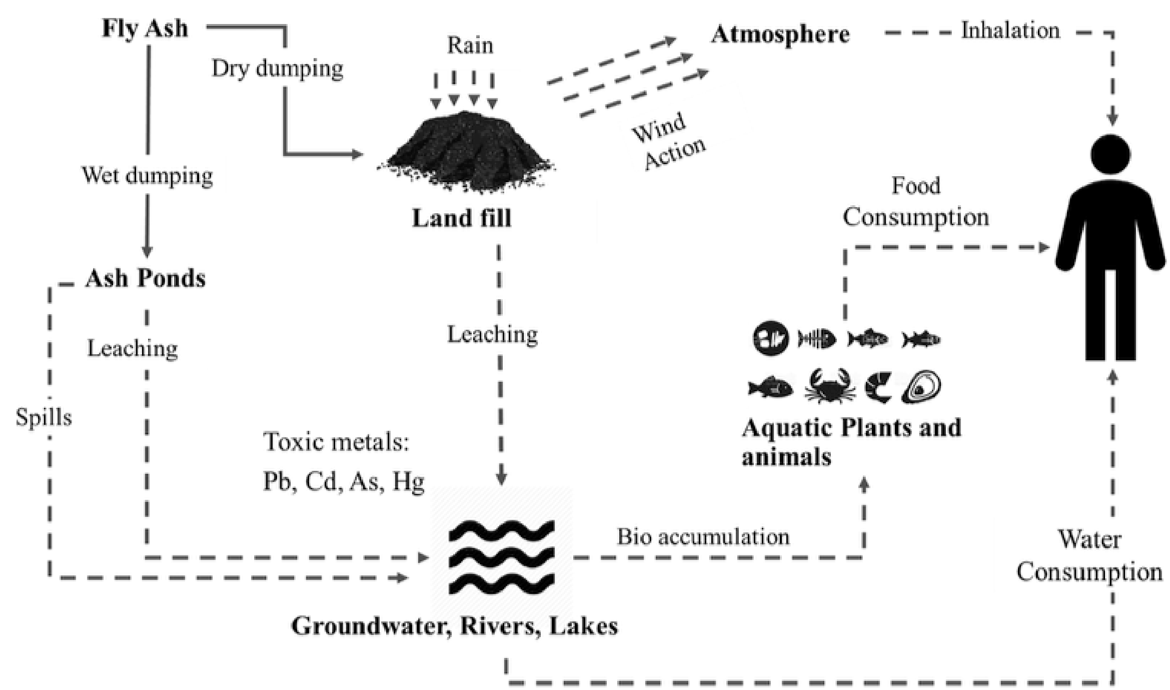


Fig. 1. Fly ash contamination pathways.

Abdallah Dindi et al., *Applications of Fly Ash for CO2 Capture, Utilization, and Storage*, 29 J. OF CO2 UTILIZATION 82 (2019), https://www.sciencedirect.com/science/article/pii/S221298201830492X.

Carbon dioxide in the air naturally reacts with alkaline chemicals in surface rocks, combining to form stable compounds. Because neither solid rock nor the carbon dioxide in the air are very reactive, this process takes a very long time. The process can be sped up, theoretically sequestering significant carbon dioxide either directly from the atmosphere (as a form of CDR) or from already concentrated carbon dioxide sources (as a form of carbon storage).[198]

Carbon mineralization was first proposed in 1990, although Klaus Lackner's work in 1995 is credited with providing the "details and foundation" for much of the later carbon mineralization research effort.[199] Since then, the process has received considerable attention from scientific research institutions as well as fossil fuel companies.[200] Shell in particular researched and patented a process for carbon mineralization.[201]

Carbon mineralization faces several challenges to its successful deployment. Similarly to ocean alkalinization, discussed below, the amount of material that would need to be used substantially exceeds the amount of coal mined annually. Estimates indicate that six to eight tons of ore would be needed for use in mineralization for each ton of coal burned, not including the emissions from mining, transportation, or process energy.[202] Neither of the two most promising natural minerals for this process—olivine and serpentine—is or could be economically mined at anything approaching this scale.

Although the National Academies of Science and others are calling for additional research into carbon mineralization, there is currently little commercial effort to deploy the form of above-ground, or ex-situ, carbon mineralization that might be considered air capture or CDR. Nonetheless, this proposed method of carbon removal and storage is already being considered as an outlet for fossil fuel by-products.

Residuals from coal combustion, also known as fly ash or coal combustion waste (CCW), contain chemicals that can be combined with carbon dioxide in carbon mineralization processes. For this reason, several proponents have suggested using coal combustion wastes and other industrial wastes, including brine solutions resulting from oil and gas production,[203] in carbon mineralization processes.[204]

For coal producers and large-scale coal consumers, the prospect of using coal combustion waste and other industrial residues for carbon storage or removal holds obvious appeal. Coal combustion wastes are among the largest unmanaged waste streams in many countries. In the United States, for example, coal combustion wastes are the second largest waste stream after municipal solid wastes. Their tremendous volumes and high level of heavy metals and other toxins render the safe disposal of CCW difficult and costly, and decades of inadequate regulation in many countries have led to massive stockpiles of CCW that can leak into ground waters, lower air quality, and result in catastrophic events when impoundments fail. As concerns about CCW—and as a result, the potential for effective regulation—have continued to rise, coal producers and users alike have begun to aggressively explore options for reframing a hazardous waste stream into a useful resource. Reframing CCW not as toxic waste but as a feedstock for carbon storage and removal could help fossil fuel producers and users pull two rabbits out of one hat—enabling the continuation of business as usual while providing a rationale for industry to transfer costly and unmanageable waste problems from one part of the environment to another in the ostensible name of climate action.

Since at least the early 2000s, the coal industry has promoted the idea of using CCW in soil remediation and reforestation efforts as a form of carbon sequestration, despite significant risks that doing so could impair plant growth and leach toxic metals into ground and surface waters.[205]

Despite the interest, there are significant limits to how much impact this method of mineral carbonation could have. One US-based study on the extent to which such wastes could be used concluded that even if all the cost-effective alkaline industrial waste were used for carbon mineralization, the amount of carbon dioxide sequestered would amount to less than 0.1% of US carbon dioxide emissions.[206] Another study estimates that carbonation of all coal fly ash globally would only account for 0.25% of emissions from coal-fired power plants.[207]

The industry is likely aware of these limitations. The Institute for Clean and Secure Energy—a research organization with funders including Chevron, The Wyoming Clean Coal Technology Fund, and John Zink Company (a Koch Industries subsidiary), among others[208]—examined this in at least one study from 2011.[209] This study concluded that "CO_2 mineralization with naturally occurring minerals is unlikely to be feasible in the near term," and that availability of industrial wastes for mineralization is limited.[210] Incentives for carbon mineralization, then, risk providing carbon-emission-intensive industries with subsidies for their waste disposal—again inverting the principle that those who pollute should internalize the costs of their pollution—without the ability to sequester meaningful amounts of carbon dioxide from the atmosphere.

Ocean Iron Fertilization and Alkalinization

The ocean is the primary carbon sink for the majority of carbon dioxide released into the atmosphere. Another option considered by those looking to sequester carbon from the atmosphere is increasing the capacity of the oceans to absorb and store carbon. Two widely discussed methods for doing this are ocean iron fertilization and ocean alkalinization.

Ocean iron fertilization is the process of dumping iron into marine areas where phytoplankton is likely to grow. The theory is that iron is the limiting nutrient holding back more robust growth of certain plankton and that adding iron to those marine ecosystems would cause massive plankton blooms. These plankton, forming their cells from carbon in the ocean, would then sink to the ocean floor at the end of their lives, accelerating the carbon-pump function of many surface marine organisms.

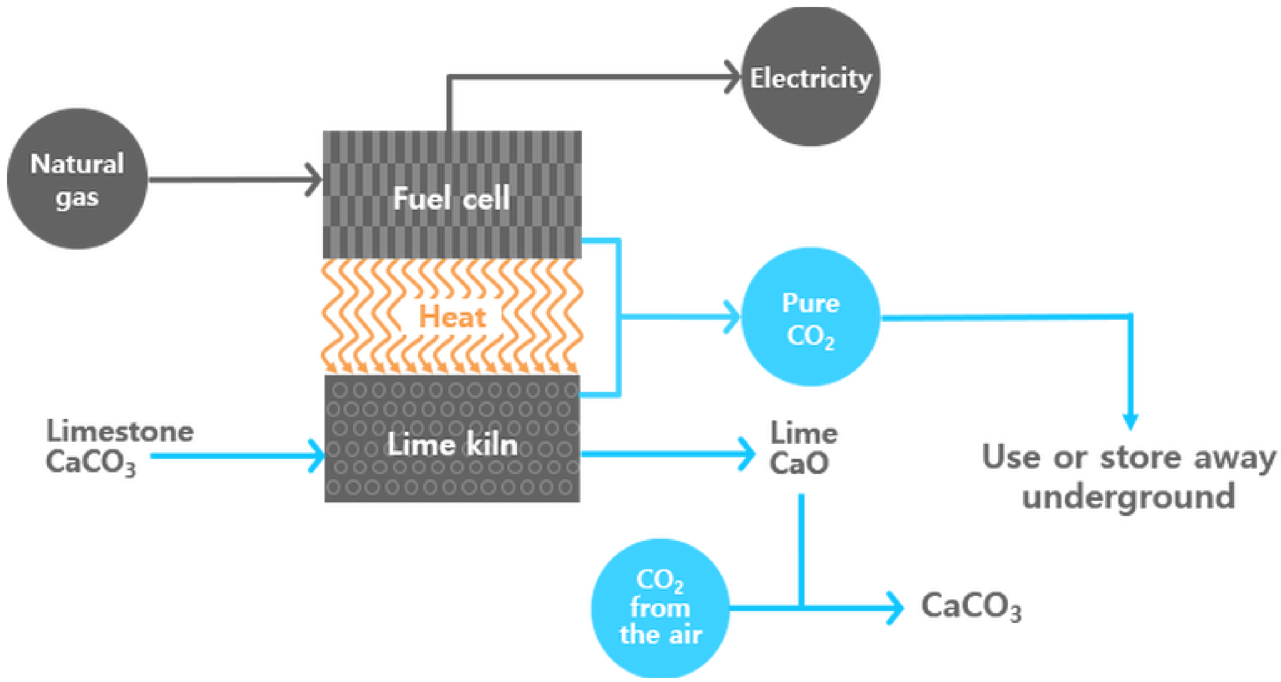
The original research into iron fertilization—at least as identified in this review—was done outside the purview of fossil fuel companies.[211] This changed in 1992, when Exxon funded a study by Wallace Broecker and T.H. Peng following up on earlier research they had conducted on the topic.[212] Exxon was not alone in exploring iron fertilization. When the Australian government launched the "first in situ iron fertilization experiment" in the Southern Ocean a few years later, Australian fossil fuel and minerals conglomerate BHP Billiton was among the small group of participating institutions.[213] The experiment triggered a statement of concern under the London Convention on Marine Pollution and ultimately contributed to a 2008 decision under the Convention on Biological Diversity to place a moratorium on iron fertilization activities.[214]

Ocean alkalinization has received more attention from both the public and fossil fuel companies. As opposed to iron fertilization, alkalinization involves neutralizing the carbon dioxide absorbed by ocean surface waters, theoretically enabling more carbon dioxide to be absorbed from the atmosphere.

Ocean alkalinization was first proposed as a CDR method in 1995 by Haroon Kheshgi, one of Exxon's chief climate researchers.[215] In 1998,[216] Kheshgi published a second study exploring the use of artificially increased ocean alkalinity to neutralize carbon dioxide accumulation from fossil fuel combustion.

The idea hasn't been promoted to the degree that DAC or BECCS has, in part because of the staggering amount of material required. Like carbon mineralization, ocean alkalinization would require mining for alkaline ore at a massive, global scale, and the energy consumed transporting it from its terrestrial source to its oceanic destination would eliminate much of the benefit.

FIGURE 14
Origen Power Diagram Showing Enhanced Weathering Process Powered by Natural Gas and Reliant on CCUS



Origen Power, Written evidence submitted by Origen Power, http://data.parliament.uk/WrittenEvidence/CommitteeEvidence.svc/EvidenceDocument/Energy%20and%20Climate%20Change/Energy%20Revolution/written/32773.html (last visited Feb. 4, 2019).

In 2008, Shell made an early investment in an open-access company called Cquestrate to pursue such efforts.[217] To make the energy-intensive process viable, Cquestrate proposed that calcination might be powered using "stranded gas" that could not otherwise economically reach markets and either releasing process emissions into the atmosphere or capturing them through CCS for use in EOR or in fuels.[218] Cquestrate appears to have ceased operation sometime after 2009, and a for-profit company Origen Power was subsequently created to promote a revised version of the concept.[219] Origen Power proposes to burn natural gas in a fuel cell, creating both electricity for sale and waste heat to decompose limestone into calcinated lime, which can then be used for direct air capture. To offset the carbon emissions from the natural gas combustion, Origen Power assumes that waste CO_2 produced in the process will be stored underground, demonstrating the technologies' continued reliance on CCS.[220] Tim Kruger, the founder of both Cquestrate and Origen Power, is also the program manager for Oxford University's Geoengineering Program.[221]

PART 5

Bioenergy, BECCS, and the Real Cost of Carbon Accounting

The most widely discussed form of CDR—and the CDR strategy most widely relied upon in current climate models and scenarios—is bioenergy with carbon capture and storage.

Bioenergy is energy produced via the combustion of biological material. Bioenergy is typically divided into two categories, biomass and biofuels. Biomass is any non- or minimally processed organic material that can be combusted for energy. Traditional biomass includes wood, discarded food and oils, or other plant material. Alternatively, biofuels are processed fuels produced from organic feedstocks, as opposed to fossil fuels.

Both biomass and biofuels—collectively called bioenergy—have been touted as carbon-neutral alternatives to fossil fuels. Regardless of whether the fuels burned are biofuels or fossil fuels, the process emits CO_2 and other GHGs into the atmosphere. Whereas the carbon in fossil fuels has been stored for millions of years, however, the carbon released by burning biomass or biofuels was drawn from the atmosphere and incorporated into the plants, algae, or other organic sources that become bioenergy feedstocks. Whether bioenergy is as carbon neutral in practice as it is in theory remains subject to ongoing debate.

There is no scenario in which bioenergy alone will remove CO_2 from the atmosphere on a net basis. To make that even theoretically possible, bioenergy must be combined with CCS to capture and store the carbon dioxide emitted when biomass or biofuels are burned. If this could be done at scale, proponents claim, BECCS could operate as a massive offset to other emissions and help reach the Paris goals.

A 2018 analysis of BECCS prepared for the Carbon Sequestration Leadership Forum (CSLF) acknowledges that BECCS has the theoretical potential to mitigate up to 3.3 gigatons of carbon per year, but cautioned that achieving reductions at this scale would require planting bioenergy crops on up to 580 million hectares of land, or roughly one-third of all arable land on Earth.[222] As has been widely recognized, the conversion of arable land at even a fraction of the scale envisioned in most models would have profound implications for food security in a growing world.

"There is no scenario in which bioenergy alone will remove CO2 from the atmosphere on a net basis."

