State Sequestration: Federal Policy Accelerates Carbon Storage, But Leaves Full Climate, Equity Protections to States

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ABSTRACT

The Intergovernmental Panel on Climate Change—the UN's expert science panel—has found that limiting climate change to prevent catastrophic harms will require at least some use of carbon capture and sequestration (CCS) unless the world rapidly shifts away from fossil fuels and reduces energy demand. There is significant uncertainty, however, about the level of lifecycle GHG reductions achievable in practice from varying CCS applications; some applications could even lead to net increases in emissions. In addition, a number of these applications create or maintain other harms, especially those related to fossil fuel extraction and use. For these reasons, many environmental justice advocates have strongly opposed the deployment of CCS applications. The recently-enacted Inflation Reduction Act (IRA) supercharges incentives for CCS, providing tax credits that bring CCS application near estimated costs of deployment. But neither the IRA nor other federal laws create a comprehensive framework to regulate CCS. Against this backdrop, U.S. states implementing climate policies will likely play a key role in determining whether and in what circumstances CCS is deployed in the U.S. This Article describes these state-federal dynamics and concludes by identifying climate and equity issues that "leadership' states should consider and potential legal tools that can be used to address those considerations.

I. INTRODUCTION

In the 2015 Paris Agreement, nations of the world agreed to limit global temperature increases to "well below 2°C above pre-industrial levels" and to "pursu[e] efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change."[1]

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[1] Paris Agreement to the United Nations Framework Convention on Climate Change, art. 2(1)(a), Dec. 12, 2015, T.I.A.S. No. 16-1104.

Human emissions of greenhouse gases (GHGs) have already caused approximately 1.1 degrees of global warming.[2] The warmest seven years on record have all occurred since 2015;[3] the earth has not seen equivalent temperatures for 125,000 years.[4] Exceeding 1.5 degrees of warming will most likely cause increases in hot temperature extremes as well as increases in heavy precipitation in some regions and drought in others, among other effects.[5] Above 2 degrees, impacts will be even more severe.[6] Exceeding even 1.5 degrees could also trigger "multiple climate tipping points," which are large changes to the climate system like collapsing ice sheets or the thawing of permafrost that can self-perpetuate warming trends independent of additional human action.[7]

According to the IPCC, CCS technologies will likely be necessary to limit warming to 2 or 1.5 degrees unless the world takes dramatic steps to reduce fossil-fuel use and energy demand in the near term.[8] In particular, CCS technologies will likely be needed as one tool to limit emissions from hard-to-decarbonize industries, such as steel and cement, and to reduce GHGs that are already in the atmosphere through use of "negative emissions" applications of CCS. They may also be useful in allowing continued use of fossil-fuel fired power plants with low GHG emissions,

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[2] Richard P. Allan et al., *IPCC, 2021: Summary for Policymakers*, *in Climate Change 2021: The Physical Science Basis*, Intergovernmental Panel on Climate Change (2021) [hereinafter *IPCC 2021 Physical Science*], https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf [https://perma.cc/7LMP-3SXZ].

[3] *2021 joins top 7 warmest years on record: WMO*, UN NEWS (Jan. 19, 2022), https://news.un.org/en/story/2022/01/1110022 [https://perma.cc/KNR9-5DKS].

[4] *IPCC 2021 Physical Science*, *supra* note 2, at 5.

[5] Myles Allen et al., *IPCC, 2018: Summary for Policymakers, in Global Warming of 1.5°C*, Intergovernmental Panel on Climate Change (2018) [hereinafter *IPCC 1.5 Rep. SPM*], http://www.ipcc.ch/report/sr15/ [https://perma.cc/97K4-U4CF].

[6] *IPCC 2021 Physical Science*, *supra* note 2, at 15–18.

[7] David I. Armstrong McKay et al., *Exceeding 1.5°C global warming could trigger multiple climate tipping points*, 377 SCIENCE 6611 (Sept. 9, 2022), http://www.science.org/doi/10.1126/science.abn7950 [https://perma.cc/C3RB-7L2Z].

[8] Jim Skea et al., *Climate Change 2022: Mitigation of Climate* Change, Intergovernmental Panel on Climate Change, TS-94 (2022) [hereinafter *IPCC Working Group III*], https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_FullReport.pdf [https://perma.cc/7EG9-VPJC]; Valérie Masson-Delmotte et al., *Global Warming of 1.5 ºC*, Intergovernmental Panel on Climate Change, at 3-7, 3-19 (2019) [hereinafter *IPCC 1.5 Rep. Full*], https://www.ipcc.ch/site/assets/uploads/sites/2/2022/06/SR15_Full_Report_HR.pdf [https://perma.cc/H22L-VNXD] (finding it "likely" that "limiting warming to 2°C or below involve[s] some amount of CDR" and that most likely CDR options are BECCS, DACCS, and afforestation; finding that in 1686 mitigation scenarios analyzed "there remains extensive use of both CDR and CCS in scenarios."); *see also* U.S. DEP'T. OF STATE & U.S. EXEC. OFF. OF THE PRESIDENT, THE LONG-TERM STRATEGY OF THE U.S.: PATHWAYS TO NET-ZERO GREENHOUSE GAS EMISSIONS BY 2050, at 1 (Nov. 2021) [hereinafter WH NET-ZERO PATHWAYS], https://www.whitehouse.gov/wp-content/uploads/2021/10/US-Long-Term-Strategy.pdf [https://perma.cc/FHU4-PADD].

in lowering the cradle-to-grave—or "lifecycle"—GHG emissions of oil and gas development, and in producing hydrogen (an energy carrier that does not directly emit GHGs as a result of combustion). President Joseph Biden's Administration has concluded that "to reach the President's ambitious climate goal of net-zero emissions economy-wide by 2050, the United States will likely have to capture, transport, and permanently sequester significant quantities of carbon dioxide."[9]

Yet CCS technologies have not been demonstrated at a broad scale, and there is significant uncertainty over the level of GHG emission reduction achievable in practice from certain applications on a lifecycle basis. Some applications could even lead to net *increases* in GHG emissions.[10] One of several factors in this uncertainty is that many CCS applications—including natural gas processing with CCS, enhanced oil recovery with CCS, and "blue" hydrogen production—rely on continued natural gas production, which results in relatively high levels of upstream methane emissions, a potent greenhouse gas. Moreover, CCS applications present other risks and uncertainties, including that high-pressure carbon dioxide (CO_2) transport and storage could result in pipeline ruptures (some of which have already occurred), contaminate soil and groundwater, or induce earthquakes.[11]

Many of these harms maintain or exacerbate historic patterns of environmental injustice that have disproportionately impacted communities of color and poor communities. Notably, many environmental justice advocates—including the White House Environmental Justice Advisory

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[9] White House Council on Env't Quality, CCS Guidance, 87 Fed. Reg. 8733, 8808-09 (notice of availability Feb. 16, 2022); *see also* WH NET-ZERO PATHWAYS, *supra* note 8, at 23, 29, 30, 46 (projecting reliance on various CCS applications).

[10] *See* Robert W. Howarth & Mark Z. Jacobson, *How green is blue hydrogen?*, 9 ENERGY SCI. & ENG'G. 1676, 1684 tbl. 2 (2021), https://onlinelibrary.wiley.com/ doi/abs/10.1002/ese3.956 [https://perma.cc/JN2U-CXR6] (finding that production of hydrogen from natural gas with CCS emits more GHG emissions than operating a combined cycle-natural gas power plant).

[11] Haroun Mahgerefteh, G. Denton & Yurii Rykov, *Pressurized CO_2 pipeline Rupture*, INST. CHEM. ENG'RS SYMP. SERIES 154, (2008); Hisham Eldardiry & Emad Habib, *Carbon capture and sequestration in power generation: review of impacts and opportunities for water sustainability*, 8 ENERGY, SUSTAINABILITY & SOC'Y 6, at 4 (2018), https://doi.org/10.1186/s13705-018-0146-3 [https://perma.cc/86U6-G7J7]; NAT'L ACADEMIES OF SCI'S, NEGATIVE EMISSIONS TECHNOLOGIES AND RELIABLE SEQUESTRATION: A RESEARCH AGENDA 337 (2019) [hereinafter NAS NEGATIVE EMISSIONS], https://nap.nationalacademies.org/catalog/25259/negative-emissions-technologies-and-reliable-sequestration-a-research-agenda [https://perma.cc/8J4S-UFQ6].

Council—have strongly opposed the deployment of CCS applications.[12] Environmental justice communities in Louisiana, New Mexico, and California opposed actions that promote CCS in those states, in part because of concerns that they will maintain or exacerbate harms related to oil and gas extraction or processing.[13]

In contrast, oil and gas companies are betting heavily on CCS to incorporate a potential climate solution into their business model.[14] Much of the technology and expertise used to sequester carbon is the same, or similar to, the technology used to extract oil and gas. In fact, the oil and gas industry developed much of the technology and processes for CCS by developing "enhanced oil recovery," which uses subsurface injection of CO_2 to increase production of oil in certain formations.[15]

CCS can also provide other important benefits, including providing a pathway for a "just transition" to fossil-fuel worker communities, reducing the number of "stranded assets," potentially reducing the overall costs of transition to low-carbon economy to the public, and reducing emissions of some co-pollutants.[16]

In short, while the IPCC assesses that some applications of CCS are necessary to limit climate change, there likely exist multiple pathways to limiting warming below 2 or 1.5 degrees with different degrees of dependence on CCS applications. At the same time, there are substantial uncertainties related to the overall effectiveness of different CCS applications, as well as significant potential risks and harms.

This assessment of the role of CCS in climate policy is important because this Article argues in Section V that the federal government has effectively supercharged CCS incentives without creating a comprehensive regulatory structure to address risks, uncertainties, and harms.

Recently, Congress passed the IRA, often referred to as the most significant climate legislation ever enacted in the U.S.[17] Because the bill

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[12] Jean Chemnick, *EJ communities are wary as CCS racks up policy wins*, E&E NEWS, (Sept. 7, 2022), https://www.eenews.net/articles/ej-communities-are-wary-as-ccs-racks-up-policy-wins/ [https://perma.cc/Z6VE-Z6EK].

[13] *See* discussion *infra* accompanying notes 233–35.

[14] *E.g. ExxonMobil announces corporate plans to 2027 – supports approximately doubling earnings and cash flow potential, reducing emissions*, EXXONMOBIL, NEWSROOM (Dec. 1, 2021), https://corporate.exxonmobil.com/news/newsroom/news-releases/2021/1201_exxonmobil-announces-plans-to-2027-doubling-earnings-and-cash-flow-potential-reducing-emissions [https://perma.cc/KQS3-JVJP]; *see also* Evan Halper, *How a pricey taxpayer gamble on carbon capture helps Big Oil*, WASH. POST, Oct. 14, 2022, https://www.washingtonpost.com/business/2022/10/09/carbon-capture-oil-gas/ [https://perma.cc/SLS4-XHBS].

[15] NAS NEGATIVE EMISSIONS, *supra* note 11, at 328.