The transformation of land at this scale has implications not only for global food security, but for the lives, livelihoods, and human rights of communities around the world. Those impacts would be most heavily felt by indigenous peoples, forest communities, subsistence farmers, and poor and marginalized communities in regions subject to food shortages or food price shocks. Beyond its human impacts, the large-scale production of bioenergy would have significant impacts on water supplies and ecosystems. Moreover, as CSLF's Bioenergy Carbon Capture and Storage Task Force observed, converting the necessary land to bioenergy would itself generate significant direct CO_2 emissions due to land cover change, loss of forests and grasslands, soil disturbance, and increased use of agricultural chemicals, thus reducing its climate benefit.[223] Indirect emissions from producing and using bioenergy would reduce those benefits still further.[224]

Reducing the immense impacts of BECCS on food security would require diverting biofuel land conversions away from croplands and into natural areas. As noted by CSLF's BECCS report, however, converting large areas of forest to bioenergy production would create net emissions of up to 135 gigatons of carbon by 2100.[225] This would transform bioenergy from a carbon sink to a massive carbon source even before the potential emissions from CCS itself were considered.[226]

Notwithstanding these risks, the comparatively greater technical feasibility of BECCs relative to other technological fixes has made it attractive for geoengineering proponents and climate modelers alike. Models of decarbonization can use BECCS as an accounting tool to offset carbon dioxide emitted from other sources and fill gaps in projected energy needs. In fact, earlier iterations of the IPCC decarbonization pathways were criticized for doing exactly this. More recently and more conspicuously, Shell's Sky Scenario, which has been lauded for its ambition, relies heavily on BECCS (and fossil CCS) to reach its targets.[227]

Due to the array of challenges with respect to scalability, sustainability, social acceptability, and human rights, however, the IPCC notes that the projected contribution of BECCS to climate reduction targets has steadily declined in recent years.[228] Accordingly, the IPCC expressly cautioned in SR1.5 against overreliance on BECCS as a mitigation or carbon removal strategy and excluded BECCS entirely from its most ambitious transformation scenario.[229]

As noted above, any potential benefit of BECCS as a CO_2 removal strategy depends on how the CCS component of

FIGURE 15
Excerpt from Summary of Global BECCS Projects

Table 2: Summary of global BECCS projects (Kemper 2015)

Project name	Location	Status	CO_2 capacity $MtCO_2/yr$	CO_2 source	CO_2 sink
Operational projects					
IL-ICCS project	Decatur, IL, USA	2nd phase operating since April 2017	1.0	Archer Daniels Midland ethanol plant, other	Saline storage, Mount Simon sandstone
Arkalon	Liberal, KS, USA	Operating since 2009	0.18-0.29	Conestoga's Arkalon ethanol plant	EOR, Booker and Farnsworth oil fields, TX
Bonanza	Garden City, KS, USA	Operating since 2011	0.10-0.15	Conestoga's Bonanza BioEnergy ethanol plant	EOR, Stuart oil field, KS
RCI/OCAP/ROAD	Rotterdam, NL	Operating since 2011	0.1 (Abengoa) 0.3 (Shell)	Shell's Pernis refinery, Abengoa's ethanol plant, Maasvlakte power plant, various other	Nearby greenhouses, TAQA's P18-4 gas reservoir after 2015
Husky Energy	Lloydminster, SK, CA	Operating since 2012	0.09-0.1	Ethanol plant	EOR, Lashburn and Tangleflags oil fields

CARBON SEQUESTRATION LEADERSHIP FORUM, TECHNICAL SUMMARY OF BIOENERGY WITH CARBON CAPTURE AND STORAGE (BECCS) 20 (2018), https://www.cslforum.org/cslf/sites/default/files/documents/Publications/BECCS_Task_Force_Report_2018-04-04.pdf.

BECCS is deployed. With limited exceptions, the economics of the CCS component of BECCS are the same as in other CCS-reliant technologies. Thus, the most likely use of captured CO_2 in BECCS projects is EOR.

The report on BECCS prepared for CSLF in 2018 agreed, acknowledging that EOR provided the primary economic market for CO_2 from BECCS facilities and highlighting that three of the only five operational BECCS projects worldwide were designed for EOR.[230]

As the paucity of active projects suggests, biofuels and BECCS occupy an uncertain place in the future of global energy supply. Outlooks for energy demand by the major integrated oil and gas companies predict modest growth in bioenergy production and consumption, yet these same companies remain invested in biofuels and promote them as the clean future of energy. While biofuels can be considerably less carbon-intense than fossil fuels, their key advantage is compatibility with systems of fossil fuel combustion, and like the DAC-produced fuels discussed above, they do not contribute to a systemic change in transportation and reliance on fossil fuels.

Most models that have considered wide-scale deployment of BECCS have considered bioenergy from terrestrial biomass, rather than biofuels. Notably, however, of eight operational or completed BECCS projects reported to CSLF, seven were for ethanol, and all benefited from government subsidies for biofuels.[231] As discussed in the prior section on DAC, the production of combustible transport fuels as a supplement to or drop-in replacement for fossil fuels serves to perpetuate and reinforce the existing fossil-fuel-based energy and transport *infra*structure rather than transform it. Even where biomass is used, BECCS serves fossil fuel interests by promoting CCS generally and distracting from other ambitious and transformative climate solutions.

Fossil Industry Investment in Biofuels and BECCS

The pursuit of biofuels dates back at least to the 1970s, and patent filings demonstrate that oil companies were early pioneers and proponents of biofuel development.[232] The Gas Research Institute (GRI)—a research apparatus formed in 1976 and funded by the natural gas industry—was funding research into biofuel production no later than the 1980s[233] and continued until 1990.[234] The GRI also collaborated with the American Gas Association, the US Energy Research and Development Administration, and the US Department of Energy to pursue a marine biomass energy research program, from 1968 until 1990.[235] While the research into marine biofuels was originally conducted for the purpose of producing fuels, the option of using such marine algae growth as a carbon sink became a subject of significant discussion in the 1990s.[236]

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Fossil fuel companies continue to invest extensively in biofuels, in large part due to renewable fuel standards.[237] Exxon maintains a substantial investment in Synthetic Genomics, Inc., a company that makes biofuels from algae.[238] Shell holds the rights to biofuels produced by SBI Bioenergy, Inc.[239] Chevron,[240] Total,[241] and Eni,[242] to name a few, also invest in and produce biofuels.

Despite these investments, multinational oil and gas companies do not appear to be planning for a massive expansion in biofuel production and use. Shell's Sky Scenario depicts an expansion of BECCS for use in electricity production, but it contends that oil will remain the primary provider for liquid fuels.[243] Exxon's and BP's energy forecasts, including those with decarbonization scenarios, similarly show a muted role for biofuels as a replacement for, or even supplement to, oil for liquid fuels.[244]

Thus, even though major oil and gas companies promote biofuels as a climate solution and actively seek government subsidies linked to biofuels, there is limited evidence that these companies are seriously looking to deploy them on a scale that would meaningfully displace oil and gas. Rather, the benefit of biofuels—as noted on several company websites—is that they are drop-in fuels that don't disrupt the functioning of fossil fuel production and distribution systems.

A 2013 presentation[245] by Wolfgang Heidug, Senior Analyst of the CCS Unit for the International Energy Agency, reveals the way in which the direct promotion of BECCS would be a financial windfall for the fossil fuel industry. In this presentation, Heidug presents the results of an analysis of various incentive policies for BECCS. In short, BECCS does not become sufficiently incentivized unless there is a positive subsidy for CCS, use of bioenergy, or both.[246] Bioenergy has to compete with other energy sources, so the CCS unit would not be added unless it were specifically incentivized. However, carbon pricing or other policies to incentivize carbon storage (such as the credits in Section 45Q) apply to BECCS as well as fossil energy with CCS. Put another way, BECCS is not likely to be the result of market alignment from unrelated prudent climate policies, but rather needs to be deliberately incentivized, and as such, the deployment of BECCS would require significant expenditure of public resources. Moreover, much of this deliberate incentivization would apply to fossil fuel energy production, leading to the problems outlined in the sections on CCS and EOR above.

In addition to its policy problems, a widespread belief in the availability of BECCS, like SRM (which will be discussed in the next section),[247] creates severe moral hazard. BECCS is attractive in part because it allows modelers to decrease their near- to medium-term ambition. Including substantial BECCS in a model allows for modelers to exceed determined carbon budgets and count on "negative emissions" from BECCS to make up the difference.[248]

Critically, this kind of potential pathway, called "overshooting," is not guaranteed to work. While it may feel intuitive in a model, we do not know that overshooting and then reducing atmospheric carbon dioxide concentrations will work as expected. Moreover, overshooting risks hitting tipping points from which positive feedbacks lead to significantly increased warming. The IPCC specifically counseled against overshooting in its SR1.5,[249] yet this is the plan set out in Shell's Sky Scenario.[250]

PART 6

Paved with Good Intentions: The Danger and Distraction of Solar Radiation Modification

Solar radiation modification refers to the suite of ideas proposed to combat global warming by reducing, reflecting, or intercepting sunlight before it has a chance to warm the atmosphere. Long before oil companies proposed paving entire landscapes to change rainfall patterns[251] and spraying black carbon into the atmosphere to weaken hurricanes,[252] scientists understood the potential for changes in the earth's albedo (the amount of sunlight reflected back into space) to modify the climate at local, regional, or larger scales.[253]

The strategies proposed for doing so are diverse, including injecting sulfur or other aerosols into the atmosphere; brightening marine clouds by injecting seawater or sulfur dioxide from purpose-built vessels or existing ships;[254] spreading tiny microbeads or foam-enhancing surfactants in the oceans;[255] deploying mirrors in space;[256] and covering deserts in plastic sheeting,[257] among many others.

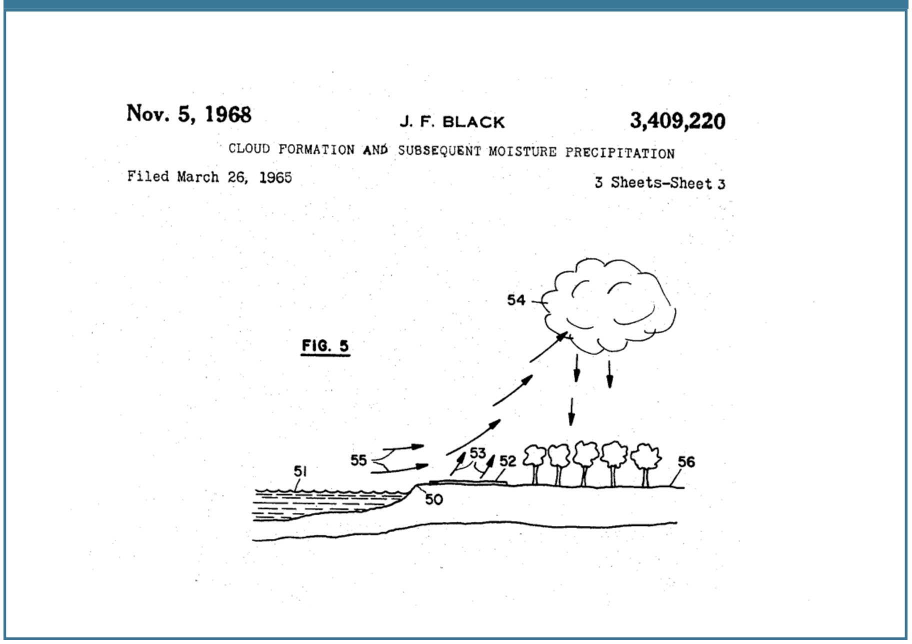
While proponents of CDR promise to pull CO_2 out of the atmosphere as a means of reducing climate impacts, SRM proponents take a different approach, seeking not to remove atmospheric greenhouse gases, but to mask or countermand their effects for the decades to millennia it takes to return CO_2 concentrations to safe levels. As three leading geoengineering advocates observed in 2014:

> "Carbon dioxide released to the atmosphere can affect the Earth's climate for millennia, thus in the absence of methods used to accelerate the removal of CO_2 from the atmosphere, CO_2 emissions commit us to millennia of altered climate. Using solar geoengineering to hold global mean temperature constant would thus require that its deployment be sustained for a long time, dependent on this residence time."[258]

If geoengineering were used to simply slow the rate of climate change rather than fully prevent warming, they argued, the length of SRM deployment could be reduced—to periods ranging from 40 to 840 years depending on the speed of transition and emissions reductions.[259] The authors, including Carbon Engineering founder David Keith, acknowledged that the only way to reduce these timelines, other than minimizing emissions in the first place, would be to combine them with CDR.[260] To a significant extent, therefore, and for reasons detailed in the preceding sections, proponents of SRM must also assume the same large-scale deployment of commercially viable CCUS, DAC, and BECCS.

With atmospheric GHG concentrations now surpassing 400 parts per million and global emissions reductions still woefully inadequate, the potential for deploying SRM—or at least testing it—has become the subject of serious discussion. Eminent climate scientist Michael MacCracken has advocated for geoengineering research and deployment for nearly three decades, but succinctly captures the sentiment among a growing body of informed observers:

FIGURE 16
Early ExxonMobil Patent for Using Asphalt to Change Rainfall Patterns



Cloud Formation and Subsequent Moisture Precipitation, U.S. Patent No. 3,409,220 (filed Mar. 26, 1965).

"With the prospects for the future now viewed with sufficient alarm and confidence to cause leaders of the world, despite all the uncertainties described in the IPCC Assessment Reports, to unanimously agree that the world's fossil fuel energy system must be replaced, the limitations of the present national commitments to emissions reductions would seem to favor serious international consideration of near-term global-scale intervention."[261]

Unlike many proposed CDR methods, and as discussed further below, there is broad agreement that some SRM approaches *would* be able to reduce solar irradiation and lower temperatures across large areas. Humanity's ability to effect such changes, even at a global scale, is beyond dispute. Indeed, we have already done so. The question is: at what cost?

Burning Fossil Fuels Proved SRM is Possible—and Demonstrated Its Risks

For more than a century, even as fossil fuel combustion raised global temperatures through the emission of CO_2 and other greenhouse gases, the emission of sulfur dioxide (SO_2) from the same fuel-burning sources was having the opposite effect. SO_2 emissions from power plants, ships, automobiles, and other sources generate sulfate aerosols that reflect a large proportion of sunlight back into space. By reducing the amount of solar energy that reaches the earth's surface, sulfate aerosols have a slight but measurable cooling effect that increases with their concentration in the atmosphere.[262] The atmospheric residence time of sulfate aerosols is far shorter than that of CO_2, so the cooling effect from individual particles is temporary, but for decades the steadily rising SO_2 emissions were sufficient to mask a substantial portion of accumulated warming across the Northern Hemisphere.[263]

Even assuming this interference with the global energy balance were unambiguously positive, however, SO_2 emissions have other, more immediate effects on human health[264] and the environment.[265] Most significantly, atmospheric SO_2 is one of the primary causes of acid rain and contributes to ozone depletion.[266]

Early Industry Interest in SRM and Stratospheric Aerosol Injection

Ironically, as measures to address sulfur dioxide's negative effects are slowly bringing emissions down in many parts of the world,[267] a small but growing chorus of voices is proposing that humanity inject still more SO_2, sulfate aerosols, or other materials into the stratosphere in the hope that the cooling it generates will mask the climate impacts of rising greenhouse gas concentrations. This injection of aerosols into the upper atmosphere, stratospheric aerosol injection (SAI), remains the most widely discussed approach to SRM, and, despite the risks, sulfur dioxide and sulfate aerosols remain the most widely discussed candidates for SAI.[268]

Bolstering this strategy is that, since sulfur dioxide is a common waste product of fossil fuel combustion, the necessary feedstocks for both SAI and some forms of marine cloud brightening (MCB) are readily available in an economy powered by fossil fuels.

In a recent, ironic example of these linkages, some proponents of geoengineering have suggested that, by reducing the albedo effects of ship emissions, recent regulations designed to protect public health by reducing SO_2 emissions from global shipping fleets have the unfortunate side effect of "interfering" with an ongoing inadvertent experiment in geoengineering.[269] As Jan Fugelsvedt and colleagues summarized in a 2009 article:

> "One might consider SO_2 emissions as a form of inadvertent geoengineering due to the cooling effects. Indeed, the proposed geoengineering scheme of deliberately seeding low-level clouds over the oceans to enhance their albedo would lead to a forcing mechanism similar to continued SO_2 emissions from shipping."[270]

While acknowledging the evident health benefits of SO_2 regulations then being considered by the International Maritime Organization, Fugelsvedt and colleagues noted that cleaning up ship pollution would reduce the modest but noticeable cooling effect those SO_2 emissions had on the climate.[271] The authors recommended that this broader context be considered in evaluations of possible regulatory measures. Others saw in the shipping example a potential justification for new geoengineering research:

> "The upcoming change does offer a different way of thinking about intentional efforts to cool the climate, known as geoengineering, according to some proponents of research in this area. Rather than some radical experiment, deliberate geoengineering could instead be seen as a way of continuing to do what we've been doing inadvertently with ships, but in a safer way."[272]

The National Academy of Sciences (NAS) noted this linkage between fossil combustion and key geoengineering technologies when discussing the prospects for geoengineering in its 1992 report *Policy Implications of Greenhouse Warming*. Citing earlier work by SS Penner, the NAS panel suggested that emissions of just "1 percent of the fuel mass of the commercial aviation fleet as particulates, between 40,000 and 100,000-foot (12- to 30-km) altitude for a 10-year period, would change the planetary albedo sufficiently to neutralize the effects of an equivalent doubling of CO_2."[273] Penner headed the Center for Energy Research at UC San Diego, which, as briefly noted earlier in this report, was founded with a grant from the Gulf Oil Foundation. Penner also chaired the Department of

FIGURE 17
Illustration of How Carbon Dust Would Be Generated and Dispensed from Jet Aircraft

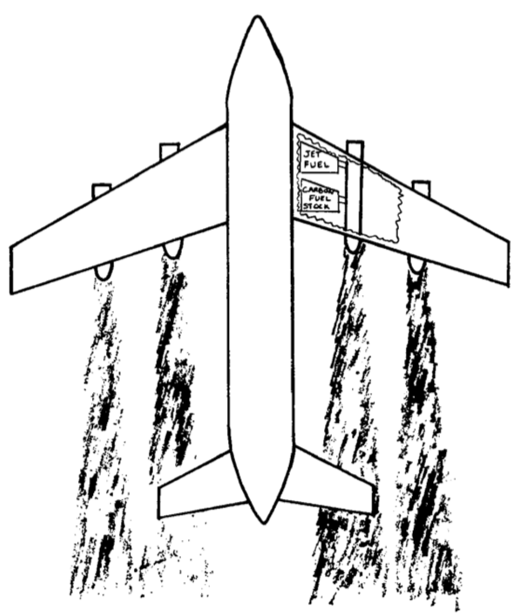


Fig. 3. Illustration of how carbon dust would be generated and dispensed from a jet aircraft.

W.M. GRAY ET AL., WEATHER MODIFICATION BY CARBON DUST ABSORPTION OF SOLAR ENERGY 73 (1974), *available at* http://www.alachuacounty.us/Depts/epd/EPAC/William%20M.%20Gray%20-%20Weather-modification%20by%20Carbon%20Dust%20Absorption%20of%20Solar%20Energy%201974.pdf

FIGURE 18

Graph by Keith and Dowlatabadi Suggesting that SRM Could be Cheaper than Reducing CO_2 Emissions

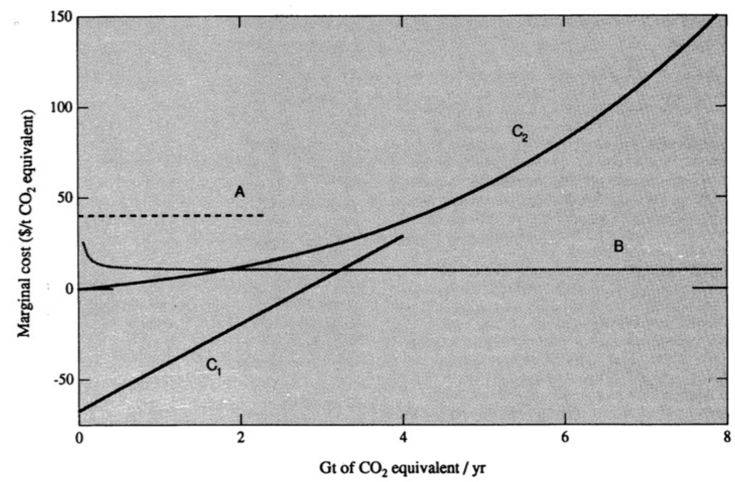


Fig. 1. Marginal cost of mitigation versus total mitigation for the United States. The lower axis is the total mitigation in Gt of CO_2 equivalent. The costs of geoengineering are given by two curves: A, CO_2 injection; and B, solar shields. Curves C, C_1, and C_2 represent a range of mitigation costs. CO_2 accounts for about half of the global-warming potential of U.S. emissions. Stabilizing GHG concentrations requires about a 60% emissions cut, for example, ~6 Gt CO_2 equivalent per year for the United States. The marginal cost of deep-ocean disposal of CO_2 (A) is taken from Golomb et al. *[1989]. Its application is limited to the total amount of CO_2 currently released by centralized facilities. The solar shield costs (B) are assumed to be $10/t with an initial capital cost of 10% of the full cost. The costs of abatement (C) are taken from the NAS report. The lower branch (C_1) is from the "technical costing method" and was generated using a linear fit to the midpoint data in Figure 11.1 of the NAS report. The upper branch (C_2) is from the "economic modeling method" (Figure Q.2) using a quadratic polynomial fit.*

David W. Keith and Hadi Dowlatabadi, *A Serious Look at Geoengineering*, 73 TRANS. AM. GEOPHYS. UNION 289 (1992), https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/91EO00231.

Energy's Fossil Energy Research Working Group, a joint enterprise between industry and academic researchers created to improve the viability of shale oil, coal liquefaction, and other fossil fuel technologies.[274]

Penner's original 1984 paper, co-authored with a graduate student funded by Shell Oil, made the motivation for proposing geoengineering explicit:

> "The notion that the most economical energy source will be replaced globally in response to longterm climate model predictions is probably false. Before policy matters of this type can be discussed reasonably, careful assessments must be made of alternative global measures that do not require curtailments of fossil-fuel applications."[275]

In lieu of reducing fossil fuel use, Penner argued that "desired changes in Earth albedo through judicious introduction of small particles can probably be accomplished at acceptable cost through the use of modified combustors on high-flying aircraft."[276]

While its application in the climate context may have been novel, the concept of using modified aircraft emissions to alter Earth's albedo and affect the climate was not. It had been proposed by Russian scientist Mikhail Budyko in the early 1970s and periodically echoed by scientists and industry researchers in the ensuing years. As discussed in Part 3, above, this was one of many strategies detailed by industry-linked researchers in 1974 to increase control of the climate while creating new markets for petroleum products.

In a follow-up paper in 1993, Penner further elaborated on the strategy.[277] Using jet fuel consumption figures provided to him by the American Petroleum Institute, Penner estimated that if one percent (2 million tons per year) of jet fuel were converted to stratospheric emissions, just under four years would be required to lower temperatures sufficiently to offset 1.5°C of warming due to climate change.[278] If the particles were created from a mixture of coal and jet fuel, the feedstocks might be secured for as little as three cents per ton.[279]

Penner noted potential concerns that stratospheric injections of this kind might damage the stratospheric ozone layer and indicated that this justified some experimentation into possible effects. Nonetheless, he argued that the potential availability of a low-cost technology to decrease temperatures made it "appropriate to delay drastic and excessively costly measures on CO_2 reduction."[280] Indeed, he argued, climate modeling itself should proceed on the assumption that the results of geoengineering experiments would likely be known long before there was certainty regarding the need for climate mitigation of other kinds.

A handwritten note on one of Penner's papers expressed the view that "[m]any famous scientists have later copied this idea without acknowledgment of my 1992-93 proposal."[281] Wallace Broecker, himself receiving climate funding from Exxon at the time,[282] briefly discussed the idea—and provided additional cost estimates—in his 1985 book *How to Build a Habitable Planet*, but provided no citations.[283] Long-time SAI advocate David Keith cited both Broecker and NAS for the concept in his widely cited 1992 review *A Serious Look at Geoengineering*.[284] In further evidence of industry's role in geoengineering research, Keith's 1992 article was funded in part under a contract with the Electric Power Research Institute.[285]

Significantly, Keith, like Penner before him, argued that one significant reason for exploring geoengineering technologies was the potential to manage the impacts of climate change much more cheaply than could be achieved through abatement alone. In a figure accompanying the paper, Keith and his co-author highlighted that the marginal cost of deploying SRM—described in the graph as a "solar shield" (represented by the flat line labeled B in the graph)—could be dramatically lower than achieving an equivalent amount of climate mitigation by reducing US greenhouse gas emissions by six gigatons of CO_2 per year (represented by curves C_1 and C_2 in the graph).[286]

While the details have changed in some respects, the core concept of using modified jet exhaust to inject particulates or aerosols into the stratosphere remains essentially intact in modern proposals for SAI. In a recent review of SAI injection options, for example, David Keith and co-authors concluded that the most economically viable approach to SAI would be to modify existing Boeing 747 aircraft or develop new airframes to inject SO_2 into the stratosphere at 60,000 feet.[287] (The lead author on the report, Justin McClellan, worked in business development for a Boeing subsidiary.[288] The third author, Jay Apt, was director of the Electricity Industry Center, which was co-founded by and receives ongoing core support from Electric Power Research Institute (EPRI).[289]) As with Penner decades earlier, Keith and colleagues acknowledged that this economic analysis was relevant not only as a necessary supplement to climate mitigation efforts, but as a cost-competitive alternative to those efforts:

> "We think this work demonstrates clearly that it is feasible by showing that several independent options can transport the required material at a cost that is less than 1% of climate damages or the cost of mitigation."[290]

The authors' assessment that solar geoengineering using SAI was cost effective compared not only to the costs of climate damages, but also to the cost of emissions reductions, was expressly restated in the paper's conclusion.[291] Far from envisioning SRM as a necessary fail-safe if mitigation technologies failed to fully eliminate GHG emissions, the authors instead concluded that SRM might prove a useful and economical component of a broader climate management system—one focused not on eliminating the drivers of climate change, but on simply keeping pace with their mounting atmospheric impacts.

> "When SRM is considered as one element of climate strategy that also includes mitigation and adaptation, it is meaningful to compare costs and in this sense one can conclude that the cost of SRM deployment of quantities sufficient to alter radiative forcing by an amount roughly equivalent to the growth of anticipated GHG forcing over the next half century is low, though SRM does not thereby mitigate the risks of the accumulated GHGs that extend far beyond this time window."[292]

Counting—and Not Counting—the Costs of SRM

As the preceding section demonstrates, one of the recurring rationales for exploring SRM is that its costs—while substantial—might be lower than the near-term costs of mitigation efforts. As with CDR, however, the economics of SRM may depend on how narrowly costs are calculated.

In their 2012 cost assessment of SAI delivery methods, Keith and McClellan acknowledged that their analysis did not consider the "implications of risks [of SAI] and of the imperfect climate compensation offered by SRM, and the costs associated with these issues."[293] In addition to significant risks of acid precipitation and potential impacts to the ozone layer, SAI would do nothing to reduce the ocean acidification caused by CO_2 deposition and, indeed, could exacerbate the problem.

There is broad recognition within the scientific community, moreover, that both SAI and MCB—will have significant effects on rainfall patterns across large regions and that these effects may be "telegraphed" to regions far removed from injection sites.[294] Like SAI, marine cloud brightening is designed to increase the amount of sunlight reflected back into space by raising Earth's albedo. However, while SAI focuses on deploying SO_2 or other aerosols in the stratosphere, MCB involves changing the reflectivity of marine clouds by injecting SO_2, sea water, or other aerosols into the atmosphere above the marine environment, using either existing ships or fleets of purpose-built vessels. Models have repeatedly indicated that the application of either category of technology at large scales would have significant impacts on global hydrological cycles.

For example, multiple studies have shown that geoengineering in the Arctic could lead to significant changes in precipitation in tropical monsoon regions of both the Northern and Southern hemispheres, increasing monsoon precipitation in the Northern hemisphere tropics but dramatically reducing rainfall across the Amazon.[295] Rainfall losses of this scale would trigger profound impacts on Amazonian ecosystems and on the indigenous peoples and local communities dependent upon those ecosystems, and they would compound the moisture losses caused by climate change itself. Despite this, engineer and MCB vessel designer Stephen Salter expressed optimism that the people of Brazil would gladly accept these losses knowing that the Amazon's loss was offset by increased rain in the Horn of Africa.[296] To address the hydrological imbalances created by geoengineering, Salter proposes a globe-spanning network of vessels injecting seawater into the atmosphere from predetermined locations and in carefully orchestrated but periodically

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recalibrated sequences, with each injection designed to offset and rebalance the ones that came before.[297]

Acid rain, ozone loss, and significant disruption of hydrological cycles are not the only risks posed by SAI and other SRM technologies. These risks include compounding the disruptive impacts of climate change itself, reducing crop yields[298] and solar energy production by reducing the amount of solar radiance reaching the earth's surface,[299] and affecting the frequency and intensity of tropical cyclones,[300] among others.

Moreover, as evidenced in the Salter paper, SRM proponents often acknowledge vast inequities in the distribution of the costs and benefits of SRM technologies, but assume those disparities will simply be accepted by local populations or dealt with later.

In the early 2000s, environmental chemist Alvia Gaskill reviewed available technologies for geoengineering and shared his findings and proposal with the US Department of Energy. Gaskill, a consulting expert for industry defendants accused of mismanaging waste oil,[301] argued that the most feasible and economical solution to climate change would be to cover 4 million square miles of desert with plastic sheeting. Gaskill calculated that the project would cost $500 billion per year for 150 years—$75 trillion in total. These costs, he concluded, compared "very favorably" to the Department of Energy's "$10/ton goal to managing carbon from power plant emissions."[302]

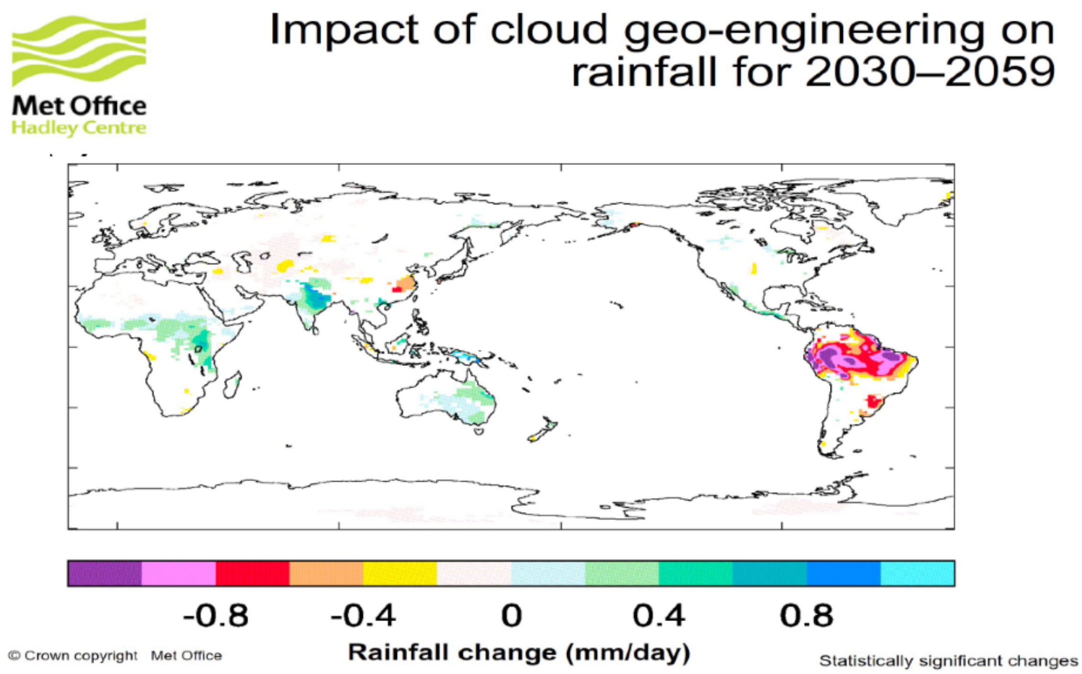
The majority of the project expenses would go into purchasing the plastic from the petrochemical companies that make it. The land, Gaskill assumed, would be given away free of charge.[303]

At first blush, the idea of covering the world's largest deserts in plastic and assuming the countries and communities affected would freely consent seems profoundly naive. Yet it parallels the continued heavy reliance on BECCS in climate mitigation scenarios and the implicit assumption that much of the world's arable land can be converted from food production to biofuels, generally without compensating affected communities for the impacts to their lands, rights, livelihoods, and lives. As in the context of CDR, such assumptions occur with troubling frequency in proposals for the deployment of SRM.

Moreover, were large-scale SRM ended before atmospheric CO_2 concentrations had been returned to safe levels, global temperatures would rapidly rise to the levels dictated by those concentrations. This rapid temperature increase and the associated disruptions to geophysical, ecological, and social systems that would ensue are known collectively as "termination shock."[304] SRM proponents argue that these risks might be managed by protecting SRM installations against attacks or disasters,[305] phasing out SRM gradually over a long period of time, or restricting the degree to which SRM is used in the first place.[306]

There is also the significant risk that the deployment of or even experimentation with SRM could increase global insecurity and increase the potential for conflict regionally or more broadly. Given the

FIGURE 19
Impact of Cloud Geoengineering on Rainfall for 2030-2059



Stephen Salter and Alan Gadian, Coded Modulation of Computer Climate Models for the Prediction of Precipitation and Other Side-effects of Marine Cloud Brightening 3 (research proposal, Jan. 25, 2013), http://www.homepages.ed.ac.uk/shs/Climatechange/DECC%20coded%20modulation.pdf.

military origins of some early geoengineering technologies, the active exploration of military technologies such as missiles or artillery shells for SRM deployment, and the use of early weather modification tools in military conflicts, some observers have highlighted the serious risk that geoengineering or geoengineering technologies might be intentionally utilized for military purposes.[307] A less discussed but even more pervasive risk is that geoengineering could exacerbate underlying, often long-standing sources of tension between groups or countries, resulting in the outbreak or recurrence of military conflict. In 2007, the United States Department of Defense recognized the potential for climate change itself to compound pre-existing tensions in this way, serving as a "threat multiplier" that increases the likelihood and potential scale of violence.[308] For example, as climate change disrupts rainfall patterns across large areas, conflicts over access to water resources are likely to grow, both within and between countries.[309] Given its potential effects on rainfall patterns, storms, and crop production—including at great distances from SRM deployment sites—geoengineering could dramatically compound resource-related conflicts in regions affected by food insecurity, water stress, and ongoing disputes over access to and control of glacial melts, monsoon rains, and the rivers and floodplains they run through.