[16] *See* discussion *infra* at Section IV.B.

[17] Pub. L. No. 117-169, § 13104; Candace Vahlsing, *New OMB Analysis: The Inflation Reduction Act Will Significantly Cut the Social Costs of Climate Change*, WHITE

was passed through the budget reconciliation process, however, it only included incentives for the deployment of climate technologies—it did not include new regulatory requirements.[18] One of the financial incentives included was a dramatic increase in tax credits for various CCS applications. These tax incentives likely bring CCS applications close to or beyond the level of economic viability. In 2022—the year that the IRA was enacted—61 new CCS projects were announced, a jump of 44 percent over the prior year.[19]

But while the IRA effectively supercharged financial incentives for CCS, the federal government has not created a complete regulatory regime for CCS projects. Existing federal regulations focus on protection of groundwater and GHG reporting requirements, though other environmental laws also apply.[20] Key gaps in federal regulations include a lack of standards for full lifecycle GHG emissions and siting protections for EJ communities, among others. The EPA has indicated that it lacks authority under existing laws to fill all of these gaps.[21]

Moreover, political analysts suggest that after the passage of the IRA, the political window for additional climate legislation may be closed for

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HOUSE WEBSITE, (Aug. 23, 2022), https://www.whitehouse.gov/omb/briefing-room/2022/08/23/new-omb-analysis-the-inflation-reduction-act-will-significantly-cut-the-social-costs-of-climate-change/#:~:text=The%20Inflation%20Reduction%20Act%20represents,a%20year%20in%20energy%20costs [https://perma.cc/RV6V-GPNE].

[18] *See* Sarah Binder, *Will the Democrats' big bill get past the hurdles of reconciliation?*, WASH. POST, Aug. 6, 2022, https://www.washingtonpost.com/politics/2022/08/06/senate-reconciliation-inflation-reduction-act/ [https://perma.cc/B8AB-QK6U].

[19] According to Global CCS Institute. *Carbon Capture Projects See Meteoric Growth in 2022*, YALE E360 (Oct. 17, 2022), https://e360.yale.edu/digest/carbon-capture-storage-ccs-growth [https://perma.cc/3NEZ-95X8].

[20] *See* discussion *infra* in Section V.

[21] For example, the EPA acknowledged in promulgating drinking water protections for geologic sequestration under the Safe Drinking Water Act (SDWA) that it did not have legal authority to address other aspects of CCS including the "capture and transport of CO_2" or the management of "human health and environmental risks other than drinking water endangerment." ANGELA C JONES, CONG. RSCH. SRVC., INJECTION AND GEOLOGIC SEQUESTRATION OF CARBON DIOXIDE: FEDERAL ROLE AND ISSUES FOR CONGRESS, No. R46192, at 17 (2020), https://crsreports.congress.gov/product/pdf/R/R46192 [https://perma.cc/3ECR-NPCN]; Federal Requirements Under the Underground Injection Control (UIC) Program for Carbon Dioxide (CO_2) Geological Sequestration (GS) Wells, 73 Fed. Reg. 43492 (proposed Jul. 25, 2008) (to be codified at 40 C.F.R. pt. 144 & 146); *but see* Proposed CEQ CCS Guidance, 73 Fed. Reg. 8808, 8809 (Feb. 16, 2022) ("the CEQ CCUS Report recognized that the Federal Government has an existing regulatory framework that is capable of safeguarding the environment, public health, and public safety as CCUS projects move forward.").

quite some time.[22] In other words, at the federal level, this partial regulation may be here to stay.

The result of all of this is that absent additional federal legislation, states will likely play a key role in determining whether, and to what degree, CCS projects will be deployed and what protections will be required. States generally have broad legal authority to address federal regulatory gaps through state climate policies.[23]

States may end up playing a role in CCS deployment that mirrors the early development of renewable energy. Federal tax credits set the stage by helping bring renewable energy projects closer to economic viability, and then state renewable energy mandates provided the policy driver necessary for large-scale deployment.[24] Notably, renewable energy policies drive deployment of renewables not only in blue states with clean energy mandates, but also in red states with abundant renewable resources where renewable projects were developed to sell into blue-state renewable energy markets.[25] California is a nascent example of this dynamic in the CCS context, as California's low-carbon fuel standard program is incentivizing the development of CCS for biofuel projects in midwestern states. Those CCS projects voluntarily meet California's standards so that they can sell into the California LCFS market.[26]

This Article articulates these dynamics and highlights the kinds of climate and equity policies states should consider with regards to CCS applications. Section II provides a summary of CCS technology. Because the climate benefits and uncertainties of CCS are central to state regulatory considerations, and because there does not exist a thorough overview of these issues in the legal literature, Section III provides such an overview. Section IV continues with an overview of non-climate drawbacks and benefits. Section V then provides an overview of the regulatory landscape, as well as federal and state incentives and state policies that may create an

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[22] *E.g.*, Rebecca Leber, *The US is closer than ever before to making major progress on the climate crisis*, VOX (Oct. 7, 2021), https://www.vox.com/22685920/democrats-infrastructure-build-back-better-climate-change [https://perma.cc/LKZ3-5RZY].

[23] *See generally* Vicki Arroyo et al., *State Innovation on Climate Change: Reducing Emissions from Key Sectors While Preparing for a New Normal*, 10 HARV. L. & POL'Y REV. 385 (2016) (describing how states have led on climate policy in absence of federal action).

[24] *See id*. at 397–98.

[25] *See, e.g.,* Nichola Groom, *California demand for wind power energizes transmission firms*, REUTERS (Feb. 15, 2017), https://www.reuters.com/article/us-usa-wind-california-insight-idUSKBN15U0GJ [https://perma.cc/T373-UJJY] (escribing how California clean energy mandate drove development of large wind farm in Wyoming).

[26] *See* discussion *infra* at Section V.C.; *see also* Luke Geiver, *Adding Up CCS Revenue Streams*, ETHANOL PRODUCER MAG. (Aug. 17, 2022), https://ethanolproducer.com/articles/19491/adding-up-ccs-revenue-streams [https://perma.cc/Q5SM-2FPT].

additional market for CCS applications. Finally, Section VI concludes by briefly identifying climate and equity policy choices and legal tools that states may wish to consider with regards to CCS applications. These state policy tools include comprehensive planning processes to determine whether and how to use CCS as part of a climate solution. They can also include gathering input from affected communities (including environmental justice communities), setting rigorous lifecycle standards, requiring reductions in upstream emissions, requiring or incentivizing projects to reduce environmental justice harms, and sending revenue to impacted communities.

II. BACKGROUND: CARBON CAPTURE AND SEQUESTRATION

CCS technologies are those that capture CO_2 from some process or from the air, and then store or "sequester" that CO_2 in the "geosphere for geological time periods, *i.e.* thousands of years."[27] CCS is distinguished from carbon, capture, and *utilization* (CCU)—defined as "where carbon . . . is captured from one process and reused for another, reducing emissions from the initial process, but is then potentially but not necessarily released to the atmosphere in following processes."[28] To add to the confusion, some processes are defined as Carbon, Capture, Utilization, *and* Storage (CCUS). These processes both use the captured carbon for a productive endeavor and then store at least some of the carbon.[29]

This Article focuses on processes that geologically sequester carbon in ways that can reduce atmospheric concentrations of GHGs. This includes processes focused exclusively on carbon sequestration, and those that seek to use carbon for a productive purpose first but later result in some level of permanent sequestration. Because the focus of this Article is on permanent sequestration, all of these applications are referred to here as CCS applications; CCUS is treated as a subset of CCS applications. CCU applications that do not sequester carbon are omitted.

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[27] N.B. the "S" in CCS is referred to as either sequestration or storage, with no difference in meaning. This Article generally uses sequestration. *IPCC Working Group III*, *supra* note 8, at 11–35.

[28] *IPCC Working Group III*, *supra* note 8, at 11–35.

[29] *Carbon, Capture, Utilization, and Storage*, INT'L. ENERGY AGENCY, https://www.iea.org/fuels-and-technologies/carbon-capture-utilisation-and-storage [https://perma.cc/65YQ-2QEA] (last visited Mar. 13, 2023).

CCS applications first capture carbon dioxide from some industrial use or from the atmosphere; they then typically compress the carbon into a supercritical fluid; and finally inject the carbon fluid down a well into a porous geologic formation covered by an impermeable rock (a "reservoir seal").[30] "Once trapped below the seal the CO_2 is expected to remain sequestered permanently unless the CO_2 encounters a permeable fault or fracture in the seal or a leaky wellbore."[31]

Carbon can be captured from different sources—from the combustion of fossil-fuels in power plants and industrial sources like cement kilns, from other industrial processes like natural gas processing and fertilizer production, from the production of hydrogen, or even directly from the ambient air.[32] In some cases, captured carbon is used for other economically valuable processes—the CCUS described above—such as enhancing the recovery of oil, prior to being sequestered.[33]

In most uses, facilities will emit carbon together with other gases, and the carbon will need to be separated out and captured from this mixed-gas stream.[34] Companies and researchers have identified multiple different techniques that can be used to isolate and capture carbon. These techniques range from mature technologies to prototype processes.[35] For example, the now-closed Petra Nova coal-fired power plant—which was the first operational post-combustion CCS facility in the United States[36]—used a chemical absorption process, the most common capture technology.[37] In this process, flue gas containing CO_2 passes through a system where it chemically reacts with amine-based solvents.[38] The flue gas is depleted of CO_2 through the interaction with the solvents, and the CO_2-rich solvents are then processed to extract and capture the CO_2.[39] This chemical absorption process is one of the most mature technologies, and is also in use to capture carbon from industrial production and fuel transformation.[40]

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[30] NAS NEGATIVE EMISSIONS, *supra* note 11, at 319.

[31] *Id.*

[32] INT'L ENERGY AGENCY, ENERGY TECHNOLOGY PERSPECTIVES 2020: SPECIAL REPORT ON CARBON CAPTURE UTILISATION AND STORAGE: CCUS IN CLEAN ENERGY TRANSITIONS 19 (2020) [hereinafter IEA CCUS REP.], https://www.iea.org/reports/ccus-in-clean-energy-transitions [https://perma.cc/Q9RP-M2N3].

[33] *Id.*

[34] *Id.*

[35] IEA CCUS REP., *supra* note 32, at 95.

[36] Sonal Patel, *Capturing Carbon and Seizing Innovation: Petra Nova Is POWER's Plant of the Year*, POWER MAG., Aug. 1, 2017, https://www.powermag.com/capturing-carbon-and-seizing-innovation-petra-nova-is-powers-plant-of-the-year/ [https://perma.cc/VU2P-YQJW].

[37] *Id.*

[38] *Id.*

[39] *Id.*

[40] IEA CCUS REP., *supra* note 32, at 95, 98.