Moral Hazard and the Geoengineering 'Fail-Safe'

Beyond the risks attendant to individual technologies, however, is a more fundamental risk inherent in the development of or even the research into SRM: that the promise of future geoengineering will provide an excuse to delay climate mitigation or to reduce the scale of ambition.

In the geoengineering context, this is often referred to as the *moral hazard* argument—the risk that the perceived ability to manage the climate crisis by engineering the climate itself will suppress ambition by governments, corporations, and individuals to reduce emissions of greenhouse gases.

Proponents of geoengineering deployment or research routinely argue that these risks are overstated, noting that all but the the most strident proponents of SRM acknowledge that SRM must be coupled with emissions reductions and emissions must ultimately be brought under control.

As this report demonstrates, however, the potential to avoid or minimize other forms of climate action—including reducing the world's reliance on fossil fuels—have been a recurring theme in CDR and SRM research alike for decades. As DAC and SRM advocate David Keith acknowledged in 1992,

> "The existence of a fallback is critically important as it allows more confidence in choosing a moderate response strategy. Moderate responses are difficult to implement when catastrophic consequences are possible from weak anthropogenic climate forcing. Fallback strategies permit moderate responses to be adopted with the knowledge that should these prove inadequate an alternate mitigative option is available."[310]

The same year Keith issued this EPRI-funded paper, EPRI founder and president emeritus Chauncey Starr put the matter more bluntly. In a paper co-authored with fellow climate denialist Fred Singer, Starr argued that the "scientific base for a greenhouse warming is too uncertain to justify drastic action at this time."[311] Significantly, Starr and his co-authors argued that action to address climate risks was unjustified because we could always geoengineer our way out of the problem—either by sucking CO_2 from the atmosphere or by deploying techniques to block incoming sunlight:

> "If greenhouse warming ever becomes a problem, there are a number of proposals for removing CO_2 from the atmosphere. . . . If all else fails, there is always the possibility of putting 'Venetian blind' satellites into earth orbit to modulate the amount of sunshine reaching the earth."[312]

Unlike Starr, Keith highlighted the potentially prohibitive costs of deep GHG reductions but did not argue that reductions were wholly unnecessary. Like other SRM advocates, however, Keith repeatedly emphasized that the availability of geoengineering provided a strong rationale for reducing near-term ambition and delaying significant emissions reductions into the future:

> "The notion of geoengineering as a fallback option provides a central—or perhaps the only—justification for taking large-scale geoengineering seriously. A fallback strategy permits more confidence in adopting a moderate response to the climate problem: without fallback options a moderate response is risky given the possibility of a strong climatic response to moderate levels of fossil-fuel combustion."[313]

As abundantly documented in the sections that follow, the potential to avoid, delay, or minimize necessary reductions in GHG emissions remains a recurring, explicit ambition of many geoengineering proponents—both within industry and within the advocacy and policy communities. This is, in an important sense, a rational and predictable response of corporations and governments. Climate change mitigation, the reduction of greenhouse gas emissions, and the shift away from a fossil fuel-based economy will not be without costs. While there will be enormous benefits, both concentrated and diffuse, there are also near-term costs to climate action and difficult decisions that need to be made quickly. A political leader deciding between prudent climate action now versus another governance priority may choose the latter if they believe that SRM implementation will buy time.

This fundamental problem—that solar geoengineering is the perfect excuse for inaction—is exactly what makes its implementation aligned with fossil fuel interests. It is therefore unsurprising that, from the earliest conversations about solar geoengineering through the present day, the fossil fuel industry has been involved in the conception of solar geoengineering options—often using fossil fuel by-products—and the promotion of SRM as a climate option.

This is a Test. But is it Only a Test?

Notwithstanding the long scientific history of the concept, and its periodic exploration by both corporations and governments, the public conversation over SRM remains in its early stages. Early and sometimes unauthorized experiments into other forms of geoengineering led to mounting concern among informed observers that open-air experimentation with SRM might soon begin. In response to these concerns, the Convention on Biological Diversity adopted a decision in 2010 creating an effective moratorium on geoengineering, including experimentation. This decision, however, is neither ironclad nor irreversible.[314]

As geoengineering generally and SRM specifically become more prominent in the climate dialogue, interest in carrying out open-air geoengineering experiments is increasing.[315] Among the most widely discussed of these potential experiments is the stratospheric controlled perturbation experiment (SCoPEx) co-led by David Keith (Mission Scientist) and Frank Keutsch (Principal Investigator) of Harvard University.[316] Keutsch is a professor of chemistry and atmospheric science at Harvard; Keith serves as faculty director for Harvard University's Solar Geoengineering Research Program (SGRP)[317] and, as discussed in the section on direct air capture, is the founder of Carbon Engineering.

Unlike some programs that seek only to pursue governance, the SGRP takes "an active stance on research with a unique mandate to develop new path-breaking technologies that might improve solar geoengineering's effectiveness and reduce its risks."[318] In conjunction with that mandate, SCoPEx is designed "to advance understanding of the risks and efficacy of SRM," with particular attention to the potential impacts of SRM on the ozone layer. Keutsch, Keith, and their co-workers acknowledge the potential for stratospheric aerosol injection to damage the ozone layer, but assert that the impacts on ozone may be reduced if the atmospheric cooling induced by SRM reduces the transport of water vapor into the lower stratosphere.[319] The SCoPEx experiment is thus designed to inform these competing hypotheses about the impacts of SRM. A second function of the experiment is to better analyze how sulfate particles behave following injection—including the size, dispersion, and resulting duration of particles, all of which will influence their reflectivity and efficiency for radiative forcing.[320]

Keith and other proponents of open-air testing of geoengineering routinely argue that such experiments are needed to determine whether geoengineering will be safe and, if so, under what conditions. It is notable in this regard that the SCoPEx proponents originally intended to deploy sulfuric acid in the experiment,[321] but modified their testing plans in the wake of public concern with the potential environmental effects of sulfate aerosols. As a result, the proponents subsequently proposed to initiate the experiment with ice and calcium carbonate instead, while leaving open the possibility of injecting sulfate aerosols at a later stage.[322]

Notably, however, Keith and others continue to assume the use of SO_2 or similar sulfate aerosol precursors in papers modeling the large scale deployment of SRM.[323] As they acknowledge in a 2017 paper, research on SRM implementation continues to focus on increasing the stratospheric burden of sulfate aerosols, "in part because it is (arguably) the only SRM method with a strong natural analog that can produce relatively uniform [increases in radiative forcing] using existing technologies."[324] Regardless of the specific testing material deployed in experiments, therefore, any actual deployment of SAI is likely to rely heavily on sulfate aerosols, with their attendant side effects. Ironically, open-air experiments small enough in size to minimize the risk of harm from these materials also increase the risk that they will be too small to fully reveal such side effects.

Troublingly, both the SCoPEx design and the broader context in which it is implemented suggest that the goal of the experiment is to move the technology forward, rather than to demonstrate that it is safe for deployment. As evidenced by their ongoing research outside of SCoPEx, Keith and his coworkers continue to actively research, refine, and promote strategies for SRM even as the deployment of SCoPEx is debated. This fact highlights another widespread concern among critics of geoengineering: that experiments such as SCoPEx are designed less to expose the potential risks of SRM technologies than to narrow the universe of potential risks, while demonstrating the basic feasibility of geoengineering technologies and opening the door to deployment at progressively larger scales.

In fact, some long-time geoengineering advocates explicitly acknowledge that a principal function of early testing is to lay the foundation for early, active deployment. In 2016, for example, MacCracken acknowledged that testing and deployment exist on a tightly woven continuum. MacCracken argued that, unless geoengineering interventions begin in the near term and gradually scale up, there is the risk that geoengineering research results might go unused.

> "Thus, while scientific and technological questions that merit additional research and, while governmental efforts are needed that develop appropriate governance mechanisms for deciding how to optimally intervene, putting off initiation of actual climate intervention until there is much greater understanding might well lead to a situation where the transient conditions associated with restoring the past's milder conditions might themselves be unacceptably disruptive."[325]

In these circumstances, MacCracken believes, geoengineering experiments provide a useful stepping stone to wide-scale deployment:

> "As an alternative to jumping from undertaking no intervention to initiating full global intervention and, in essence, imposing human control of the complex global climate system, establishing a research program to explore potential regionally focused, tropospheric interventions might serve as a useful interim step between not intervening at all and jumping straight to global-scale intervention."[326]

As documented more fully below, MacCracken is far from alone in this view that a principal benefit of open-air testing is that it eases the path to large-scale deployment. This perspective is shared by the American Enterprise Institute and in one important instance, discussed further below, by NASA.

Industry Influence in SRM

As discussed more fully above, the prospect of tinkering with Earth's albedo—whether in the atmosphere, in the oceans, or on the earth's surface—was an area of early and active inquiry in weather modification and geoengineering. Fossil fuel interests, including particularly the oil industry, were early and active participants in this research.[327] For decades, however, it was widely recognized that the risks and side effects of SRM far outweighed any potential benefits.[328]

Beginning in the 1990s, the concept of actively deploying SRM on a global scale was resurrected—either as a last-ditch solution to the climate crisis or as a quick and relatively inexpensive fix to mask the impacts of accumulating greenhouse gas emissions. Producers and users of fossil fuels were key actors in this resurgence.

As noted in the preceding section, the utility industry's Electric Power Research Institute co-funded David Keith's early research into geoengineering in 1992. That same year, EPRI founder and president emeritus Chauncey Starr wrote a series of papers actively disputing the state of climate science, emphasizing uncertainties and arguing against action to

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address the crisis. In one of the most influential of these papers, co-authored with fellow climate denialist Fred Singer, Starr argued, “The scientific base for a greenhouse warming is too uncertain to justify drastic action at this time.”[329] Should climate risks ever prove significant, the authors argued, we could geoengineer our way out of the problem.[330]

EPRI’s contributions to the field, however, pale in comparison to those by Exxon and other oil industry actors.

Exxon scientists Haroon Kheshgi and Brian Flannery were actively writing about geoengineering, and specifically SRM and ocean alkalinization, from the 1990s onward, with Kheshgi proving particularly active and influential.[331] Both are acknowledged for their contribution to MacCracken’s 1991 paper *Geoengineering the Climate*.[332] In 1997, Flannery and Kheshgi were primary authors of a chapter on geoengineering in Robert G. Watts’s book *Engineering Response to Global Climate Change*.[333] Kheshgi, Flannery, and other industry scientists were a constant, conspicuous presence in meetings and reports that returned geoengineering to the center of the climate debate.

NASA Workshop on Solar Radiation Management

In 2006, NASA and the Carnegie Institution of Washington Department of Global Ecology hosted a workshop to determine the research needs of the scientific community regarding solar geoengineering.[334] In addition to Keith and Exxon’s Kheshgi, the participants included Lee Lane of the American Enterprise Institute (AEI),[335] which at the time maintained an active and ongoing campaign to undermine public confidence in climate science. In an AEI report published that same year, Lane had argued against the Kyoto Protocol, carbon taxes, and cap-and-trade proposals and instead urged increased R&D funding for geoengineering, his term for using “technologies that would avoid harmful climate change while allowing emissions.”[336] Among other options, Lane noted, this could include “increasing earth’s albedo to offset the warming effects of rising GHG concentrations.”[337]

Lane was listed as the lead author on the NASA workshop report published in 2007. The report outlined two alternate visions to justify research into SRM geoengineering. The first was that mitigation efforts might fail and render geoengineering necessary, in which case it would be useful to have tested, cost-effective technologies on the shelf.[338] The second, which received more extensive and more positive treatment, argued that the development and “preemptive” deployment of SRM could “buy time” because implementing GHG reductions would require the development of "new, far lower cost emission abatement technologies."[339] At its heart, this vision of geoengineering was less about addressing the climate crisis than avoiding economic disruptions caused by prematurely reducing emissions:

> "Economic efficiency requires minimizing the present value of the sum of the damages from climate change and the costs of reducing those damages. By constraining the rise in temperature, solar radiation management deployment could reduce the damages of climate change. At the same time, postponing the deepest emission cuts until cheaper abatement technology is available is a key to abatement cost-effectiveness."[340]

Presciently, the workshop report also highlighted that early testing, if successful, would naturally increase pressure for deployment of the technology:

> "Nevertheless, should experimentation confirm the efficacy and safety of solar radiation management, a preemptive deployment offers major advantages. These include:
>
> - The opportunity for efficient deployment growing logically and progressively out of testing;
> - The possibility of lowering the present value of both damages from climate change and the costs of greenhouse gas abatement;
> - A more direct rationale for near term research and development;
> - More time to implement other policies should deployment of full-scale solar radiation management produce disappointing results or unacceptable side effects."[341]

As envisioned by the report authors, therefore, early geoengineering experiments would lead, logically and progressively, to the deployment of geoengineering technologies. These technologies, in turn, could reduce the near-term costs of greenhouse gas abatement by delaying emissions reductions while lowering the "present value" of climate damages.[342] Notably, the authors recognized that one important benefit to this accelerated testing and deployment of geoengineering was that there would be more time to choose other courses of action if the results from geoengineering proved disappointing or disastrous.[343]

This vision of geoengineering outlined in the NASA workshop report—that early deployment of SRM would provide an excuse to delay other forms of climate action; that even with advance testing and experimentation, significant adverse impacts might not become apparent until after SRM was deployed at scale; and that early reliance on SRM was justified because other forms of climate action could be used to save the day if SRM failed—turns widely touted rationales for geoengineering testing and deployment on their heads.

Ironically, the benefits and likely progression of early testing highlighted in the NASA report validate one of the recurring critiques of SRM testing: that a primary function of that testing is to accelerate the early deployment of the technology. As both the report authors and geoengineering critics seem to agree, extensive research programs are likely to lead to progressively larger-scale open-air experiments, which will blur the lines between SRM research and SRM deployment.[344] While proponents of SRM research may disagree that they are advocating for its ultimate deployment, in the absence of ironclad prohibitions and a stronger global commitment to emissions mitigation, it is reasonable to expect that SRM research will be considered the first step to SRM deployment.

Novim Climate Engineering Report

Another report released in 2009 has had an equal or greater impact on the geoengineering debate. The report, entitled *Climate Engineering Responses to Climate Emergencies*,[345] was released by Novim, a nonprofit group founded at the University of California Santa Barbara the previous year. Drawing on the work of a specially convened study group, the Novim report outlined a research agenda for stratospheric aerosol injection, the most commonly advocated form of SRM.[346] The lead author and study group convener, Steve Koonin, was Chief Scientist at BP when the group was convened.[347] A brief "Note on Conflicts" in the report acknowledges that Koonin's role at BP could be perceived as a conflict, as "some readers may perceive anyone working at any oil company to have an interest in distracting society from the job of reducing global CO_2 emissions, since the use of their products creates these emissions."[348] Nonetheless, the study group concluded that "no individual brings a conflict of interests, either personal or professional, to this work."[349] Moreover, despite disclosing Koonin's relationship with BP, other connections remained undeclared. Robert Socolow of Princeton was and is the director of the Carbon Mitigation Initiative, a program funded primarily by BP.[350] Keith, who also participated, founded Carbon Engineering the same year this report was released.

Koonin became Under Secretary for Science at the US Department of Energy in May 2009, shortly before the Novim report was released. In 2014, he ran a controversial op-ed in the *Wall Street Journal* entitled "Climate Science is Not Settled,"[351] followed three years later by another op-ed proposing a "red team" exercise to test the scientific consensus on climate change.[352] Scott Pruitt, climate denier and controversial head of the US Environmental Protection Agency under Donald Trump, tried but failed to hire Koonin to carry out this exercise.[353]

Bipartisan Policy Center's Climate Remediation Report

Another report came two years later. In 2010, the Bipartisan Policy Center (BPC), a US think tank, convened a "Blue Ribbon Task Force on Climate

Remediation." The task force was to "develop recommendations for the US government concerning geoengineering research and oversight policy."[354] In 2011, the task force released a report urging the US government to invest in a federal geoengineering research program.[355] This BPC report does not provide a specific set of funders. However, the 2011 BPC annual report contains a list of supporters including the ExxonMobil Foundation, American Gas Association, Dominion Resources, Eni, Entergy, Alliance Energy, America's Natural Gas Alliance, Chevron, ConocoPhillips, Exelon, Pioneer Natural Resources, Schlumberger, Shell Oil, and Southern Company.[356]

BPC has been extensively criticized for the apparent influence such funding arrangements hold over the topics it explores and the conclusions it reaches.[357] Several reports have focused specifically on the heavy influence of BPC's oil, gas, and chemical industry donors on the outcomes of its ostensibly unbiased work.[358] Perhaps unsurprisingly, BPC continues to support not only geoengineering research, but the increase of subsidies through 45Q, the use of those subsidies to deploy direct air capture,[359] and the use of the captured carbon for EOR, drop-in fuels, and plastics.[360]

Why Industry Influence Matters

The NASA, Novim, and BPC reports are among a handful of extremely influential documents on SRM that have helped move geoengineering from the far fringes of the climate debate toward its center. In addition to a 2009 report from The Royal Society, these reports are among the most influential developments in the public debate around SRM. All three were funded or heavily influenced by fossil fuel interests and individuals closely connected to those interests.

This industry influence in SRM, while perhaps less pervasive than at earlier stages, continues today. Many of the same individuals and institutions that receive fossil fuel funding remain deeply engaged in the space. For example, in September 2018, the Harvard Project on Climate Agreements and the SGRP conducted a research workshop on the governance of solar geoengineering.[361] Among the funders of the project is BP.[362] The Harvard Environmental Economics Program, with which the Project on Climate Agreements is closely affiliated, receives funding from Chevron and Shell.[363]

The universe of individuals and institutions shaping the debate over SRM, once relatively limited, has been growing rapidly in recent years, particularly as representatives of civil society and the Global South demand a greater role in the debate. These communities are by no means monolithic in their perspectives. While skepticism and concern about geoengineering are widely shared among environmental and human rights non-governmental organizations, a small but significant number of organizations have expressed cautious support—or at least potential openness—to the development of geoengineering governance, research, or limited testing. Actors from the Global South have expressed a diversity of perspectives from outright opposition to geoengineering research to a simple demand for a seat at the table and a role in that research.[364]

Accordingly, it would be inaccurate to suggest that the fossil fuel industry remains the sole instigator or driver of contemporary debates over geoengineering. There is evident and significant interest in both the scientific understanding and legal control of SRM among scientists, politicians, activists, scholars, and entrepreneurs from an array of sectors and disciplines.

At the same time, it is impossible and unwise to ignore the recurring influence of fossil fuel industries and interests in the research and policy agenda for geoengineering. Representatives of the industry, or individuals funded by companies within the industry, have been present at every stage. Fossil fuel companies have funded, sometimes in large part, workshops, reports, individuals, and institutions that have helped develop the domestic and international agenda for discussing and researching solar radiation management and geoengineering as a whole. As will be discussed below, the research networks for geoengineering are surrounded and interpreted by a parallel group of industry-linked individuals and institutions, who are actively promoting SRM to policymakers and the public alike, often in terms that prioritize industry interests and maintaining the status quo.

It bears repeating that the simple belief in the efficacy or necessity of SRM has material impact on efforts to pursue needed mitigation and adaptation. As acknowledged in Novim's note on conflicts of interest, and extensively documented in the next section, efforts to pursue SRM—in earnest or merely as a distraction—may be directly aligned with efforts to stall emissions reduction efforts, efforts which the fossil fuel industry has been and continues to be engaged in.

The New Climate Denial

Investigations from *InsideClimate News*, the *LA Times*, Climate Investigations Center, and others have revealed deep and persistent connections between funding by fossil fuel companies and the denial of climate change or opposition to climate action. This funding frequently flows through layers of front groups and astroturf organizations and is often hard to track. Still, many key climate-action-opposed individuals and organizations are well-known recipients of fossil fuel funding and are also active promoters of geoengineering, especially solar radiation management.

One of the more prominent figures in this space is Julian Morris, the director of the International Policy Network (IPN) and former director of the Environmental Programme at the Institute for Economic Affairs. Both the Institute and IPN are known to have received significant funding from Exxon.[365] Morris is a prominent denier of the validity of climate science and has worked for multiple organizations funded by fossil fuel companies. In 2008, he published an article entitled *Which Policy to Address Climate Change?*, first published by IPN and later republished by the Institute.[366] In this article, Morris proposed geoengineering as the preferred alternative to greenhouse gas mitigation efforts, simultaneously downplaying the certainty of the risks posed by climate change and the risks of geoengineering.[367] Notably, Morris argues that geoengineering should be left to the private sector, rather than government control.[368]

David Schnare, senior environmental fellow at the Thomas Jefferson Institute (TJI), has advocated for geoengineering deployment.[369] Schnare has repeatedly argued that climate change does not pose a significant threat or, alternately, that it is too late to solve the problem.[370] TJI has received funding from the opaque Donors Trust and Donors Capital Fund, a pair of organizations that provide funding to numerous climate denial groups, as well as the Charles G. Koch Foundation.[371]

Schnare has advocated for geoengineering on several occasions,[372] but two notable moments were in 2007 and 2008. In 2007, Schnare testified before the US Senate Committee on Environment and Public Works regarding the effects of climate change on the Chesapeake Bay. In his testimony, he expressly advocated for geoengineering and conversely claimed that climate mitigation was the real threat to the bay.[373] In 2008, Schnare delivered a conference paper at the Heartland Institute's International Conference on Climate Change entitled *Climate Change and the Uncomfortable Middle Ground: The Geoengineering and "No Regrets" Policy Alternative*.[374] In his presentation at the Heartland Institute conference, Schnare argued for immediate solar geoengineering.[375] Again, even the most strident advocates of SRM research acknowledge that it is nowhere near ready for deployment at scale.

The following year, Lee Lane, co-director of the American Enterprise Institute's Geoengineering Project and lead author of the report on NASA's 2006 SRM workshop, testified to the US Congress in support of a program of geoengineering research.[376] Lane reiterated and amplified the economic messages from that workshop, arguing that SRM research was necessary because some nations considered measures to reduce GHG emissions not worth the cost.[377] AEI has been funded by Exxon, Amoco, Donors Capital Fund, and the Charles G. Koch Foundation,[378] has engaged in direct opposition to climate science,[379] and continues to oppose action on climate change.[380] Indeed, even as Lane completed NASA's workshop report in 2007, AEI and Exxon were caught offering a group of scientists $10,000 each to publicly dispute the findings of the latest IPCC report.[381]

From approximately 2008 to 2010, Lane and AEI advocated aggressively for research into and consideration of geoengineering.[382] In addition to his testimony before the US Congress, Lane hosted a conference on geoengineering[383] and authored several articles, book chapters, and other writings.[384] One of these papers, *An Analysis of Climate Engineering as a Response to Climate Change*, was produced for the climate-action-opposed Copenhagen Consensus Center (CCC)[385] and later incorporated into a book by CCC president Bjørn Lomborg.[386]

AEI's Geoengineering Project appears to have simply disappeared after 2010. While it is difficult to know exactly why, the change in the political context of the United States may offer an explanation. The event description for the June 2008 conference on geoengineering notes, "Congress is likely to enact federal climate legislation in 2009."[387] Another event, an AEI-sponsored discussion panel titled *Evaluating the Geoengineering Option* in February 2010, was framed as follows: "At a time when Congress prepares for a looming battle about the Environmental Protection Agency's plans to regulate greenhouse gases under the Clean Air Act, could geoengineering, also known as climate engineering, offer a better alternative?"[388] These descriptors make it clear that AEI was aware of the potential for climate regulation in the United States between 2008 and 2010. Notably, after 2010, when federal climate policy in the United States seemed unlikely to advance, the Geoengineering Project disappeared.

The influence of these think tanks, many of which actively deny the reality of climate science or oppose action on climate, should be understood as both a signal and a risk. As a signal, they make clear that those institutions that oppose action on climate, either for commercial or ideological reasons, likely see geoengineering as a diversion of public and political will. Moreover, because of the influence these organizations have, such promotion of geoengineering compounds the already problematic political and moral hazard risks of geoengineering research and deployment.

Evidence has already emerged that this concern is one that should be taken seriously. In 2008, Newt Gingrich, former Speaker of the US House of Representatives and fellow at the American Enterprise Institute,[389] cited AEI's work on geoengineering in his opposition to the Climate Security Act of 2007, which would have created a national cap-and-trade program for the United States.[390] More recently, at a hearing in November 2017, Representatives Lamar Smith and Randy Weber—both noted climate denialists—indicated their support for dedicated research into geoengineering as a climate solution.[391]

Most proponents of geoengineering research acknowledge the political and moral hazard risks of geoengineering and even acknowledge how these ideas can be used by those opposed to emissions reduction. Despite these acknowledgements, they continue to push for additional research and investment in the development of these techniques. Because these risks have real impacts on the debate over climate responses and climate policy, they cannot be lightly dismissed.[392]

PART 7

We Must and Can Stay Below 1.5°C without Geoengineering

The question thus arises: *Can we keep global temperature increase below 1.5°C without relying on geoengineering technologies?* A growing body of research suggests not only that the world must do precisely that, but that it *can*. Indeed, setting aside the false promise of geoengineering and focusing on accelerating the energy transition, is the safest, surest way to confront the climate crisis.

In its Special Report on 1.5 degrees, the IPCC cautioned explicitly and repeatedly regarding the inherent limitations and profound risks of relying on geoengineering approaches to solve the climate crisis.

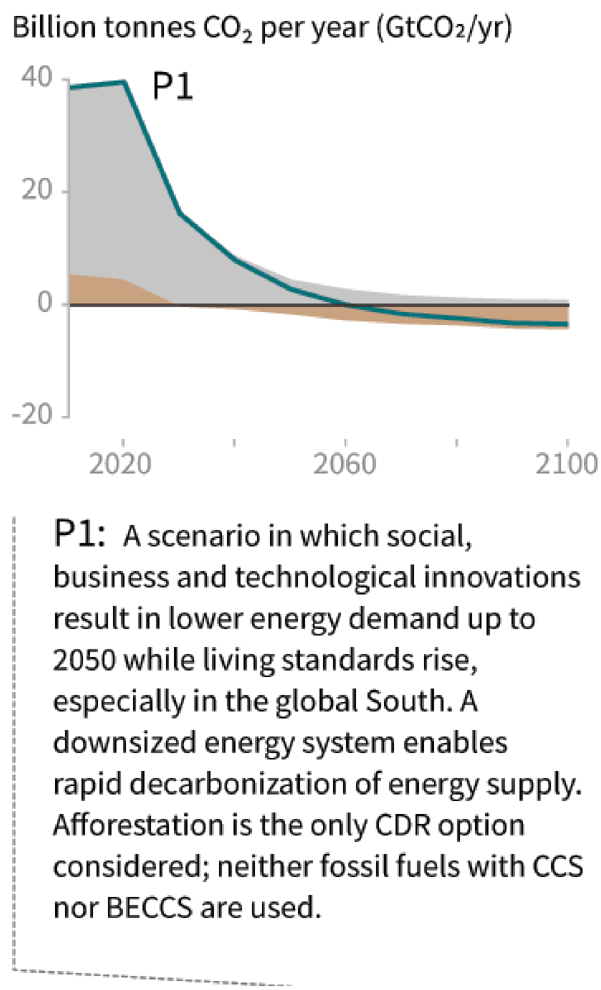
As noted by the IPCC, and discussed throughout this report, potential pathways with a high deployment of BECCS and other technological CDR methods include a high likelihood of exceeding (overshooting) the 1.5-degree limit, and rely on CDR to bring temperatures back down over long periods of time. With respect to those methods, the IPCC observed that:

> "Most CDR options face multiple feasibility constraints, which differ between options, limiting the potential for any single option to sustainably achieve the large-scale deployment required in the 1.5°C-consistent pathways described in Chapter 2 (high confidence)."[393]

The IPCC found the risks of relying on SRM greater still. Accordingly, it declined to incorporate SRM in any form into its modeled pathways to 1.5 degrees.

> "Uncertainties surrounding solar radiation modification (SRM) measures constrain their potential deployment. These uncertainties include: technological immaturity; limited physical understanding about their effectiveness to limit global warming; and a weak capacity to govern, legitimize, and scale such measures… Even in the uncertain case that the most adverse side-effects of SRM can be avoided, public resistance, ethical concerns and

FIGURE 20
IPCC Pathway 1 to 1.5°C



IPCC, *Summary for Policymakers*, in GLOBAL WARMING OF 1.5°C: AN IPCC SPECIAL REPORT ON THE IMPACTS OF GLOBAL WARMING OF 1.5°C 13 (V. Masson-Delmotte et al. eds., 2018), https://www.ipcc.ch/site/assets/uploads/sites/2/2018/07/SR15_SPM_version_stand_alone_LR.pdf.

potential impacts on sustainable development could render SRM economically, socially and institutionally undesirable."[394]

The IPCC nonetheless identified a pathway by which the world can stay below 1.5 degrees of warming while avoiding SRM, BECCS, DACS, and other speculative CDR technologies, and making more limited use of nature-based carbon reductions achieved through afforestation, reforestation, forest conservation, and land use.[395]

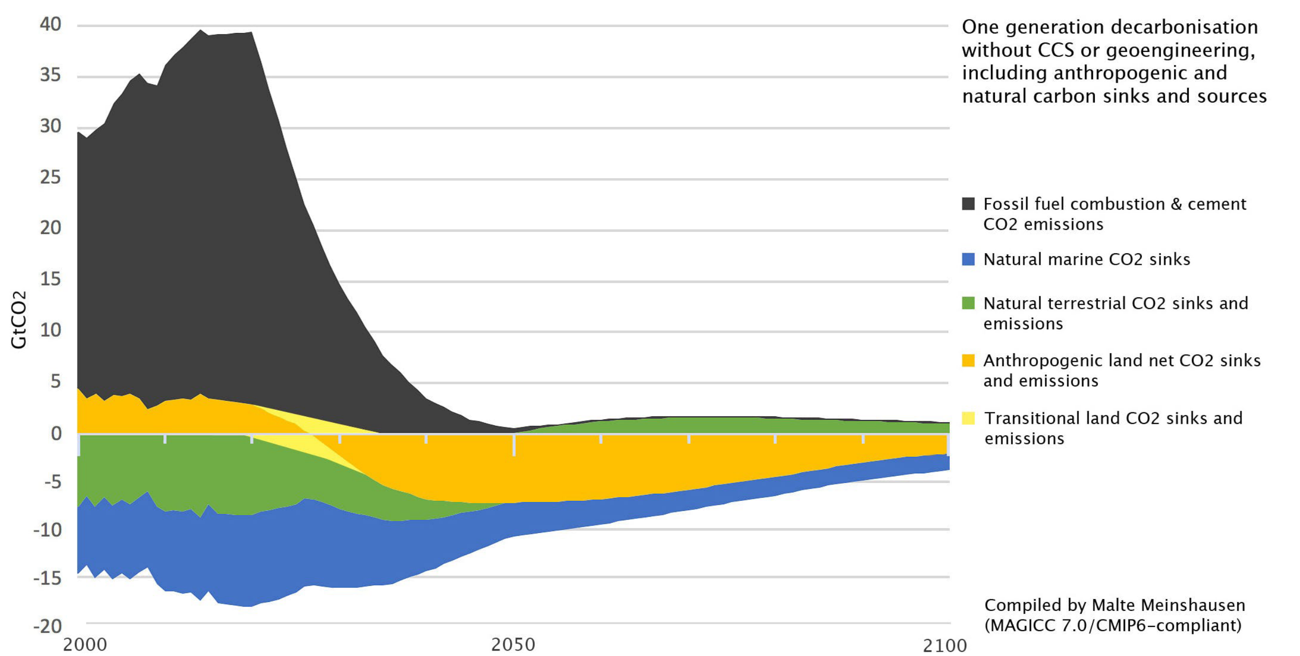
It found that the pathways with the highest likelihood of keeping warming to below 1.5 degrees relied on only limited deployments of CDR from natural sources.