Other types of capture technologies include oxy-fuel separation, membrane separation, calcium looping, chemical looping, and direct separation.[41]

The second component of a CCS system is transporting the captured carbon to a geological sequestration site.[42] The chief methods for transport are through pipeline and ship.[43] Oil and gas producers have already developed an extensive CO_2 pipeline system in North America for the purpose of enhanced oil recovery.[44] Some analysts have also urged the reuse of existing natural gas pipelines for future CO_2 transport,[45] though there are a number of technical issues that would need to be resolved.[46] While ships have not yet been used for significant transport of CO_2, the technology is similar to mature technology used to transport liquid petroleum and natural gas.[47]

The third component of a CCS system includes injecting the CO_2 into a suitable geologic formation.[48] In most cases, CO_2 is first compressed into a supercritical condition before it is sequestered.[49] This compression decreases the volume of the CO_2 and provides it with the density of a liquid.[50] CO_2 condensed to a supercritical condition must be sequestered at depths below 2600 feet to maintain its supercritical state (and therefore maintain the volume benefits of compression).[51]

There are several different types of formations that may be suitable for permanent storage of CO_2, but the two types with the largest capacity are

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[41] *Id*. at 98–100.

[42] *See id*. at 103.

[43] Truck or rail could also be used, but at higher cost. *Id*.

[44] As of 2020, there was nearly 5000 miles of CO_2 pipeline, transporting over 70 megatons per year, in use in North America for the purpose of EOR. The vast majority of those were located in Texas, New Mexico and Colorado, and were transporting CO_2 for EOR in the Permian Basin. *Id*. at 103–05.

[45] *Id*. at 105–07.

[46] CO_2 is optimally transported at higher pressures than natural gas and older oil and gas pipelines may have corrosion issues. *Id*.

[47] *Id*. at 107 ("[O]nly around 1,000 tonnes of food quality CO_2 is shipped in Europe every year from large point sources to coastal distribution terminals.").

[48] *See id*. at 112.

[49] Supercritical CO_2 exists at temperatures more than 88 degrees Fahrenheit and pressures more than approximately 1,057 psi. DEREK VIKARA ET AL., NAT'L ENERGY TECH LAB'Y, DEPT. OF ENERGY, CO_2 LEAKAGE DURING EOR OPERATIONS – ANALOG STUDIES TO GEOLOGIC STORAGE OF CO_2 73 (2019) [hereinafter NETL EOR LEAKAGE REP.], https://www.netl.doe.gov/energy-analysis/details?id=AB4A73DA-5937-444C-855F-78E583EA58FE [https://perma.cc/4Z3W-558U] (last visited Aug. 16, 2022).

[50] *Id*.

[51] *Id*.; IEA CCUS REP., *supra* note 32, at 112.

deep saline formations and depleted oil and gas reservoirs.[52] Deep saline formations are porous formations filled with brine, or salty water, and can be found both on- and off-shore.[53] Depleted oil and gas reservoirs are porous rock formations—most often sandstone or carbonates—that previously held hydrocarbons for thousands to millions of years.[54] Because they have already trapped these liquids or gases, they are prime candidates for sequestering CO_2.[55]

Selecting an appropriate basin is potentially "the single-most important factor for secure and reliable CO_2 sequestration."[56] An appropriate site must have a reservoir large enough to accommodate at least 50-100 megatons of CO_2 and must be permeable enough to "accommodate injection at commercially meaningful rates."[57] Critically, the site must also have a reservoir seal—usually composed of shale—that will effectively prohibit CO_2 from escaping for over thousands of years.[58] Beyond these foundational features, other considerations include:

> [T]he absence of permeable faults and fractures penetrating the seal, a known and ideally low number of existing wells that could provide leakage pathways, favorable geomechanical conditions to avoid fracturing the reservoir or seal during injection, suitable conditions for monitoring, low likelihood of affecting groundwater, and compatibility with existing land and resource use.[59]

Depending on the site, the project may also use "secondary mechanisms" to ensure that the CO_2 is trapped in the formation and does not escape and contaminate groundwater or leak into the atmosphere. These mechanisms can include dissolution of CO_2 into brine (solubility trapping), immobilization

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[52] IEA CCUS REP., *supra* note 32, at 112, 114. Other types of potentially viable formations include un-mineable coal, basalt formations, and organic-rich shale basins. NAT'L ENERGY TECH. LAB'Y, U.S. DEP'T OF ENERGY, CARBON STORAGE ATLAS 9, 27, 29–30 (5th ed. 2015) [hereinafter CARBON STORAGE ATLAS], https://www.netl.doe.gov/coal/carbon-storage/strategic-program-support/natcarb-atlas [https://perma.cc/7DU9-2DQG].

[53] *Carbon Storage FAQs*, NAT'L ENERGY TECH. LAB'Y, https://www.netl.doe.gov/carbon-management/carbon-storage/faqs/carbon-storage-faqs [https://perma.cc/V6YC-SJYP] (last visited Aug. 15, 2022); IEA CCUS REP., *supra* note 32, at 112; EPA groundwater protection regulations prohibit sequestration in saline formations with less than 10,000 parts per million of dissolved solids to protect drinking water resources. 40 C.F.R § 144.3 (2010) (defining "underground source of drinking water"); Peter Kelemen et al., *An Overview of the Status and Challenges of CO_2 Storage in Minerals and Geological Formations*, 1 Front. Clim. 1, 5 (2019), https://www.frontiersin.org/articles/10.3389/fclim.2019.00009 [https://perma.cc/D3JE-X4WD].

[54] CARBON STORAGE ATLAS, *supra* note 52, at 25–26.

[55] CARBON STORAGE ATLAS, *supra* note 52, at 25–26.

[56] NAS NEGATIVE EMISSIONS, *supra* note 11, at 319.

[57] *Id.*

[58] *Id.* at 321.

[59] *Id.* at 321.

of the CO_2 by capillary forces (residual gas trapping), or mineralization through chemical interactions between the CO_2, brine, and rock.[60]

A recent study that conservatively modelled CO_2 storage in geologic reservoirs found a high likelihood that leakage levels would be low if subject to regulation.[61] "CO_2 storage in regions . . . that are regulated using current best practice will retain 98% of the injected CO_2 over 10,000 years in more than half of cases, and result in maximum leakage of 6.3% of the injected CO_2 in fewer than 5% of cases."[62] In contrast, the study found in its worst-case, "unregulated" scenario that in five percent of cases, up to 33 percent of sequestered CO_2 could leak.[63] Leakage in these worst-case scenarios typically occurs through improperly abandoned legacy wells.[64]

While the global amount of CO_2 storage capacity in geologic formations is uncertain, it is estimated to be very large and able to accommodate substantial sequestration in many regions.[65] For example, according to the International Energy Agency (IEA), even the lowest estimates of CO_2 technical storage capacity exceed the capacity that would be needed to achieve net zero emission in a scenario where CCS technologies play a large role.[66]

The United States is one of the global regions estimated to have among the largest capacities for geologic sequestration.[67] U.S. states conservatively

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[60] NAS NEGATIVE EMISSIONS, *supra* note 11, at 321–22.

[61] Juan Alcalde et al., *Estimating geological CO_2 storage security to deliver on climate mitigation*, 9 NATURE COMMC'N 2201 (2018), https://www.nature.com/articles/s41467-018-04423-1 [https://perma.cc/MS4B-SQAK].

[62] *Id.* at 9.

[63] *Id.*

[64] "This leakage is primarily through undetected and poorly abandoned legacy wells, and could be reduced through identification and remediation of leakage if a comprehensive site screening and monitoring program is deployed. Importantly, natural subsurface trapping mechanisms mean that this leakage will not continue indefinitely. Consequently, even with mitigation actions restricted solely to repair of abandoned wells that blow out, regions with a legacy of poorly regulated subsurface operations can reliably and robustly store and retain 78% of injected CO_2." *Id.*

[65] IEA CCUS REP., *supra* note 32, at 113; *IPCC Working Group III*, *supra* note 8, at 6–36 (Even if usable capacity is assumed to be an order of magnitude less than theoretical potential, it is "still more than the CO_2 storage requirement through 2100 to limit temperature change to 1.5 C").

[66] IEA CCUS REP., *supra* note 32, at 14, 114 ("Even the lowest estimates of global storage capacity of around 8,000 Gt far exceeds the 220 Gt of CO_2 that is stored over the period 2020-70 in the Sustainable Development Scenario.").

[67] *IPCC Working Group III*, *supra* note 8, at 6–37; *see* tbl. 6.2.

estimated to have over 15 gigatons of sequestration capacity include: Alabama, California, Colorado, Florida, Georgia, Illinois, Indiana, Kentucky, Michigan, Mississippi, Montana, Nebraska, New Mexico, North Dakota, Oklahoma, Pennsylvania, South Carolina, Texas, Utah, Washington, West Virginia, and Wyoming.[68] In addition, analysts estimate a substantial amount of offshore sequestration capacity existing in U.S. waters.[69]

Because geologic sequestration needs to be virtually permanent to serve as a climate change solution, a final and critical step in the CCS system is monitoring the site for long periods of time to ensure the project is performing as designed.[70] Long-term monitoring is a requirement of several regulatory, incentive, and market programs—including the EPA's underground injection control program for CO_2 sequestration and California's CCS protocol,[71] both described in more detail below.[72] CCS projects need to also be governed by an effective liability and long-term management scheme to ensure their long-term integrity.[73]

The oil and gas industry has been sequestering CO_2 for enhanced oil recovery (EOR) since the 1970s—often referred to as CO_2-EOR.[74] Based on this experience, the capture of CO_2 from natural gas processing, long-distance transport in pipelines, and injection for the purposes of EOR are considered "mature" technologies by the IEA.[75] Other technologies, such as chemical absorption from coal-fired power generation; hydrogen production from natural gas; compression of CO_2 from bioethanol production; and CO_2 storage in saline aquifers are analyzed to be in the "early adoption"

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[68] Alabama, Florida, Georgia, Louisiana, Mississippi, and Wyoming are conservatively estimated to have between 100 and 200 gigatons of storage, and Texas nearly 500. CARBON STORAGE ATLAS, *supra* note 52, at 110–11 (low estimate, total storage resources).

[69] *Id*.

[70] NAS NEGATIVE EMISSIONS, *supra* note 11, at 325.

[71] 40 C.F.R. § 146.90; CAL. AIR RES. BD., CARBON CAPTURE AND SEQUESTRATION PROTOCOL UNDER THE LOW CARBON FUEL STANDARD (Aug. 13, 2018) [hereinafter Cal. LCFS CCS Protocol], https://ww2.arb.ca.gov/resources/documents/carbon-capture-and-sequestration-protocol-under-low-carbon-fuel-standard [https://perma.cc/U79X-YQHZ].

[72] *See* Cal. LCFS CCS Protocol, *supra* note 71, at Section C.

[73] *See* NETL EOR LEAKAGE REP., *supra* note 49, at 89. EOR described in more detail *infra* at Section III.A.

[74] NAS NEGATIVE EMISSIONS, *supra* note 11, at 328. Other industrial analogs that provide useful experience with similar processes include subsurface natural gas storage (which has been practiced for over 100 years) and the injection and disposal of hazardous and non-hazardous wastes (like municipal and industrial wastewater) into deep confined rock formations. NETL EOR LEAKAGE REP., *supra* note 49.

[75] Under the definition created by U.S. National Aeronautics and Space Administration (NASA), mature technologies are those that "have reached sizeable deployment and for which only incremental innovations are expected." The IEA also analyzes that chemical absorption of CO_2 from ammonia production is a mature technology. IEA CCUS REP., *supra* note 32, at 93–96.

phase.[76] Still other CCS applications like direct air capture and CO_2 capture from cement and iron and steel making, "are still at the demonstration or prototype stage," denoting less mature phases of technology.[77]

But even though certain component pathways are considered mature, this is generally true for the purpose of producing oil—not for projects that are specifically intended to permanently sequester CO_2 as a climate strategy.[78] While there are more than 134,000 EOR wells injecting CO_2 in the United States,[79] there have only been five commercial-scale sequestration projects in saline aquifers whose purpose was long-term sequestration of CO_2.[80] EOR projects are similar to permanent sequestration projects in many respects, but also have significant differences. Only about 20 percent of the CO_2 used for EOR is captured from anthropogenic sources such as processing plants or power plants—the majority of CO_2 used for EOR comes from naturally occurring underground reservoirs.[81] Because CO_2 is a valuable commodity in EOR projects, and because the goal of EOR is to maximize oil production, producers seek to "*minimize* the amount of CO_2 left in the reservoir."[82] According to a DOE study, the production process generally results in sequestration of approximately 30 to 40 percent of CO_2 used to produce a given well.[83] Perhaps most importantly, EOR with CO_2 injection is not subject to rigorous monitoring requirements to ensure that sequestration is permanent.[84] EPA regulations do require some monitoring of EOR wells, but the regulations are

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[76] *Id.* at 94, 96.

[77] *Id.* at 96.

[78] NETL EOR LEAKAGE REP., *supra* note 49, at 70 ("Although the technologies pertaining to each component of the CCS value chain . . . are at various stages of maturity, and in some cases, they have been separately proved and deployed at commercial scales . . ., fully-integrated CCS systems are still considered costly and not entirely matured.").

[79] CONG. RSCH. SERV., CO_2 UNDERGROUND INJECTION SELECTED DIFFERENCES FOR ENHANCED OIL RECOVERY AND GEOLOGIC SEQUESTRATION 1 (2020) [hereinafter CRS, EOR AND SEQUESTRATION DIFFERENCES], https://crsreports.congress.gov/product/pdf/IF/IF11578 [https://perma.cc/VWC9-F3CK].

[80] As of 2019, NAS NEGATIVE EMISSIONS, *supra* note 11, at 329–30.

[81] CRS EOR and Sequestration Differences, *supra* note 79, at 1.

[82] NETL EOR LEAKAGE REP., *supra* note 49, at 7.

[83] NETL EOR LEAKAGE REP., *supra* note 49, at 17 (this amount–sometimes referred to as "incidental storage"–is sequestered because it is no longer economical to continue trying to produce the well).

[84] *Compare* 40 C.F.R. § 146.23 *with* 40 C.F.R. §§ 146.90–95; CRS EOR and Sequestration Differences, *supra* note 79, at 2; NETL EOR LEAKAGE REP., *supra* note 49, at 9, 34–36 ("minimal monitoring required" vs. "extensive monitoring and financial responsibility requirements.").

designed to prevent contamination of ground water, not to prevent leakage to the surface.[85]

In 2019 the National Academies of Science (NAS) published a report setting forth a "research agenda" for various negative emission technologies, including geologic sequestration.[86] With regard to geologic sequestration, the NAS found that "[s]caling up global CO_2 sequestration in deep sedimentary formations to 5-10 [gigatons per year] CO_2 [equivalent] is an enormous task that requires research to ensure its secure and reliable implementation."[87] The study further found that the increased scale of deployment in particular will require "better information to assess risks, select sites, and provide assurances of their safety and effectiveness."[88] It also identified a number of specific topics that would require further research related to the long-term effectiveness of permanent geologic storage and associated risks, including: increasing the effectiveness of site characterization and selection methods; improving confidence in secondary trapping mechanisms and accelerating their trapping speed; assessing and managing risk in compromised sequestration systems; improving monitoring and lowering costs for monitoring and verification; and quantifying and managing the risks of induced seismicity.[89]

In short, the oil and gas industry has been sequestering CO_2 for about half a century as a technique to extract oil, and many components of CCS technology have been proven through this experience. At the same time, CCS as a component of enhanced oil recovery has been focused on efficiently promoting the extraction of oil—not on permanently sequestering large amounts of CO_2 to remove GHGs from the atmosphere. For these permanent sequestration applications at large scales, some elements of these technologies require further research to ensure safety and effectiveness when deployed at scale, including those related to ensuring permanent sequestration, and assessing and mitigating risk.

III. THE POTENTIAL FOR CLIMATE MITIGATION OF VARIOUS CCS APPLICATIONS

Many industrial applications have the potential to reduce GHG emissions through CCS. They include adding CCS to existing or new power plants and industrial facilities, enhanced oil recovery, "blue" hydrogen production, direct air capture, and "bio-energy" with CCS. These applications all hold

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[85] CRS EOR and Sequestration Differences, *supra* note 79, at 2.

[86] As described below, geologic sequestration of CO_2 may lead to negative emissions depending on the specific process.

[87] NAS NEGATIVE EMISSIONS, *supra* note 11, at 336.

[88] *Id.*

[89] *Id.* at 336–47.

different degrees of promise and uncertainty regarding net GHG reduction, and they can also create different challenges. Because these uncertainties go to the heart of the value of CCS as a climate strategy, and because there is a lack of a comprehensive overview of these uncertainties in the legal literature, this section provides such an overview.

For the purpose of this Article, the level of "GHG reduction benefit" refers to a "cradle-to-grave" lifecycle analysis (abbreviated in the technical literature to "LCA"). Lifecycle analyses seek to identify the net greenhouse gas emissions that result from the production of a good or service.[90] Lifecycle analyses can have different "boundaries" and assumptions: a lifecycle analysis can narrowly focus on the "gate-to-gate" emissions at a specific industrial facility, or it can broadly consider emissions from all of the "cradle-to-grave" inputs and outputs of a process.[91] For example, for the production of a kilowatt hour of electricity generated by a coal-fired power plant, a cradle-to-grave analysis would involve estimating the GHG emission associated with extracting the coal, with transporting it to the power plant, with processing it into fuel, and with combusting it to ultimately create electric energy.[92] When CCS is added to the equation, the quantity of CO_2 permanently sequestered is subtracted from the GHG emission resulting from all these processes.[93] Indirect effects are also considered—for example, if a process relies on growing corn for fuel, the lifecycle process generally considers whether the land used for growing fuel-corn might indirectly result in additional deforestation elsewhere around the world, removing carbon sinks.

Lifecycle analyses are complicated. There is an international standard for how to conduct such analyses,[94] yet outcomes vary dramatically based on assumptions used and how the "boundaries" are defined.[95] This Article

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[90] *Lifecycle Analysis of Greenhouse Gas Emissions under the Renewable Fuel Standard*, U.S. ENV'T PROT. AGENCY, https://www.epa.gov/renewable-fuel-standard-program/lifecycle-analysis-greenhouse-gas-emissions-under-renewable-fuel [https://perma.cc/9QCA-CPRG] (last visited Sept. 15, 2022).

[91] Gregory Cooney et al., *Evaluating the Climate Benefits of CO_2-Enhanced Oil Recovery Using Life Cycle Analysis*, 49 ENV'T. SCI. TECH. 7491, 7493 (2015), https://doi.org/10.1021/acs.est.5b00700 [https://perma.cc/P4T2-9UYV].

[92] *Cf.*, *id.*

[93] *See id.*

[94] *ISO 14044:2006: Environmental management—Life cycle assessment—Requirements and guidelines*, ISO, https://www.iso.org/cms/render/live/en/sites/isoorg/contents/data/standard/03/84/38498.html [https://perma.cc/8KAE-YPC9] (last visited Sept. 15, 2022).

[95] Cooney et al., *supra* note 91, at 7493.

summarizes what is known about the "cradle-to-grave" lifecycle emissions of various CCS applications, taking into account net emissions starting from production of raw materials (e.g., extraction of fossil fuels) to the end use of any product (e.g., combustion of oil produced through EOR).[96]

This section begins by first clarifying that EOR using naturally occurring CO_2—by far the most common form of EOR—does not provide any GHG reduction benefit on a lifecycle basis and is, therefore, not a climate policy. It then moves to a second category of policies that may provide some level of avoided or reduced GHG emissions from applications that are currently in use. These applications continue to emit some lifecycle GHG emissions and are, therefore, inconsistent with long-term GHG reduction needs, unless residual emissions are offset in some other way. They can, however, potentially serve as bridge applications in the medium term to help reduce emissions from current levels. Such strategies vary greatly in terms of their overall level of emissions reduction, cost, and non-climate impacts. The final category of policies holds potentially the most promise from a GHG perspective: negative emissions applications. Applications like BECCS and direct air capture can potentially sequester more greenhouse gas emissions than they emit and can therefore reduce the level of GHGs that already exist in the atmosphere. These applications are the least tested and have the most uncertainty. A final section sums up analyses about the potential roles of these different applications in limiting warming to 2 or 1.5 degrees.

A. No Climate Benefit: EOR with Naturally-Occurring CO_2

EOR is a technique used to increase the amount of oil that can be produced from a given oil field.[97] When an oil field is first brought into production, oil flows because of the naturally occurring pressure in the formation.[98] As oil is extracted, however, the volume diminishes, reducing flow rates.[99] A typical next phase is to inject water (or sometimes natural gas) to increase pressure in the reservoir. This "waterflooding" boosts production rates for a time, but eventually loses effectiveness.[100] EOR is one of several potential "third-phase" or tertiary techniques. Where conditions are appropriate, CO_2 is injected down an injection well in a supercritical state, where it mixes with oil that was not pushed out by the waterflooding; the

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[96] *Id.*

[97] NETL EOR LEAKAGE REP., *supra* note 49, at 12.

[98] NETL EOR LEAKAGE REP., *supra* note 49, at 12.

[99] *Id.*

[100] *Id.*

pressure of the CO_2 injection pushes the CO_2-oil mixture toward the production well.[101]

Most EOR projects in the United States use CO_2 that is naturally occurring underground.[102] For example, one major source of CO_2 for EOR in the Permian basin is New Mexico's Bravo Dome, where subterranean geologic processes produced CO_2 that became trapped in an underground sandstone layer.[103] This CO_2 is then extracted for use in EOR.[104]

Approximately 30 to 40 percent of the CO_2 used in the production of a given well will again be trapped underground once further production of the well is no longer economically viable.[105] Where the CO_2 was originally sourced from underground reservoirs, however, this "incidental storage" does not provide a climate benefit because the CO_2 used would not have otherwise been emitted into the atmosphere.[106] Without the EOR project, it would have remained in the ground and would not have had any climate-forcing effect on the atmosphere. In fact, oil produced with naturally occurring CO_2 is, on average, *more* GHG-intensive than average crude oil.[107] This is because EOR requires more energy on a lifecycle basis than other methods.[108] For this reason, EOR using naturally occurring subsurface CO_2 is not a climate strategy and is not further considered in this Article.