"These are pathways with very low energy demand facilitating the rapid phase-out of fossil fuels and process emissions that exclude BECCS and CCS use and/or pathways with rapid shifts to sustainable food consumption freeing up sufficient land areas for afforestation and reforestation. Some pathways use neither BECCS nor afforestation but still rely on CDR through considerable net negative CO_2 emissions in the AFOLU sector around mid-century."[396]

Critically, these pathways place an early, heavy priority on reducing energy demand and rapidly phasing out fossil fuels.

A new analysis released in February 2019 demonstrates that this change is feasible. In *Achieving the Paris Climate Agreement Goals*, a group of twenty researchers led by Sven Teske released a first-of-its-kind model detailing the changes needed to achieve the climate targets of the Paris Agreement within sectors, within regions, and for the planet as a whole.[397] Affirming and amplifying the work of the IPCC, Teske and his co-authors conclude that realistic pathways exist to keep the world below 1.5 degrees without using CCS or geoengineering, but emphasize that staying within 1.5 degrees requires the virtually complete elimination of fossil fuel emissions and fossil fuel *infrastructure* by 2050. More specifically, global coal production must decline by 95% from 2015 levels by 2050, including the complete elimination of lignite. Natural gas production must be reduced by 94%, and oil must fall to less than 9% of current production.[398]

FIGURE 21
One Generation Decarbonization Without CCS or Geoengineering



SVEN TESKE, ACHIEVING THE PARIS CLIMATE AGREEMENT GOALS: GLOBAL AND REGIONAL 100% RENEWABLE ENERGY SCENARIOS WITH NON-ENERGY GHG PATHWAYS FOR +1.5°C AND +2°C (2019), https://www.springer.com/gb/about-springer/media/press-releases/corporate/achieving-the-paris-climate-agreement-goals/16443362.

Renewables are Eliminating the Rationale for Coal and Gas in Energy Generation

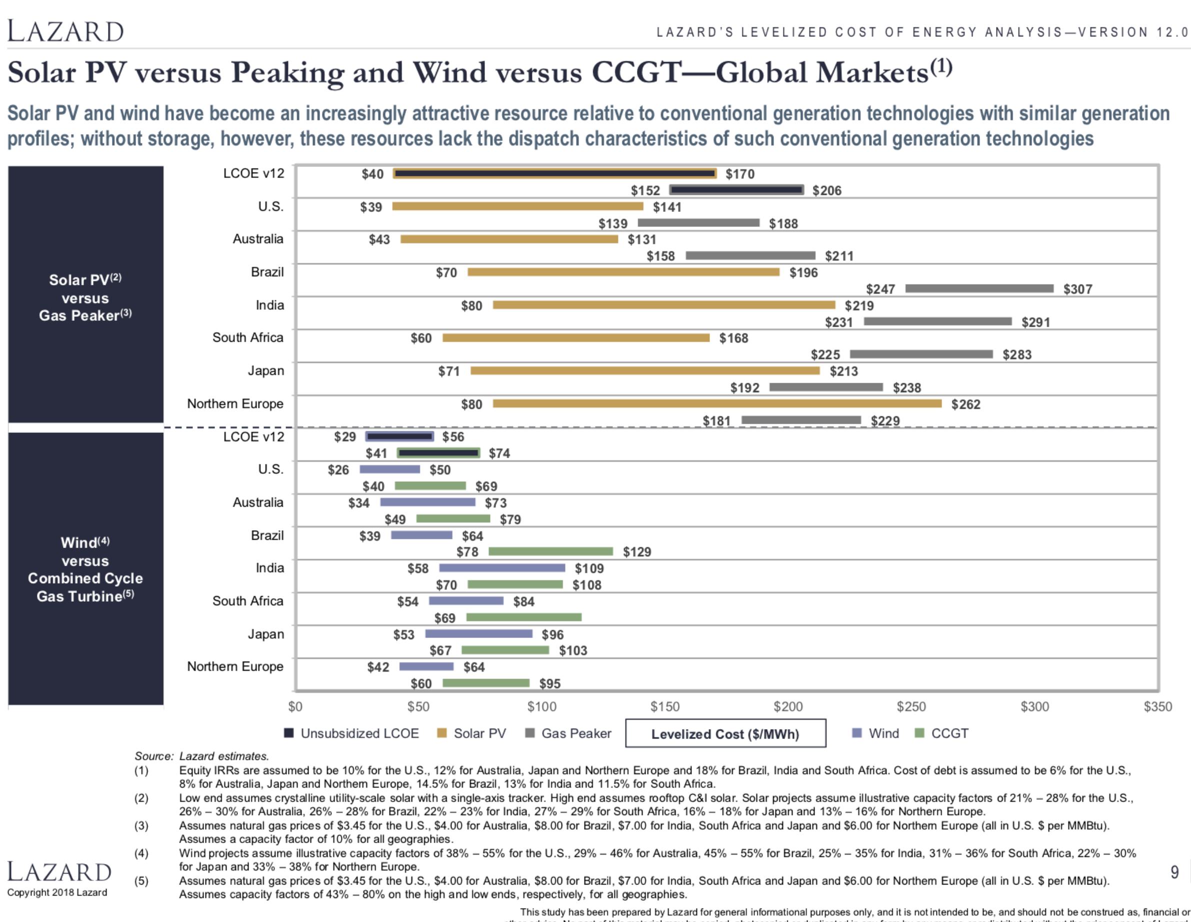
Transforming our economy at this speed and scale poses a profound challenge, but not an insurmountable one. However, the longer we delay the transition, the smaller the chance we have to avoid catastrophic warming.[399]

Provided we stop bringing new fossil fuel *infra*structure online now, our existing fossil fuel *infra*structure does not yet irreparably commit the world to 1.5 degrees of warming. As Christopher Smith and his co-authors noted in *Nature Communications*, "geophysics does not yet commit the world to a long term warming of > 1.5 C."[400] Immediate action provides a greater than 50% chance of staying below that limit if the world simply phases out existing fossil fuel *infra*structure at the end of its design lifetime.

Our technological capacity to make this transition is greater than is widely recognized. Over the last two decades, rapid declines in the costs of renewable technologies, particularly solar photovoltaics (PV) and wind, have made them increasingly cost competitive against fossil fuel *infra*structure around the world. A recent analysis by Carbon Tracker concluded that new wind and solar plants will be cheaper than 96% of existing coal-fired power plants globally by 2030.[401]

China is emblematic of this trend. China is both the largest consumer of coal-fired power and the global leader in renewable energy deployments. After an extended period in which renewable energy grew so quickly that it exceeded available subsidies, and in which deployment costs fell dramatically, China announced in January 2019 that it would remove the caps

FIGURE 22
Lazard Analysis Showing Wind and Solar PV are Cost Competitive with Natural Gas in Some Circumstances



Levelized Cost of Energy and Levelized Cost of Storage 2018, LAZARD (Nov. 8, 2018), https://www.lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2018/.

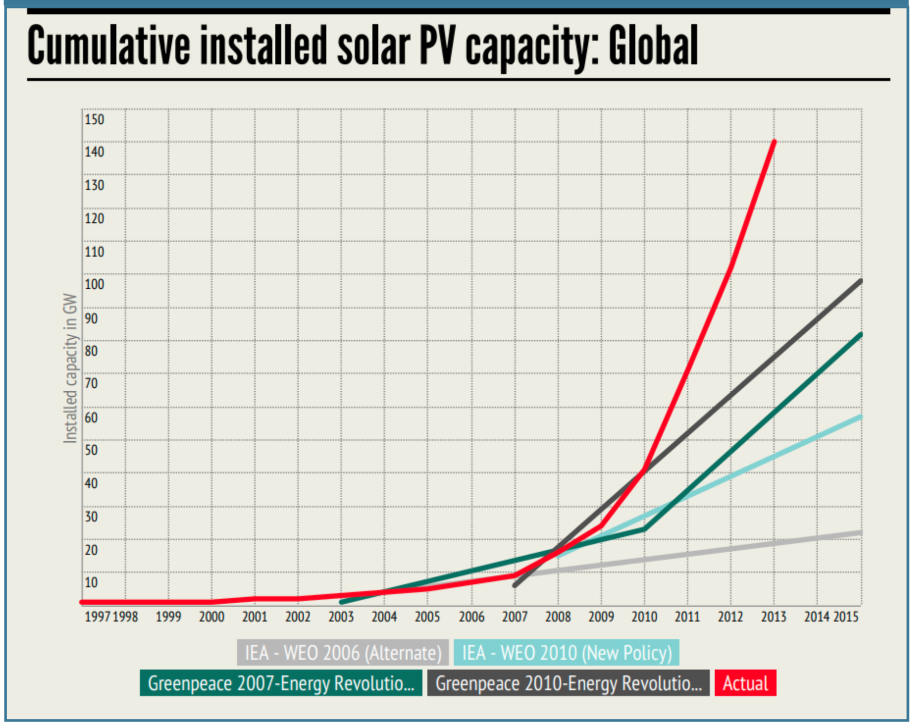
for deploying unsubsidized renewables nationwide. The news sent renewable energy stocks in the country soaring.[402] At the same time, this growth only increases the challenges to China's existing fleet of coal-fired power plants. A separate analysis by Carbon Tracker found that 40% of the country's coal-fired power stations are already losing money, and that this figure could rise to 95% by 2040. Carbon Tracker projects that it will be cheaper to build new wind farms than operate existing plants by 2021, and that a new solar PV installation could be cheaper than coal by 2025.[403]

India, the second largest builder of new coal plants after China, has also seen new coal plant builds stall at growing rates, as long-standing barriers to renewable energy deployments are eased.[404] In early 2019, the country announced plans to bid out 500 gigawatts (GW) of new renewable energy capacity by 2028, with the goal of adding 40 GW of non-hydro renewables per year.[405]

The economics of the energy transformation are increasingly affecting natural gas as well. In its most recent analysis of the levelized cost of energy (LCOE) of competing power generation technologies, global consulting firm Lazard concluded that both solar PV and wind have become an increasingly attractive resource relative to gas-fired power generation.[406] For example, solar PV installations had a lower LCOE than gas peaking plants across every region evaluated. Onshore wind was cheaper than or competitive with combined-cycle gas turbine plants across those same regions. While Lazard recognized that additional breakthroughs in storage technology were needed to fully replace fossil *infra*structure, recent years have witnessed precisely such breakthroughs.[407]

For example, a key rationale for continuing to rely on natural gas in the face of falling renewable energy prices is that natural gas can be dispatched quickly to respond to rapid changes in electricity demand. However, as the Center for International Environmental Law reported in a prior analysis, battery storage is increasingly performing the same function as quickly or more quickly.[408] As a result, deployments of grid-scale storage are accelerating.[409] In the US, the epicenter of the fracking boom for natural gas, this could render some 6 GW of new natural gas peakers unnecessary by 2027.[410]

FIGURE 23
Cumulative Installed Solar PV Capacity: Global



Infographic, Meister Consulting Group, The energy world is undergoing massive transformation (Mar. 2015), https://web.archive.org/web/20160413062109/http://www.mc-group.com/wp-content/uploads/2015/03/MCG-Renewable-Energy-Revolution-Infographic.pdf.

The Pace of Renewable Deployments Consistently Exceeds Official Forecasts

Over the long term, the potential capacity for energy production from renewable sources far exceeds projected global energy needs. As Teske observes, for example:

> "Various research projects have analysed renewable energy potentials and all have in common that the renewable energy potential exceeded the current and projected energy demands over the next decades by an order of magnitude."[411]

For at least two decades, however, energy experts have systematically underestimated the pace of innovation, cost reductions, and deployment for renewable energy and energy efficiency technologies. In 2015, Meister Consulting Group conducted a performance comparison of 15 separate long-term forecasts of renewable energy deployments by an array of institutions, corporations, and nonprofits.[412] Across the board, it found that long-term forecasts had underestimated the speed and scale of renewable energy deployments, often dramatically.

> "Over the past 15 years, a number of predictions—by the International Energy Agency, the US Energy Informa-

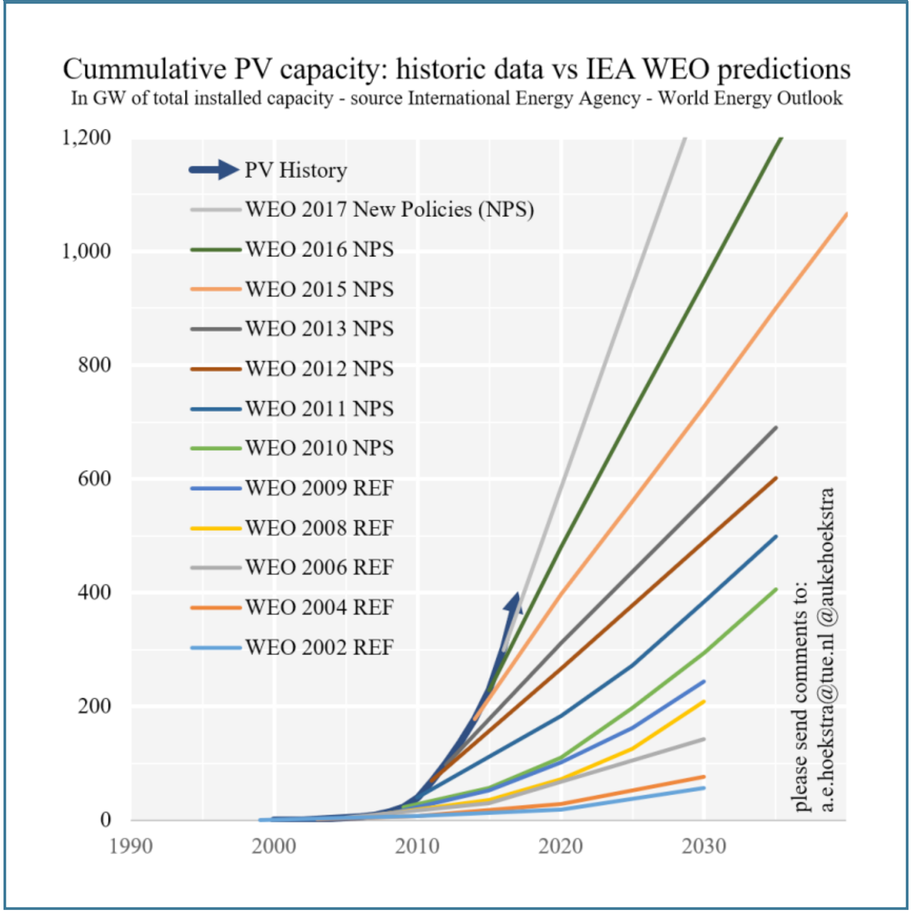
tion Administration, and others—have been made about the future of renewable energy growth. Almost every one of these predictions has underestimated the scale of actual growth experienced by the wind and solar markets. Only the most aggressive growth projections, such as Greenpeace's Energy[R]evolution scenarios, have been close to accurate."[413]

More tellingly, even Greenpeace had underestimated the speed of change with respect to both wind power and solar photovoltaics.[414] Since 2005, Greenpeace has released a series of *Energy Revolution* reports intended to present an ambitious but feasible vision for addressing climate change. In its 2007 scenario, Greenpeace projected the world would install 60 GW in solar photovoltaic capacity by 2013.[415] By 2010, Greenpeace had revised that 2013 projection dramatically upward to 75 GW of solar power.[416] As Meister noted, however, actual installed global capacity for solar PV reached 140 GW.[417] Actual deployments had more than doubled the most ambitious projection in the space of six years. The International Energy Agency, whose *World Energy Outlook* is the most widely used reference for global energy deployments, fared much worse, underestimating 2013 solar PV deployments by 600% in 2006 and by over 200% in 2010.[418]

In the ensuing years, renewable energy projections by both IEA and the US Energy Information Administration have continued to dramatically understate the actual pace of growth.[419] (See, for example, Figure 17.) In light of this continued failure to properly predict renewable energy growth, IPCC renewable energy scenarios built on the deeply pessimistic and demonstrably inaccurate assumptions of these bodies must be treated with profound skepticism.

The significance of these potential underestimates is even more striking when projections are evaluated over the longer time horizons relevant to meeting the 1.5-degree target.

FIGURE 24
Cumulative PV Capacity: Historic Data vs. IEA WEO Predictions



Auke Hoekstra, *Photovoltaic Growth: Reality Versus Projections of the International Energy Agency – With 2018 Update*, STEINBUCH (Nov. 19, 2018), https://steinbuch.wordpress.com/2017/06/12/photovoltaic-growth-reality-versus-projections-of-the-international-energy-agency/.