B. Some Climate Benefits: CCS Applications that Partially Reduce Emissions as Compared to Business-as-Usual Application

A second category of carbon sequestration applications are those that reduce or avoid GHG emissions through sequestration as compared to similar, non-CCS applications. There are many flavors of such strategies. Profiled here are some of the most discussed applications, including sequestration of CO_2 from post-combustion gases in fossil fuel-fired power plants and industrial sources, and CO_2 resulting from non-combustion industrial processes, including ammonia and natural gas processing. Two

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[101] NETL EOR LEAKAGE REP., *supra* note 49, at 12–14.
[102] CRS EOR and Sequestration Differences, *supra* note 79, at 1.
[103] NETL EOR LEAKAGE REP., *supra* note 49, at 22.
[104] NETL EOR LEAKAGE REP., *supra* note 49, at 88.
[105] *Id*. at 17.
[106] *See* Cooney et al., *supra* note 91, at 7492 ("The use of anthropogenic CO_2 for EOR would be necessary to realize a climate benefit based on the sequestration of that CO_2").
[107] Cooney et a., *supra* note 91, at 7497.
[108] *Id*.

special applications are also profiled below. The first is EOR with CCS, which is EOR using anthropogenic CO_2 to permanently sequester CO_2. This may reduce lifecycle emissions of oil and gas production, but it could potentially promote an unsustainable reliance on fossil fuels. The second special application is the production of "blue" hydrogen, which consists of using CO_2 to offset emissions from methane cracking to create an energy carrier that produces no combustion emissions but carries other risks.

1. Sequestration From Power Plants or Industrial Sources and Processes

Fossil-fuel power plants were, until recently, the largest source of GHG emissions in the United States;[109] energy and heat-generation combined represent the largest global sub-sector of GHG emissions.[110] The IPCC finds that limiting global warming to 2 degrees Celsius requires rapid and deep reductions in energy system emissions, and that net-zero energy systems will generally rely on "electricity systems that produce no net CO_2 or remove CO_2 from the atmosphere."[111] Yet fossil-fuel fired power plants are built to run for decades, and many have decades left of useful life, "effectively locking in their emissions unless they are modified in some way to emit less or are retired early."[112] These emissions are substantial. Scientists find that most pathways that limit warming to 2 degrees or less rely on substantial early retirements or retrofits with CCS.[113]

One potentially important reason for maintaining at least some fossil fuel-fired power plants with CCS is their ability to provide firm, dispatchable

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[109] U.S. ENV'T PROT. AGENCY, *Data Highlights: Inventory of U.S. Greenhouse Gas Emissions and Sinks:1990-2020*, at 3 (2022), https://www.epa.gov/system/files/documents/2022-04/us-ghg-inventory-1990-2020-data-highlights.pdf [https://perma.cc/RHT4-7W28].

[110] *IPCC Working Group III*, *supra* note 8, at 2–30.

[111] *IPCC Working Group III*, *supra* note 8, at 6–3.

[112] IEA CCUS REP., *supra* note 32, at 56; *see* IEA, The Role of CCUS in Low-Carbon Power Systems 36 (2020) [hereinafter CCUS in Low-Carbon Power Systems], https://iea.blob.core.windows.net/assets/ccdcb6b3-f6dd-4f9a-98c3-8366f4671427/The_role_of_CCUS_in_low-carbon_power_systems.pdf [https://perma.cc/2J4Z-DETS] ("the average age of coal-fired power plants in Asia is only 13 years old, and new plants continue to be built around the world, particularly in Asia (the average technical lifetime of a power plant is 50 years)").

[113] IEA CCUS REP., *supra* note 32, at 56–57 ("Cumulative emissions from existing industrial plants and power stations alone would reach more than 600 Gt by 2070 unless those assets are modified or repurposed in some way to emit less, or are retired early."); *IPCC Working Group III*, *supra* note 8, at 90, Box TS.8 ("Without early retirements, or reductions in utilization, the current fossil infrastructure will emit more GHGs than is compatible with limiting warming to 1.5°C"); *IPCC Working Group III*, *supra* note 8, at 6-15 ("Limiting global warming to 2ºC or below requires a rapid shift away from unabated coal consumption (coal without CCS) in the energy system by 2050 . . . This will require . . . accelerated retirement of existing coal plants").

electricity on demand.[114] Renewable energy resources, such as solar and wind, are expected to supply much of the electricity required in a zero-carbon electricity system of the future, largely due to their low cost.[115] Yet these technologies provide variable or intermittent power, meaning they only generate electricity when the sun is shining and the wind is blowing.[116] The variability of these sources can be successfully mitigated by a variety of strategies, including the use of grid-scale batteries. At least one study demonstrated that renewables and batteries combined can supply all needed power on the grid under certain conditions, though this conclusion is debated.[117] At the same time, other studies have found that including some power plants that can provide constant power—and that can ramp up quickly to respond to peaks in electricity demand—may provide a less costly or more reliable way to achieve a net-zero electricity system.[118] Fossil gas or coal plants with CCS are potential sources of such "firm" power, though there are also other viable sources, including geothermal, biogas, hydrogen combustion, and nuclear.[119]

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[114] Ejeong Baik et al., *What is different about different net-zero carbon electricity systems?*, 2 ENERGY & CLIMATE CHANGE 100046, 100046 (2021), https://linkinghub.elsevier.com/retrieve/pii/S2666278721000234 [https://perma.cc/Q4JA-BGRV].

[115] *See, e.g.*, WH NET-ZERO PATHWAYS, *supra* note 8, at 26–29.

[116] *See* Baik et al., *supra* note 114, at 100047.

[117] Mark Z. Jacobson et al., *Low-cost solution to the grid reliability problem with 100% penetration of intermittent wind, water, and solar for all purposes*, 112 PROC. NAT'L ACAD. SCI. 15060, 15065 (2015), https://www.pnas.org/doi/10.1073/pnas.1510028112 [https://perma.cc/4NEU-JKUF] (concluding a low-cost "wind, water, solar" approach is feasible in many places in the world). There is an active debate as to whether achieving a 100% grid is feasible or prudent, even if there are no "fundamental technical" barriers. *See* Paul Denholm et al., *The challenges of achieving a 100% renewable electricity system in the United States*, 5 JOULE 1331, 1331–32 (2021), https://www.sciencedirect.com/science/article/pii/S2542435121001513 [https://perma.cc/AW68-MFAJ].

[118] Baik et al., *supra* note 114, at 100046; Nestor A. Sepulveda et al., *The Role of Firm Low-Carbon Electricity Resources in Deep Decarbonization of Power Generation*, 2 JOULE 2403, 2403 (2018), https://www.sciencedirect.com/science/article/pii/S2542435118303866 [https://perma.cc/V94D-JM3S].

[119] Baik et al., *supra* note 114, at 100046 (definition of "clean firm resources").

Power plants can capture CO_2 from the exhaust gas of the fossil fuel combustion process,[120] most often using the amine-based chemical absorption process described above.[121]

Modifying existing power plants for CCS is costly (although IRA incentives significantly mitigate these costs).[122] It also adds substantial energy requirements—a common estimate is that an additional 25 percent of energy from fossil combustion is necessary to capture the carbon.[123] This additional combustion must be factored into how much total carbon is captured, and how much escapes into the atmosphere.[124]

Until recently, these economic factors, combined with a lack of policy support, prevented the development of power plants with CCS.[125] Only two commercial-scale power plants have been retrofitted with CCS as of this writing; the Petra Nova project in Texas, and the Boundary Dam project in Saskatchewan, Canada.[126] The Petra Nova project closed in May 2020 due to economic factors.[127] This is changing, however, as there are currently at least twenty power plant CCS projects in development.[128] This includes eleven projects in the United States,[129] driven largely by new CCS tax incentives.[130]

Industrial plants and processes are similarly large emitters of GHGs that can be retrofitted or constructed with CCS. Approximately a quarter of

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[120] There are also technologies for capturing CO_2 pre-combustion and by combusting fuels in a nearly pure-oxygen environment (oxy-fuel combustion), but these are in early stages. Vincent Gonzales et al., *Carbon Capture and Storage 101*, RESOURCES FOR THE FUTURE (2020), https://www.rff.org/publications/explainers/carbon-capture-and-storage-101/ [https://perma.cc/BV2Z-NMY2].

[121] *See* discussion *supra* accompanying notes 39–40.

[122] *Levelized Cost Of Energy, Levelized Cost Of Storage, and Levelized Cost Of Hydrogen*, LAZARD.COM (Oct. 28, 2021), http://www.lazard.com/perspective/levelized-cost-of-energy-levelized-cost-of-storage-and-levelized-cost-of-hydrogen/ [https://perma.cc/H55M-LRFL] (last visited Mar. 13, 2023) (finding coal-fired power plant with CCS more expensive than geothermal, wind, and solar).

[123] *See* Robert W. Howarth & Mark Z. Jacobson, *How green is blue hydrogen?*, 9 ENERGY SCI. & ENG'G. 1676, 1681 (2021), https://onlinelibrary.wiley.com/doi/abs/10.1002/ese3.956 [https://perma.cc/JN2U-CXR6].

[124] *Id*.

[125] CCUS in Low-Carbon Power Systems, *supra* note 112, at 5.

[126] *Id*. at 28.

[127] *Id*. at 28.

[128] *Id*. at 29.

[129] *Id*.

[130] GLOB. CCS INST., GLOBAL STATUS OF CCS 2022 18 (2022), [hereinafter GLOBAL STATUS OF CCS 2022], https://status22.globalccsinstitute.com/wp-content/uploads/2022/11/Global-Status-of-CCS-2022_Download.pdf [https://perma.cc/9K7N-WFQF].

global GHG emissions can be attributed to the industrial sector.[131] Critically, in some high-emitting sectors, such as steel, iron, cement, and fertilizer production, CCS may be the only technology that can achieve deep decarbonization of these processes.[132]

Many of these industrial facilities are capable of carbon capture either after combustion—as with power plants—or at other stages of processing. In some applications, however, capturing CO_2 is more expensive and complicated. This includes the emissions-intensive industries of iron, steel, and cement production, where there are more dilute CO_2 streams and multiple capture points.[133] As a result, only a few post-combustion industrial plants with CCS are currently operating, including an iron and steel facility in Abu Dhabi and a refinery in Canada.[134] As with power plants, tax incentives are driving the development of more projects, including in the U.S.[135]

In contrast, there are some processes where adding CO_2 capture is easier and less complicated, including natural gas processing. Natural gas extracted from the ground contains many gases, liquids, and impurities that must be stripped away to produce the dry gas—composed almost entirely of methane—that is sold to the consumer.[136] One of these byproduct gases that must be stripped away is CO_2.[137] Because natural gas processing plants have been separating out byproducts for nearly a decade, natural

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[131] Mai Bui et al., *Carbon capture and storage (CCS): the way forward*, 11 ENERGY ENV'T SCI. 1062, 1074 (2018), https://pubs.rsc.org/en/content/articlelanding/2018/ee/c7ee02342a [https://perma.cc/VEU3-8XNE].

[132] GLOB. CCS INST., GLOBAL STATUS OF CCS: SPECIAL REPORT: INTRODUCTION TO INDUSTRIAL CARBON CAPTURE AND STORAGE 4 (2016) [hereinafter INTRO TO INDUSTRIAL CCS], https://www.globalccsinstitute.com/resources/publications-reports-research/industrial-ccs [https://perma.cc/28YY-MDU3]; *see also* WH NET-ZERO PATHWAYS, *supra* note 8, at 34.

[133] IEA, TRANSFORMING INDUSTRY THROUGH CCUS 26–27 (2019), https://iea.blob.core.windows.net/assets/0d0b4984-f391-44f9-854f-fda1ebf8d8df/Transforming_Industry_through_CCUS.pdf [https://perma.cc/8BWX-Z543] (see table and accompanying note describing high capture costs for cement, iron, and steel, and noting that high end of cost range includes capture entire facility including from dilute point sources).

[134] GLOBAL STATUS OF CCS 2022, *supra* note 130, at 53–54 (listing only one iron and steel, one oil refinery, and two cement facilities out of 43 CCS facilities currently operating or in construction).

[135] *See id*. at 18.

[136] INTRO TO INDUSTRIAL CCS, *supra* note 132, at 9.

[137] *Id*.

gas processing can often provide highly concentrated streams of CO_2 at relatively low cost.[138]

The production of nitrogen fertilizer from fossil gas also produced CO_2 as a byproduct.[139] Because both natural gas processing and fertilizer production have CO_2 separation built into the underlying process, they account for most of the existing commercial-scale industrial carbon-capture operations.[140]

In terms of climate mitigation benefits, these technologies provide some benefit by reducing a significant portion of GHG emissions from power plants and industrial facilities.

A critical question, however, is how much CO_2 from the power plant or industrial facility exhaust is being captured. Capturing carbon also requires additional energy to run the process—a common assumption is that carbon capture reduces available energy for operations by 25 percent.[141] If the source of energy for the industrial process produces GHGs anywhere across its lifecycle, then this "energy penalty" translates into additional GHG emissions. For example, adding carbon capture to a natural gas processing plant requires sourcing and combust roughly 25 percent more gas to produce the same amount of electricity. The lifecycle emissions from this additional gas reduce the GHG benefit of the CCS unless the non-combustion emissions are also captured or otherwise offset.

Most analyses cite CCS facility capture rates of around 90 percent of emissions from the combustion process.[142] Some scholars note, however, that there is little available data that reflects actual long-term CO_2 capture rates, which may include periods where carbon capture equipment is down for repair.[143] For example, two existing coal-fired power plants with CCS

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[138] Guloren Turan, *CCS: Applications and Opportunities for the Oil and Gas Industry*, GLOB. CCS INST. 2 (May, 2020), https://www.globalccsinstitute.com/wp-content/uploads/2020/05/Brief-_CCS-in-OAG-3.pdf [https://perma.cc/3ZE4-TRV9].

[139] INTRO TO INDUSTRIAL CCS, *supra* note 132, at 11.

[140] *CCUS in Industry and Transformation*, IEA (May 2019), https://www.iea.org/reports/transforming-industry-through-ccus (last visited Jan. 5, 2023) (see chart of industrial CCS facilities currently operating); INTRO TO INDUSTRIAL CCS, *supra* note 132, at 8–12 (profiling natural gas processing and fertilizer CCS operations).

[141] Howarth & Jacobson, *How green is blue hydrogen?*, ENERGY SCI. ENG'G. 1681 (2021), https://web.stanford.edu/group/efmh/jacobson/Articles/Others/21-GreenVsBlueH2.pdf [https://perma.cc/D35L-SZ8S]; *see also* Sgouris Sgouridis et al., *Comparative Net Energy Analysis of Renewable Electricity and Carbon Capture and Storage*, 4 NATURE ENERGY 456 (2019), https://www.nature.com/articles/s41560-019-0365-7 [https://perma.cc/UME7-H9S8] (discussing CCS energy penalty).

[142] IEAGHG, *Towards Zero Emissions CCS in Power Plants Using Higher Capture Rates or Biomass* 6, 9–14 (2019) [hereinafter *Zero Emissions CCS*], https://ieaghg.org/publications/technical-reports/reports-list/9-technical-reports/951-2019-02-towards-zero-emissions [https://perma.cc/HZ6Y-NXP3].

[143] Howarth & Jacobson, *supra* note 141, at 1680.

reportedly capture between 55 and 72 percent of CO_2 from exhaust streams.[144] At the same time, other studies have shown that for some applications, such as power plants, near net-zero levels of carbon capture for direct emissions are technically possible (i.e., 99 percent), potentially without a much higher marginal cost.[145]

Even if near zero capture rates are possible for some applications, they are likely not possible for others. The IPCC states that "[a]s a general rule it is not possible to capture all the carbon dioxide emissions from an industrial plant."[146]

Finally, many of these processes include substantial upstream GHG emissions. For example, the extraction of coal and natural gas results in methane leaks or emissions that must be accounted for.[147]

For these reasons, the cradle-to-grave lifecycle GHG emissions of most CCS applications based on fossil fuel use are substantial. A 2017 study found that the lifecycle emissions of coal- and natural-gas fired power plants with CCS were in the range of 78 to 110 grams of CO_2 equivalent per kilowatt hour.[148] An earlier analysis estimated that adding CCS to these power plants can reduce emissions 64 to 78 percent on a lifecycle basis.[149] While these emission rates are significantly lower than fossil plants without CCS, they are still substantial and much higher than lifecycle GHG emissions from renewable or nuclear power plants.[150]

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[144] *Id.*

[145] Overall carbon intensity of coal and gas power plants would still be higher than for renewables or nuclear due to indirect emissions. *Zero Emissions CCS*, *supra* note 142, at ix.

[146] *IPCC Working Group III*, *supra* note 8, at 11–36.

[147] John E. T. Bistline & David T. Young, *The Role of Natural Gas in Reaching Net-Zero Emissions in the Electric Sector*, 13 NATURE COMMC'N 4743, at 1 (2022), http://www.nature.com/articles/s41467-022-32468-w [https://perma.cc/62U4-YX3D].

[148] Michaja Pehl et al., *Understanding Future Emissions from Low-Carbon Power Systems by Integration of Life-Cycle Assessment and Integrated Energy Modelling*, 2 NATURE ENERGY 939 (2017), https://www.nature.com/articles/s41560-017-0032-9 [https://perma.cc/QE7N-J5J6]; Simon Evans, *Solar, Wind and Nuclear Have 'Amazingly Low' Carbon Footprints, Study Finds*, CARBON BRIEF (Dec. 8, 2017), https://www.carbonbrief.org/solar-wind-nuclear-amazingly-low-carbon-footprints/ [https://perma.cc/T6UR-S2S7].

[149] Bhawna Singh et al., *Comparative Life Cycle Environmental Assessment of CCS Technologies*, 5 INT'L J. GREENHOUSE GAS CONTROL 911 (2011), https://www.sciencedirect.com/science/article/pii/S1750583611000429 [https://perma.cc/AZ84-EXLX].

[150] Evans, *supra* note 148.

If CCS applications become widespread, in the long term these "residual" emissions may pose a significant barrier to achieving the GHG emissions reductions that are needed.[151]

A final consideration is cost, especially relative to other net-zero options. CCS is expensive relative to other technologies, estimated at costing between $50 and $200 per ton of sequestered CO_2.[152] Where substitutes are available, CCS may be more expensive. For example, not only are renewable and solar power plants much cheaper than CCS, but many other sources of "clean, firm" power—such as geothermal power plants[153]—may also be cheaper than retrofitting existing conventional plants with CCS, while also reducing other negative externalities, such as conventional pollution.[154] As discussed in Sec. IV below, however, new federal incentives in the IRA significantly improve the economic viability of CCS in various applications.

2. *EOR Sequestration With Anthropogenic CO_2 Emissions*

As discussed above, EOR with anthropogenic CO_2 emissions can offer a climate benefit, but this depends on several factors including the nature of the specific project and whether the oil displaces higher carbon-intensity oil in the global market. Approximately 20 percent of EOR oil production in the U.S. uses CO_2 from anthropogenic sources—usually from natural gas processing, oil refining, or fertilizer production.[155] Because EOR-facilitated oil production permanently sequesters an average of 0.3 metric tons of CO_2 per barrel of oil produced, EOR-produced oil has the potential to reduce lifecycle emissions—including emissions from the ultimate

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[151] *Zero Emissions CCS*, *supra* note 142, at viii (observations from IPCC integrated assessment models "indicated that the residual emissions from fossil-fuel power stations represented a significant CO_2 emission that needed to be addressed").

[152] *IPCC Working Group III*, *supra* note 8, at 12–18, 12–19.

[153] *Id*. (comparing geothermal with CCS).

[154] Edgar G. Hertwich et al., *Integrated life-cycle assessment of electricity-supply scenarios confirms global environmental benefit of low-carbon technologies*, 112 PROC. NAT'L ACAD. SCI. 6277, 6277 (2015), https://www.pnas.org/doi/10.1073/pnas.1312753111 [https://perma.cc/5BX8-7UBW]; *see* discussion of criteria and hazardous pollution *infra* at Section IV.A.1.

[155] CRS, EOR AND SEQUESTRATION DIFFERENCES, *supra* note 79, at 1; NAT'L ENERGY TECH LAB'Y, CARBON DIOXIDE ENHANCED OIL RECOVERY: UNTAPPED DOMESTIC ENERGY SUPPLY AND LONG TERM CARBON STORAGE SOLUTION 11 (2010), https://netl.doe.gov/sites/default/files/netl-file/NETL_CO2-EOR-Primer.pdf [https://perma.cc/EA43-EJJ3]; *Commercial EOR Projects using Anthropogenic Carbon Dioxide*, CARBON CAPTURE AND SEQUESTRATION TECHNOLOGIES PROGRAM AT MIT, https://sequestration.mit.edu/tools/projects/index_eor.html [https://perma.cc/6HAC-94U4] (last visited Jan. 5, 2023).

combustion of the oil—as compared to non-EOR produced crude oil.[156] That said, some aspects of the EOR process *increase* lifecycle GHG emissions. EOR production itself is more energy intensive, increasing GHG emissions in the production process. EOR also increases the amount of oil that can be economically produced in an oilfield—effectively increasing the supply of oil—and therefore likely increases oil consumption.[157]

There have been several analyses of lifecycle EOR emissions.[158] At least some have concluded that under certain circumstances, EOR with anthropogenic CO_2 can result in net reductions of GHG emissions compared to conventional oil production. For example, the IEA concludes that even when global displacement of non-EOR oil is considered, "[EOR with anthropogenic CO_2] can generate an emissions reduction benefit."[159] The environmental advocacy organization Clean Air Task Force interpreted the IEA data to conclude that EOR generally "results in a 37% reduction in CO_2 emissions per barrel compared to conventional oil production."[160]

At the same time, other studies have found that EOR could increase emissions or provide very little benefit in certain scenarios; for example, when CO_2 is sourced from a coal-fired power plant. A 2009 study found that sourcing CO_2 form one type of "advanced coal" power plant would result in "significant net emissions;"[161] a 2015 study found that another type of "advanced coal" power plant would result in very small lifecycle

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[156] CLEAN AIR TASK FORCE, CO_2 EOR YIELDS A 37% REDUCTION IN CO_2 EMITTED PER BARREL OF OIL PRODUCED 1 (2019), https://www.catf.us/wp-content/uploads/2019/06/CATF_EOR_LCA_Factsheet_2019.pdf [https://perma.cc/JK7A-YPBX].