In 2007, Greenpeace estimated that the world might achieve 7,134 GW of installed renewable capacity by 2050.[420] By 2015, the *more conservative* of two Greenpeace scenarios projected the world would install nearly 7,800 GW by 2030, thus achieving a higher renewable target two decades sooner.[421] In the more ambitious scenario, Greenpeace projected that the world could achieve 100% renewable energy by 2050.[422]

Installed solar surpassed 390 GW by the end of 2017,[423] added another 98 to 109 GW in 2018, and is projected to add between 109 and 125 GW per year in 2019 and 2020, with growth continuing to accelerate over time.[424] Continued progress at this pace would help keep the world within a 2 degree target. To stay within 1.5 degrees, the pace of change will need to accelerate still further.

In arguments that have been widely discredited, some prominent geoengineering advocates have cautioned against such an expansion. (See Box 2: The Curious Case of Dr. Keith and the Wind Farms.)

The Energy Revolution in the Transport Sector Extends Far Beyond Cars

Even as the world increases its supply of renewable energy, however, it must dramatically reduce and ultimately eliminate CO_2 emissions from the transport sector. Proponents of inaction and of geoengineering alike have long argued that emissions caused by transportation will be far more difficult to eliminate because much of the transport sector poses range, weight, and energy density demands that battery electric technologies can't meet.

However, just as in the energy sector, the rate of technological development and the adoption of electric vehicles (EVs) are far outpacing past projections. As Teske observes, "Transport modelling has shown that the 2.0°C and 1.5°C pathways can be met when strong and determined measures are taken, starting immediately."[436] Therefore, in the 1.5-degree pathway outlined in *Achieving the Paris Climate Agreement Goals*, reliance on internal combustion engines declines with increasing speed after 2022, falls to roughly 10% by 2040, and gradually tapers out as legacy vehicles reach end of life.[437]

The accelerating research and deployment of EV technology for passenger cars is only the most visible sign of this revolution. By early 2018, every major car manufacturer in the world had announced significant investments in electric vehicle development and deployment, and several companies or sub-national jurisdictions had adopted phase-out dates for internal combustion engines.[438] By the end of 2018, China had placed more than a million electric vehicles on the road and announced new policy measures designed to further accelerate EV production.[439] In addition, dramatic sales of Tesla's Model 3 sedan, combined with the pending rapid rollout of other new EVs to global markets, led an oil industry investment analyst to caution that rules of fossil fuel demand growth long considered unchangeable are, in fact, changing:

> "That's 150,000 cars that don't consume gasoline. And it's not just Tesla. Porsche, Audi, and BMW are all coming out with all-electric vehicles in 2019. So the inelasticities of demand in this market are fundamentally changing."[440]

Critically, these advances extend well beyond cars to nearly every segment of the transport sector. India, the world's fourth largest producer of automobiles, has been comparatively slow in its advancement of electric cars[441] but is accelerating electrification of two-wheeled vehicles, which provide the primary route to mobility for the country's growing population.[442] China has deployed more than 400,000 electric buses to replace traditional and high-emitting diesel buses,[443] with 30 Chinese cities announcing plans to fully electrify their municipal transit by 2020.[444] Just a few years after the technology was ridiculed for lacking any viable market, electric buses account for 13% of global bus fleets and rising, and Bloomberg New Energy Finance projects that electric buses will be cheaper to own and operate than their diesel counterparts within the next two to three years.[445]

Medium- and heavy-duty freight vehicles are following a similar path, with early innovators in the electric truck space now racing against startups and global manufacturers alike to bring fleets of battery electric trucks to both long-haul and short-haul markets.[446] Given the heavy fuel demands and correspondingly high emissions from road transport, the comparatively short range requirements of most medium-duty freight vehicles, and the potential economies of scale associated with vehicle fleet operations, the potential for rapid deployment and early emissions reductions from this segment is particularly significant.

FIGURE 25

Rapid Decline of Internal Combustion Engines under 2°C and 1.5°C Scenarios

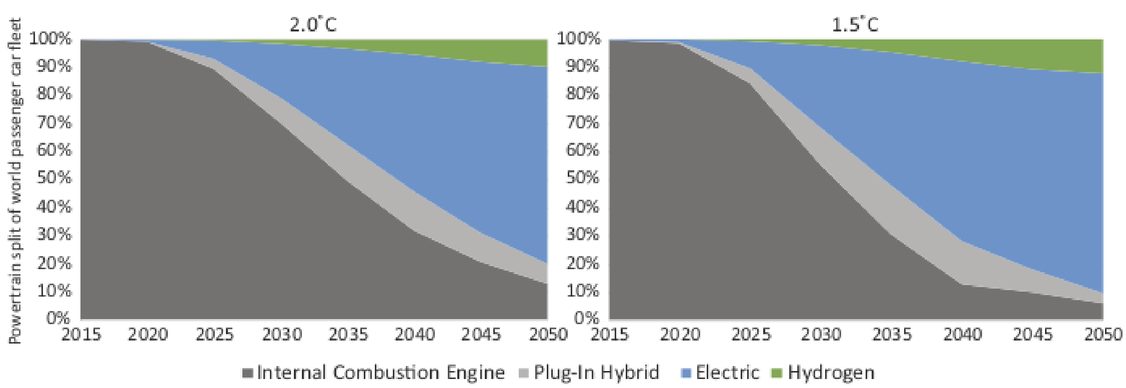


Fig. 3 Powertrain split of the world passenger car fleet in the 2 °C Scenario (left) and 1.5 °C Scenario (right)

Johannes Pagenkopf et al., *Transport Transition Concepts*, in SVEN TESKE, ACHIEVING THE PARIS CLIMATE AGREEMENT GOALS: GLOBAL AND REGIONAL 100% RENEWABLE ENERGY SCENARIOS WITH NON-ENERGY GHG PATHWAYS FOR +1.5°C AND +2°C (2019), https://www.springer.com/gb/about-springer/media/press-releases/corporate/achieving-the-paris-climate-agreement-goals/16443362, at 140 (Figure 6.10).

BOX 2

The Curious Case of Dr. Keith and the Wind Farms

In late 2018, Harvard Professors Lee Miller and David Keith published two papers on the power density of wind and solar power, the potential land requirements for meeting all or substantially all of a country's primary energy demand with wind or solar, and the potential environmental and social impacts of large-scale deployments. The first of these papers calculated the power densities for wind and solar installations, and argued that, because these power densities were low, deploying wind or solar at sufficient scale to meet a substantial portion of primary needs would exceed the available land in many countries. By way of example, the authors suggested that meeting 40% of Germany's energy needs with wind power would require that all of the country's land be dedicated to wind power.[425] The article met with a rapid and critical response from Stanford renewable energy expert Mark Jacobsen,[426] who noted that Miller and Keith had dramatically overestimated the land requirements of wind power—and thus its impacts on other land uses and the environment.[427]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In a second paper, published at the same time, Miller and Keith highlighted that turbulence caused by wind turbines creates temporary and highly localized temperature increases above wind installations. Remarkably, they extrapolated from this impact that the climate benefits of large-scale wind power might be substantially offset by these temperature increases.[428] In a Harvard University press release announcing the research, Keith opined, "The direct climate impacts of wind power are instant, while the benefits of reduced emissions accumulate slowly." Accordingly, he argued, "If your perspective is the next 10 years, wind power actually has—in some respects—more climate impact than coal or gas. If your perspective is the next thousand years, then wind power has enormously less climatic impact than coal or gas."[429] Renewable experts again debunked the findings.[430] In a frank and detailed rebuttal, Mark Jacobsen concluded that "these results are 100% wrong and should not be relied on to affect policy in any way."[431]

Notwithstanding such critiques, the Miller and Keith papers generated a flurry of stories in the popular media warning about wind power's potentially harmful impact on the climate.[432] One outlet that initially published and then revised its story on the research changed its headline to read: "A new study on the side effects of wind energy is almost begging to be misused by climate change deniers."[433] As predicted, the papers were welcomed by both geoengineering advocates and climate deniers alike.[434]

Neither the research papers, nor the Harvard press release announcing their publication, disclosed Keith's role as a leading advocate of solar radiation modification nor his personal financial stake in direct air capture, a technology that would be substantially less valuable in an economy that transitioned rapidly to renewable energy.[435]

Even in the most challenging transport segments, such as shipping, the drive to deploy battery electric technology is growing. Recognizing the tremendous potential cost savings of substituting electricity for diesel and marine fuels, the first battery electric cargo ships and ferries are now being deployed in Europe and Asia.[447] To date, these deployments have focused on coastal, intra-coastal, and river shipping, where shorter haul distances and access to shore facilities allow more frequent charging. These vessel categories account for a substantial portion of ship-borne freight in Europe and Asia, and, when battery technologies are deployed, have the potential to significantly reduce emissions from both shipping and road transport. For example, an electric cargo carrier currently under development in Norway will replace an estimated 40,000 heavy truck journeys per year.[448] In early 2019, global shipping leader Maersk also announced that it would begin deploying

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batteries to reduce fuel costs on ocean-going container vessels as early as 2020.[449]

Moreover, despite the stringent power and safety requirements of aircraft, EV technology is now in active development for use in private and commercial air operations.[450] Aircraft manufacturer Boeing and airline operator JetBlue have jointly invested in Zunum Aero, which plans to bring a hybrid-electric commuter plan to market by 2020.[451] British-based EasyJet plans to begin electric aircraft operations by 2030.[452] And Norway has announced plans for all short-haul flights originating in the country to be 100% electric by 2040.[453]

Low-Tech, Win-Win Approaches to Climate Mitigation and Carbon Removal are Ready to Be Scaled Up

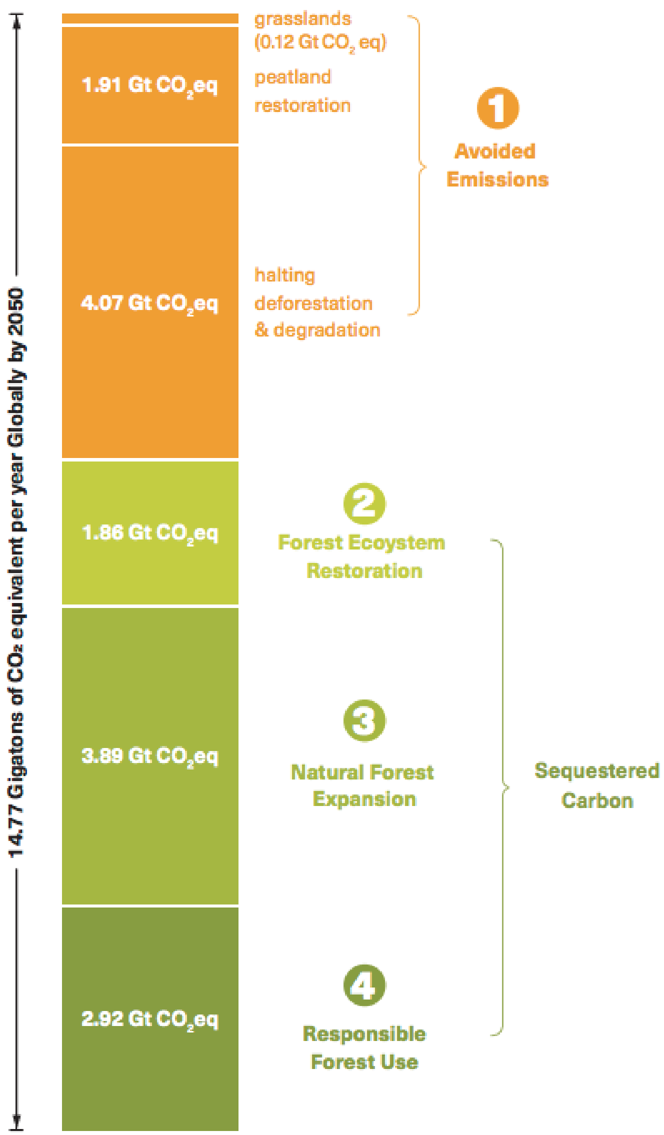
Even as it cautioned about the risks and uncertainties of BECCS, DACS, and other technological forms of carbon dioxide removal, the IPCC recognized the availability and potential benefits of more natural approaches to CDR. Among these are approaches for "the enhancement of terrestrial and coastal carbon storage in plants and soils such as afforestation and reforestation, soil carbon enhancement, and other conservation, restoration, and management options for natural and managed land, and coastal ecosystems."[454]

Some of these approaches, including those for afforestation and reforestation, pose both benefits and potentially significant risks for indigenous peoples, small-scale agriculture, and the environment depending on how and at what scale they are deployed. Others, however, offer significant potential for win-win scenarios that reduce atmospheric CO_2 while protecting the environment and improving the resilience of local communities. Im-

FIGURE 26
Mitigation Potential Across All Ecosystem-Based Pathways

FIGURE 2
Mitigation Potential Across All Ecosystem Based Pathways

Terrestrial ecosystems are key to climate mitigation. 1 Avoiding ecosystem conversion to other land-uses is the first priority to prevent CO_2 emissions entering the atmosphere. 2 Restoration of degraded natural forests increases and further protects existing carbon stocks. 3 Regeneration by allowing forests to regrow in recently forested areas delivers large sequestration potential. 4 Responsible use of forests requires reducing harvest, and using wood products more efficiently.



KATE DOOLEY ET AL., CLIMATE LAND AMBITION RIGHTS ALLIANCE, MISSING PATHWAYS TO 1.5C: THE ROLE OF THE LAND SECTOR IN AMBITIOUS CLIMATE ACTION (2018), https://www.climatelandambitionrightsalliance.org/report.

portantly, many of these win-win approaches could be implemented almost immediately, with relatively modest costs and a high likelihood of local and public support.

A 2018 study by the Climate Land Ambition and Rights Alliance (CLARA) examined in detail the risks, benefits, scalability, and potential impact of these approaches.[455] While recognizing and emphasizing the risks of BECCS, plantation forestry, biofuel production, and other large-scale monocultures, the CLARA study identified a wide range of policy tools that could store or draw down atmospheric CO_2 while simultaneously addressing needs for adaptation, food security, access to fresh water, and community land rights. These win-win climate tools include:

- Protecting and restoring natural forests, peatlands, and grasslands;
- Restoring forest ecosystems by fostering natural regeneration and reforestation;
- Improving forest management practices to reduce emissions from existing forests;
- Applying agro-ecological principles to increase carbon uptake through agroforestry and conservation of agricultural soils;
- Addressing the climate impacts of livestock production; and
- Reducing meat consumption and food waste.[456]

Considered together, these achieve mitigation and carbon removals of nearly 15 gigatons per year by 2050. The authors of the CLARA report acknowledged that not all of these approaches can be deployed to the full potential of natural systems. For example, were natural forests to recover to their pre-industrial extent, the arable land available for food production or other human uses would be substantially reduced.[457] They noted, however, that adopting complementary strategies to reduce meat consumption and food waste could free up significant areas of

FIGURE 27
Land-Use Sequestration Pathways Showing Annual Sequestration Rates Over Time

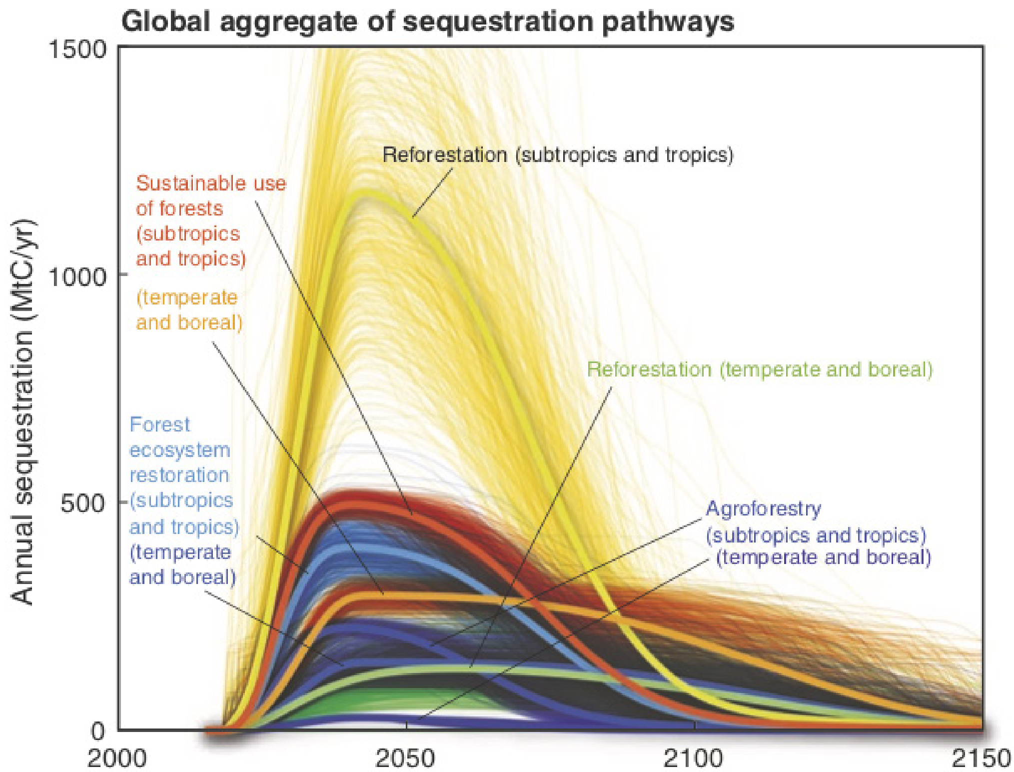


Fig. 4.1 Land-use sequestration pathways showing annual sequestration rates over time

Malte Meinshausen and Kate Dooley, *Mitigation Scenarios for Non-Energy GHG*, in SVEN TESKE, ACHIEVING THE PARIS CLIMATE AGREEMENT GOALS: GLOBAL AND REGIONAL 100% RENEWABLE ENERGY SCENARIOS WITH NON-ENERGY GHG PATHWAYS FOR +1.5°C AND +2°C (2019), https://www.springer.com/gb/about-springer/media/press-releases/corporate/achieving-the-paris-climate-agreement-goals/16443362, at 79-93.

land for recovery of natural ecosystems or for agroforestry.