[157] *Id.*

[158] *See* VANESSA NUÑEZ-LOPEZ ET AL., CARBON LIFE CYCLE ANALYSIS OF CO_2-EOR FOR NET CARBON NEGATIVE OIL (NCNO) CLASSIFICATION (Final Report*)* 2 (2019), https://www.osti.gov/biblio/1525864-carbonlife-cycle-analysis-co2-eor-net-carbonnegative-oil-ncno-classification-final-report [https://perma.cc/NSR3-9ZAE] (*see* tbl. 1.1. Summarizing EOR lifecycle analyses).

[159] Assuming additional monitoring and verification. *See* THE INT'L ENERGY AGENCY, STORING CO_2 THROUGH ENHANCED OIL RECOVERY 32–33 (2019) [hereinafter IEA EOR REP.]; *see also* Bui et al., *supra* note 131, at 1119 (finding that when displaced emissions are taken into account, "net CO_2 emissions vary from about 0.7 to 0.8 tonne CO_2-equivalent per tonne CO_2 stored.").

[160] CLEAN AIR TASK FORCE, *supra* note 156, at 1.

[161] Jaramillo et al., *Life Cycle Inventory of CO_2 in an Enhanced Recovery Oil System*, 43 ENV'T SCI. TECH. 8031, 8027–32 (2009) (analyzing a hypothetical EOR application that sequestered 90% of CO_2 produced at an integrated coal gasification combined cycle (IGCC)).

GHG benefits as compared to conventional crude oil.[162] Similarly, several studies find that assumptions about the global oil market are key—EOR oil only leads to net GHG reductions if it displaces higher carbon-intensity, non-EOR oil.[163]

The vast majority of current EOR applications are optimized for cost-effective recovery of oil, not for sequestering carbon.[164] The IEA has noted that with the right policy incentives (perhaps those like the EOR tax credits in the IRA), producers could be incentivized to co-prioritize oil production and carbon sequestration.[165] An IEA analysis described and modeled scenarios where producers "choose to use and store more CO_2 to recover more oil."[166] Both the IEA and another analysis find that such scenarios increase net reductions of lifecycle GHG emissions compared to conventional EOR.[167]

3. *"Blue Hydrogen" Sequestration*

Hydrogen is one of the most common elements in the universe,[168] and is produced in large quantities today for use in oil refining and manufacture of ammonia for fertilizers.[169] It also has the potential to serve an important role in the transition to a net zero-carbon economy, because it is a "well-established energy carrier" that does not emit GHGs at the point of use.[170] In other words, once hydrogen is produced, it can deliver substantial energy through combustion or through chemical reaction in a fuel cell without creating GHG emissions through those processes. Hydrogen is therefore a promising technology to reduce emissions from hard-to-decarbonize industrial applications (e.g., steel, cement, methanol, and ammonia

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[162] Analyzing a supercritical pulverized coal power plant as the source of CCS. In comparison, a natural gas combined cycle power plant provides significant benefits. Cooney et al., *supra* note 91, at 7497.

[163] Bui et al., *supra* note 131, at 1119 (without displacement "the 'Balanced' CO_2-EOR+ process is essentially carbon neutral"); *see also* IEA EOR REP., *supra* note 159, at 32–33 ("Varying the life-cycle emissions intensity of the displaced oil has a significant impact on the estimate of the emissions reductions that accrue from EOR+ activities.").

[164] Bui et. al., *supra* note 131, at 1116.

[165] IEA EOR REP., *supra* note 159, at 17.

[166] IEA EOR REP., *supra* note 159, at 17.

[167] *Id.* at 32–33; Bui et. al., *supra* note 131, at 1119.

[168] *The Role of Hydrogen and Ammonia in Meeting the Net Zero Challenge*, THE ROYAL SOC'Y 2 (2021) [hereinafter Royal Society Hydrogen Brief], https://royalsociety.org/-/media/policy/projects/climate-change-science-solutions/climate-science-solutions-hydrogen-ammonia.pdf [https://perma.cc/WJ36-PX6W].

[169] INT'L. ENERGY AGENCY, THE FUTURE OF HYDROGEN: SEIZING TODAY'S OPPORTUNITIES 17 (2019) [hereinafter IEA HYDROGEN REP.], https://www.iea.org/reports/the-future-of-hydrogen [https://perma.cc/NVZ5-2WXC].

[170] *Id.*

production). Hydrogen fuel cells or low-carbon hydrogen fuels could similarly be used to power cars, trucks, trains, and planes with zero direct GHG emissions.[171] The gas could also be used on the electric grid: hydrogen fuel cells can produce electricity, and natural gas turbines can be repowered to combust hydrogen.[172] Some proponents even envision using hydrogen as a fuel for heating homes and businesses, and even cooking.[173]

There are different methods of producing hydrogen. Some of these production methods result in significant quantities of greenhouse gas emissions on a lifecycle basis.

"Green hydrogen" refers to hydrogen produced by electrolysis, where an electric current is used to separate water into hydrogen and oxygen.[174] When this process is powered solely by renewable electricity, there are no direct GHG emissions from the process.[175] Electrolysis is relatively energy-intensive, so it would require substantial quantities of renewable electricity; it also requires significant quantities of relatively pure water.[176] Because green hydrogen does not directly produce GHGs, it does not use CCS. It is, therefore, not a focus here.

In contrast, the vast majority of commercial hydrogen today—96 percent —is produced through either steam methane reforming (SMR) or coal

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[171] *Id.* at 124.

[172] Potentially hydrogen blended with fossil-gas. *Id*. at 59.

[173] Howarth & Jacobson, *supra* note 141, at 1677 (noting industry group Hydrogen Council has called for heating of all homes with hydrogen in the future).

[174] INT'L RENEWABLE ENERGY AGENCY, GREEN HYDROGEN COST REDUCTION: SCALING UP ELECTROLYSERS TO MEET THE 1.5 °C CLIMATE GOAL 16 (2020), https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf [https://perma.cc/V7NT-6JE2].

[175] *Id*.; *but cf.* Wilson Ricks et al., *Minimizing emissions from grid-based hydrogen production in the United States*, 18 ENV'T RESH. LETTER 014025 (Jan. 6, 2023), https://dx.doi.org/10.1088/1748-9326/acacb5 [https://perma.cc/6GFR-24BN] (finding that relying on grid supplied electricity without 100 percent hourly matching to clean energy resources does not produce zero-carbon hydrogen).

[176] *See* INT'L RENEWABLE ENERGY AGENCY, GREEN HYDROGEN COST REDUCTION: SCALING UP ELECTROLYSERS TO MEET THE 1.5 °C CLIMATE GOAL (2020), https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf [https://perma.cc/V7NT-6JE2] (largest single cost of green hydrogen is cost of renewable energy); Rebecca R. Beswick et al., *Does the Green Hydrogen Economy Have a Water Problem?*, 6 ACS ENERGY LETTERS, 3167 (2021), https://doi.org/10.1021/acsenergylett.1c01375 [https://perma.cc/7JHP-EGTH].

gasification.[177] SMR is much more prevalent, especially in the U.S., and is known as "grey hydrogen."[178] SMR applies high-pressure steam to methane to produce hydrogen; the methane is almost always sourced from natural gas.[179] This process is also energy intensive and produces a substantial amount of CO_2 as a byproduct.[180]

As with other fossil-fuel producing applications, CCS has the potential to mitigate some GHG emissions associated with SMR hydrogen production. SMR combined with CCS is referred to as "blue hydrogen."[181] Carbon can be captured from two different streams of CO_2 in the SMR process: the CO_2 that is created as a byproduct of the reforming process, and the CO_2 that results from the combustion of natural gas to provide the heat energy needed for SMR.[182] When carbon capture is applied to the synthetic gas stream that emerges from the steam reforming process, it can reduce direct facility GHG emissions by 60 percent; when it is additionally applied to the flue gas, it can capture 90 percent or more emissions from the SMR process, but at a significantly higher cost.[183]

On a lifecycle basis, however, GHG emissions from blue hydrogen are expected to be substantial.[184] This is largely because of the upstream methane emissions associated with natural gas development.[185] Because methane is a very potent greenhouse gas—30 times more potent than CO_2

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[177] Howarth & Jacobson, *supra* note 141, at 1677. There are other methods of producing hydrogen. Partial oxidation and autothermal reforming (ATR) are two other methods that can be used to produce hydrogen from fossil gas. IEA HYDROGEN REP., *supra* note 169, at 38.

[178] Pingping Sun et al., *Criteria Air Pollutants and Greenhouse Gas Emissions from Hydrogen Production in U.S. Steam Methane Reforming Facilities*, 53 ENVT'L. SCI. TECH. 7103, 7103 (2019), https://doi.org/10.1021/acs.est.8b06197 (noting 95 percent of U.S. hydrogen produced by SMR).

[179] IEA HYDROGEN REP., *supra* note 169, at 38.

[180] Sun et al., *supra* note 178, at 7104.

[181] IEA HYDROGEN REP., *supra* note 169, at 34.

[182] SMR uses electricity and also considers lifecycle GHG emissions from the electricity production. Rocio Gonzalez Sanchez, *Assessing hydrogen emissions across the entire life cycle*, CLEAN AIR TASK FORCE (2022), https://www.catf.us/2022/10/hydrogen-lca-emissions-across-life-cycle/ [https://perma.cc/T25G-RD5S] (last visited Nov 16, 2022).

[183] The IEA estimates the cost of SMR flue-gas carbon capture at $50 per metric ton CO_2, and the cost of flue-gas + process carbon capture at $80 per metric ton. IEA HYDROGEN REP., *supra* note 169, at 39-40 (noting the IEA estimates the cost of SMR flue-gas carbon capture at $50 per metric ton CO_2, and the cost of flue-gas + process carbon capture at $80 per metric ton); *but cf.* Howarth & Jacobson, *supra* note 141, at 1682 (noting available data showing mean capture rate from SMR process at existing facility of 78 percent *of process emissions*).

[184] Howarth & Jacobson, *supra* note 141, at 1682-83.