Recognizing the important contribution of indigenous peoples and forest communities to meeting conservation and climate goals, the authors highlighted the critical need to address issues of land tenure and to fully respect and protect the control of indigenous peoples over their traditional territories as intrinsic elements of climate solutions.[458]

Kate Dooley of the University of Melbourne, one of two lead authors on the CLARA paper, further extended this analysis in a contribution to Teske's *Achieving the Paris Climate Agreement Goals*.[459] Dooley and co-author Malte Meinshausen noted that large-scale reforestation, particularly in the tropics and subtropics, had the largest potential to contribute to climate mitigation, with the second greatest gains coming from better protecting existing forests from illegal and unsustainable logging.[460] By setting aside a portion of existing, actively logged forests for ecosystem restoration, atmospheric carbon could be reduced while simultaneously restoring ecosystem functions and increasing the resilience of natural biological communities.[461]

Taking the median of the pathways identified, the protection and restoration of natural forests and agricultural soils has the theoretical potential to store nearly 152 gigatons of carbon by 2150, an amount equal to all historic emissions from land use.[462] The many benefits of this approach would include increased biodiversity protection, reduced erosion, improved climates at the local scale, and reductions in air pollution.

As the CLARA report cautioned, however, these figures represent only the theoretical potential of land-based strategies, and the levels of achievable storage and carbon removal would likely be much lower once competing needs for food security and land tenure are taken into account. Thus, the authors argue, land-use strategies should be adopted only as a complement to ambitious and aggressive mitigation efforts, including a rapid transition away from fossil fuels.

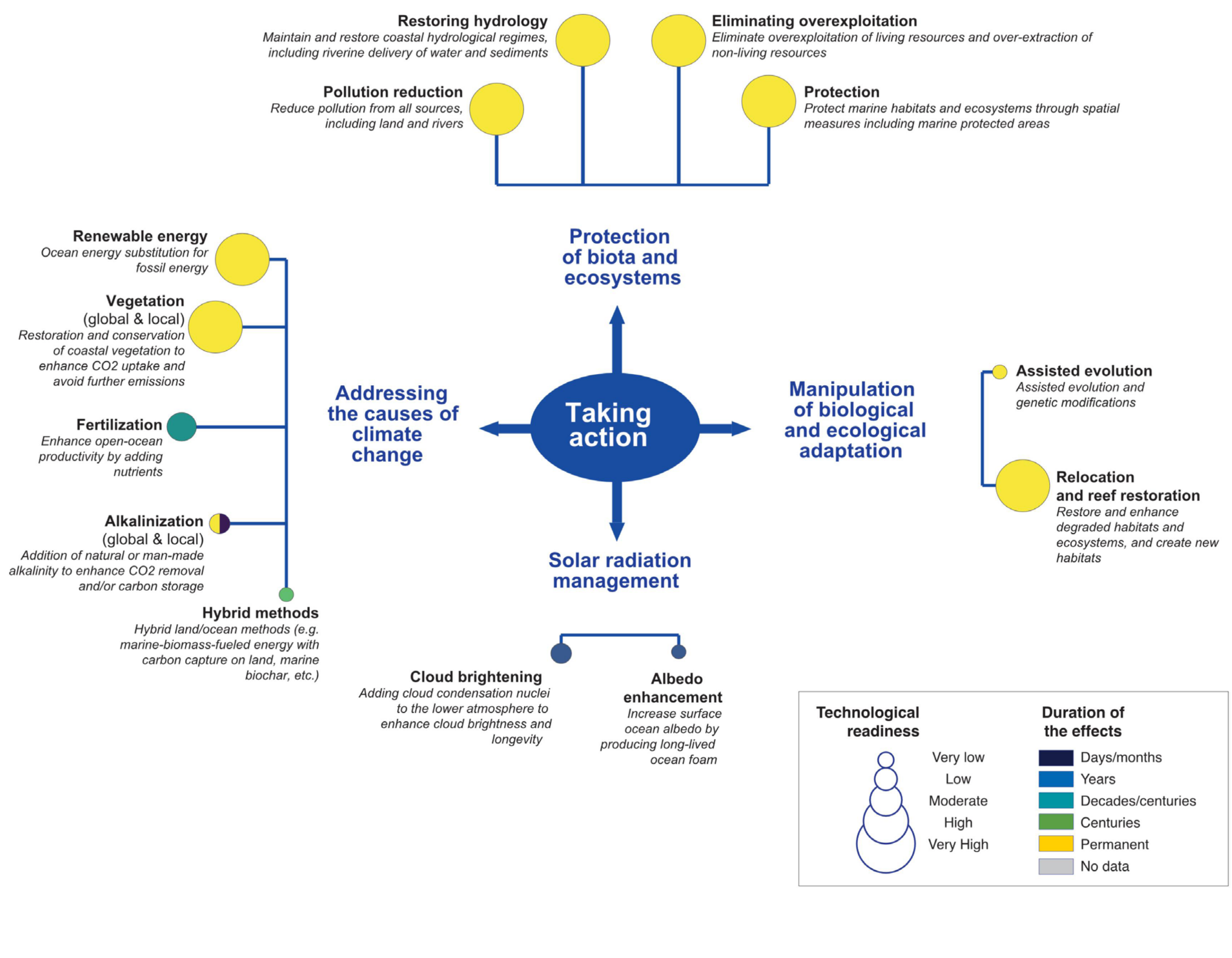
As Teske concluded, “the important result of this study is that the addition of land-use CO_2 and other GHG emission pathways to energy-related scenarios yields scenarios that stay below or get below 1.5 °C warming without a reliance on massive net negative CO_2 emission potentials towards the second half of this century.”[463]

A recent analytical survey of potential climate interventions in the world’s oceans reached similar conclusions, finding that an array of known and implementation-ready strategies have higher benefits and lower risks for climate, coastal communities, and marine ecosystems than strategies based on geoengineering.[464]

For the survey, a team of 17 researchers from leading universities and research institutes around the world reviewed 13 potential interventions in the world’s oceans that included both geoengineering technologies (cloud brightening, albedo enhancement, ocean fertilization, and alkalinization), deployment of renewable energies, adaptation, and more nature-

FIGURE 28

Comparison of 13 Potential Ocean-Based Climate Solutions



Jean-Pierre Gattuso et al., *Ocean Solutions to Address Climate Change and Its Effects on Marine Ecosystems*, 5 FRONTIERS IN MARINE SCI. (2018), https://www.frontiersin.org/articles/10.3389/fmars.2018.00337/full.

based strategies, such as restoring coastal ecosystems and vegetation, protecting habitats and species, and reducing pollution and overexploitation.

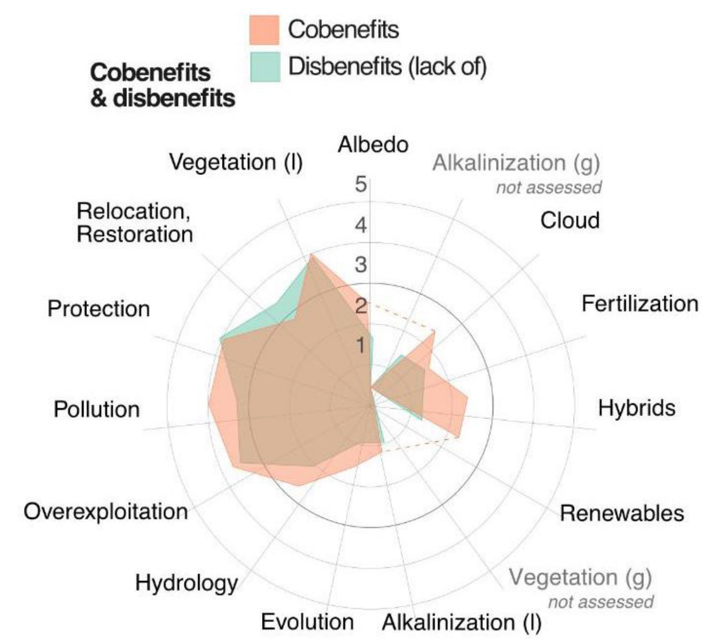
Potential interventions were evaluated based on their impact, duration, technological readiness, cobenefits, and absence of "disbenefits" (negative impacts).

Consistently, and as discussed in this report, geoengineering and similar technological interventions to climate impacts on the oceans were characterized by low to very low degrees of technical readiness, limited zones of potential positive impact, high risks of negative impacts, and few, if any, cobenefits. By contrast, strategies such as scaling up renewable energy, restoring and conserving coastal vegetation, and protecting biota and ecosystems from overexploitation, pollution, and habitat destruction have high to very high degrees of technological readiness, benefits that are permanent in duration, high levels of cobenefits, and a general absence of negative impacts.[465]

Taken together, these studies demonstrate that, while the early and rapid phase-out of fossil fuels is central to staying below 1.5 degrees, a wide array of feasible, technologically ready, and widely beneficial strategies exist to help address the climate crisis without relying on risky and uncertain geoengineering technologies.

FIGURE 29

Assessment of Cobenefits and Disbenefits of 13 Ocean-Based Climate Solutions



Jean-Pierre Gattuso et al., *Ocean Solutions to Address Climate Change and Its Effects on Marine Ecosystems*, 5 FRONTIERS IN MARINE SCI. (2018), https://www.frontiersin.org/articles/10.3389/fmars.2018.00337/full.

PART 8

Conclusions

After a century of early warnings and decades of relative inaction, the global community now faces an ultimatum: Act immediately to reduce global CO_2 emissions 45% by 2030 and to net zero by around 2050, or commit humanity and the earth to catastrophic levels of climate change. The window of opportunity is narrow and closing rapidly. Making the necessary reductions will demand an immediate and dramatic transition of our economy away from fossil fuels and toward cleaner, safer forms of energy.

Faced with the stark realities of climate change and a continued lack of ambition from major governments, a growing number of proponents argue that assuming the world can make the needed changes is naïve and dangerous, and that, accordingly, humanity must consider other options.

This report suggests a different conclusion: that the only feasible way to keep the world below 1.5 degrees is to rapidly transform our fossil economy. Drawing on the history, present landscape, and future prospects for geoengineering, this analysis demonstrates the numerous and dangerous ways in which geoengineering threatens to further entrench the fossil *infra*structure that drives climate change and to commit present and future generations to the compounded risks of both climate change and large-scale geoengineering.

Carbon Dioxide Removal is the Carbon (Fossil Fuel) Industry in Another Form

To a profound degree, the viability of strategies for carbon dioxide removal depends on the widespread, economical deployment of carbon capture and storage—and thus on the continued production of burnable fuels through enhanced oil recovery, enhanced coal bed methane, or fossil fuel substitutes produced from biofuels or direct air capture.

This dependence on and promotion of CCS would extend the lifetimes of existing coal and gas *infra*structure and promote the construction of new fossil *infra*structure, which would continue producing and burning fossil fuels for decades to come.

Direct air capture requires enormous energy inputs, consuming renewable energy that could otherwise be used to displace fossil-fueled power. Moreover, DAC is intended for use in the further production of liquid fuels or, like CCS, in enhanced oil recovery, creating powerful incentives to slow the transition away from internal combustion engines.

BECCS poses enormous risks to human rights, is fundamentally reliant on CCS, and may not be feasible or even emissions-negative at scale.

Meanwhile, enhanced weathering will only be viable—if at all—if it benefits coal-burning utilities and similar industries seeking to dispose of massive, toxic stockpiles of coal combustion waste and industrial slag.

Moreover, even as CDR technologies promote new oil and gas production, the prospect of future negative emissions enables major oil, gas, and coal producers to project the continued use of their products for decades to come, discouraging needed investments in cleaner, more viable alternatives.

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Solar Radiation Management is a Dangerous Distraction—and Simply Dangerous

Since at least the 1960s, human interference with the earth's radiation balance has been seen as a potential driver of future profits for fossil fuel producers and users. Since the beginning of the modern climate debate, these same companies have looked to geoengineering as a promising alternative to emissions reductions.

For at least three decades, the fossil fuel industry has argued that the prospect of solar radiation management and other forms of geoengineering justifies delaying or minimizing other actions to address climate change.

That perspective has been repeatedly echoed by other geoengineering proponents as well, who envision a future in which the world continues burning fossil fuels and actively controls the earth's radiation balance for decades or centuries to mask the resulting climate impacts.

Even the least speculative of these technologies pose profound and widely recognized risks to the climate, agriculture, and the environment—the consideration of which is routinely discounted or deferred by many advocates of SRM.

Whether open-air experiments could reduce the risks associated with particular technologies is uncertain. That such testing would provide a rationale for wider deployment of the technologies involved is likely. That geoengineering is more likely to compound the climate crisis than to alleviate it is clear.

Geoengineering Does Not Solve the Problem at the Heart of the Climate Crisis: Reliance on Fossil Fuels

The evidence outlined in this report points to a simple but essential truth: Almost all geoengineering proposals serve to entrench and benefit fossil fuel interests rather than solve the climate crisis. By promoting the development of new fossil fuels and costly fossil *infra*structure, by diverting resources away from proven mitigation strategies to costly boondoggles, and by sustaining the myth that meaningful climate action can be safely delayed or narrowly constrained, geoengineering threatens to undermine real solutions at the time when they are most urgently needed.

As this report demonstrates, the distraction of geoengineering is not simply dangerous; it is unnecessary. While most proposed approaches to CDR and SRM remain speculative, the technologies we need to reduce emissions, transform our economy, and confront the climate crisis are available, proven, and scalable.

Confronting the challenge of climate change is not a matter of future technology, but present political will and economic investment.

Elected officials, bureaucrats, activists, and the public are being forced to reckon with geoengineering, in part because of the severity of the crisis and in part because fossil fuel interests have helped usher geoengineering into the public debate. The global community now has to decide whether it will take the hard steps to rapidly and equitably transition its economies away from fossil fuels and into more sustainable systems, or whether it will bet on unproven, questionably effective, and dangerous technologies that serve the interests of the industry at the root of the climate crisis.

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FUEL TO THE FIRE

How Geoengineering Threatens to Entrench Fossil Fuels and Accelerate the Climate Crisis

Fuel to the Fire: How Geoengineering Threatens to Entrench Fossil Fuels and Accelerate the Climate Crisis investigates the early, ongoing, and often surprising role of the fossil fuel industry in developing, patenting, and promoting key geoengineering technologies. It examines how the most heavily promoted strategies for carbon dioxide removal and solar radiation modification depend on the continued production and combustion of carbon-intensive fuels for their viability. It analyzes how the hypothetical promise of future geoengineering is already being used by major fossil fuel producers to justify the continued production and use of oil, gas, and coal for decades to come. It exposes the stark contrast between the emerging narrative that geoengineering is a morally necessary adjunct to dramatic climate action, and the commercial arguments of key proponents that geoengineering is simply a way of avoiding or reducing the need for true systemic change, even as converging science and technologies demonstrate that shift is both urgently needed and increasingly feasible. Finally, it highlights the growing incoherence of advocating for reliance on speculative and risky geoengineering technologies in the face of mounting evidence that addressing the climate crisis is less about technology than about political will.

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