[185] Christian Bauer et al., *On the climate impacts of blue hydrogen,* 1 SUSTAINABLE ENERGY & FUELS 6, 66, 688 (2022) (noting methane leakage from oil and gas production an important contributor to climate change, occurs across entire supply chain, and field studies show it has been underreported).

on a 100 year timescale—these emissions play an outsize role in the lifecycle emissions analysis.[186] Moreover, applying full CCS to a SMR powered by natural gas significantly increases natural gas requirements, and will result in higher levels of uncaptured upstream methane emissions.[187]

For these reasons, independent lifecycle studies of blue hydrogen have found that a leaky natural gas supply chain will severely undermine the lifecycle GHG reduction benefit.[188] A 2022 study concluded that "only a low methane emission rate of the natural gas supply chain combined with a high CO_2 removal rate at the hydrogen production plant allows for substantial reductions of GHG emissions from a life cycle perspective."[189] A 2021 study reached an even more negative conclusion, finding that in almost all scenarios, blue hydrogen creates a net *increase* in emissions: "the greenhouse gas footprint of blue hydrogen, even with capture of carbon dioxide from exhaust flue gases, is as large as or larger than that of natural gas [combustion]."[190]

Finally, hydrogen itself is an indirect greenhouse gas that is four to nine times more potent than CO_2 over a 100-year time horizon.[191] However,

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[186] *Id.* ("[T]he climate impacts of blue hydrogen can hinge on the sources and magnitude of [upstream oil and gas methane] emissions, because they can make up a major fraction of the total GHG emissions when a high level of CO_2 capture (and storage) is applied within the supply chain").

[187] *See* Howarth & Jacobson, *supra* note 141, at 1683, fig. 1 (comparing quantity of natural gas required to produce a unit of hydrogen through SMR with full CCS with producing a unit of hydrogen with capture carbon from only the synthetic gas stream).

[188] Bauer et al., *supra* note 185, at 69 ("[O]nly a low methane emission rate of the natural gas supply chain combined with a high CO_2 removal rate at the hydrogen production plant allows for substantial reductions of GHG emissions from a life cycle perspective."); Howarth & Jacobson, *supra* note 141, at 1683 ("Combined emissions of carbon dioxide and methane are greater . . . for blue hydrogen . . . than for any of the fossil fuels . . . [m]ethane emissions are a major contributor to this . . ."); *see also* Niall Mac Dowell et al., *The hydrogen economy: A pragmatic path forward*, 5 JOULE 2524, 2526, fig. 2 (2021), https://www.sciencedirect.com/science/article/pii/S2542435121004426 [https://perma.cc/4JDJ-RU7F] (finding that blue hydrogen achieves lifecycle GHG emissions that are substantially less than gray hydrogen when conditioned on "high rates of CO_2 capture, and tight control over methane emissions from the natural gas supply chain . . . .").

[189] Bauer et al., *supra* note 185, at 69.

[190] Howarth & Jacobson, *supra* note 141, at 1684, tbl. 2 (finding that when analyzed on a 100-year timescale, blue hydrogen with full CCS can provide benefits over natural gas combustion with a fugitive methane emission rate below 2.5 percent).

[191] Mac Dowell et al., *supra* note 188, at 2528. For a description of how hydrogen indirectly contributes to atmospheric warming, *see* Ilissa B. Ocko & Steven P. Hamburg, *Climate Consequences of Hydrogen Emissions*, 22 ATMOSPHERIC CHEM. & PHYSICS 9349, 9350 (2022), https://acp.copernicus.org/articles/22/9349/2022/ [https://perma.cc/QT5B-842F].

hydrogen's climate-forcing effects are short lived, and are much more potent in the near term: 33 times as potent as CO_2 over a 20 year time period.[192] While hydrogen does not produce GHGs when combusted or reacted in a fuel cell, it does contribute to global warming if it leaks during transport.[193] And because hydrogen is "a tiny molecule that is hard to contain . . . [it] can leak across the entire value chain."[194] At least one study has shown that hydrogen transport in pipelines would result in leakage roughly similar to that found in natural gas.[195]

In sum, there exists a broad consensus that hydrogen will likely be needed in some degree to reach net-zero emissions. It will likely be critical in some heavy industry sectors (steel, cement, ammonia) and perhaps aviation, and may play an important role in other sectors, like transportation and electricity.[196] While green hydrogen clearly has a lower GHG footprint, blue hydrogen is currently two to three times less expensive than green hydrogen,[197] and "the supply of green hydrogen in the future seems limited for at least the next several decades."[198] Many have therefore suggested that blue hydrogen can play the role of a "bridge" to green hydrogen.[199]

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[192] Ocko & Hamburg, *supra* note 191, at 9350.

[193] Mac Dowell et al., *supra* note 188, at 2528 ("[H]ydrogen . . . is itself a greenhouse gas . . . . Given its propensity to leak, this impact must also be accounted for.").

[194] Nicola Warwick et al., ATMOSPHERIC IMPLICATIONS OF INCREASED HYDROGEN USE 54 (2022), https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1067144/atmospheric-implications-of-increased-hydrogen-use.pdf [https://perma.cc/U8YJ-Z8XL]; *cf.* Ocko & Hamburg, *supra* note 191, at 9350 (finding "hydrogen's indirect warming potency per unit mass is around 200 times that of carbon dioxide").

[195] Alejandra Hormaza Mejia, Jacob Brouwer & Michael Mac Kinnon, *Hydrogen leaks at the same rate as natural gas in typical low-pressure gas infrastructure*, 45 INT'L J. HYDROGEN ENERGY 8810, 8824 (2020), https://www.sciencedirect.com/science/article/pii/S0360319919347275 [https://perma.cc/46DR-584D].

[196] *IPCC Working Group III*, *supra* note 8, at TS–52, 54 ("Common characteristics of net-zero energy systems will include . . . use of alternative energy carriers such as hydrogen, bioenergy, and ammonia to substitute for fossil fuels in sectors less amendable to electrification;" "[b]ecause some applications (e.g., aviation) are not currently amenable to electrification, it is anticipated that 100% renewable energy systems will need to include alternative fuels such as hydrogen or biofuels.").

[197] IRENA, GREEN HYDROGEN COST REDUCTION: SCALING UP ELECTROLYSERS TO MEET THE 1.5°C CLIMATE GOAL 1, 1 (2020), https://irena.org/publications/2020/Dec/Green-hydrogen-cost-reduction [https://perma.cc/8EC8-H5HM].

[198] Howarth & Jacobson, *supra* note 141, at 1677.

[199] *E.g.*, Mac Dowell et al., *supra* note 188, at 2528; MCKINSEY & CO. HYDROGEN COUNCIL, HYDROGEN FOR NET-ZERO: A CRITICAL COST-COMPETITIVE ENERGY VECTOR 20, Exhibit 6 (2021), https://hydrogencouncil.com/wp-content/uploads/2021/11/Hydrogen-for-Net-Zero_Full-Report.pdf. [https://perma.cc/7ZPT-PEN4]; Howarth & Jacobson, *supra* note 141, at 1677 ("As of 2021, there were only two operating [SMR with CCS facilities] . . . one operated by Shell in Alberta, Canada, and the other operated by Air Products in Texas, USA.").

The data on the GHG reduction benefits from blue hydrogen are mixed at best. Producing low-carbon hydrogen on a lifecycle basis through SMR with CCS is likely only possible with low levels of fugitive methane emissions in the natural gas supply chain–levels that likely do not currently exist in many regions.[200] High levels of carbon capture from both process and flue emissions are also likely necessary. Moreover, "it is unlikely that complete elimination of gross emissions associated with hydrogen production will ever be cost-effective," and "[t]his burden will likely be greater in the case of blue hydrogen."[201] In a worst-case scenario, blue hydrogen could present a net increase in GHG emissions compared to simple combustion of natural gas.

C. Highest Potential Climate Benefit: Negative Emissions Technologies

The world's collective GHG emissions have led to more than one degree of warming, and our current policy trajectory does not reduce GHG emissions quickly enough to limit warming to 2 degrees.[202] This realization has accelerated research into the possibility of using negative emission technologies (NETs)—these are technologies that, on a lifecycle basis, *remove* GHGs from the atmosphere.[203] Two of the key "carbon dioxide removal" (CDR) strategies incorporate CCS: bioenergy with carbon capture and storage (BECCS) and direct air carbon capture and storage (DACCS).[204] There are other negative emissions strategies that do not rely on CCS—for example, afforestation and enhanced weathering—but they are not discussed here.[205]

There has been a substantial debate on whether, and to what degree, policymakers should pursue negative emissions strategies.[206] One major

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[200] *E.g.,* Bauer et al., *supra* note 185, at 68 (noting studies found a national average emissions rate of 2.3 percent, 60 percent higher than EPA inventories, and a more recent study finding a 9 percent emission rate in the Permian basin).

[201] Mac Dowell et al., *supra* note 188, at 2528.

[202] *See* discussion *infra* accompanying notes 2–9.

[203] Jérôme Hilaire et al., *Negative Emissions and International Climate Goals-Learning From and About Mitigation Scenarios*, 157 CLIMATIC CHANGE 189, 189 (2019), https://doi.org/10.1007/s10584-019-02516-4 [https://perma.cc/U2T8-2X39].

[204] Bioenergy with Carbon Capture and Storage, INT'L ENERGY AGENCY, https://www.iea.org/reports/bioenergy-with-carbon-capture-and-storage [https://perma.cc/AGY4-K39V] (last visited Mar. 14, 2023).

[205] Hilaire et al., *supra* note 203, at 205.

[206] *IPCC Working Group III*, *supra* note 8, at 3–15.

concern is that popularization of these strategies could reduce the political appetite for taking critical near-term action to reduce emissions.[207]

1. Bioenergy With Carbon Capture and Sequestration (BECCS)

Plants and trees—referred to as biomass in the energy context—capture carbon dioxide through photosynthesis. They can also be converted into energy, including through combustion in power plants or through processing into biofuels.[208] Several power plants around the world are powered by biomass, such as wood pulp, trees from tree farming, forest residue, grasses, and agricultural byproducts.[209] When these biomass resources are combusted or processed for energy, they release GHGs, as well as other pollutants, just like fossil fuels.[210] But because the carbon dioxide was initially captured by the plants from the atmosphere—and because new plants can be regrown to again absorb carbon dioxide—the release of carbon dioxide from biomass can be modest in its effect on the climate.[211]

On a lifecycle basis, biomass energy production has other sources of greenhouse gas emissions, including harvesting, transporting, and processing the feedstock. An important factor in lifecycle analysis is whether the use of biomass feedstocks has indirect effects on the quantity of forests and other carbon sinks in the world. For example, lifecycle analysis assesses whether growing corn for fuel in the U.S. will result in increased deforestation in the Amazon for food production.[212] For these reasons, biomass energy usually has significant lifecycle GHG emissions, although

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[207] Clair Gough et al., *Challenges to the Use of BECCS as a Keystone Technology in Pursuit of 1.5^{0}C*, 1 GLOBAL SUSTAINABILITY e5, at 3 (2018), https://www.cambridge.org/core/journals/global-sustainability/article/challenges-to-the-use-of-beccs-as-a-keystone-technology-in-pursuit-of-15c/5E8AE2ECC9DCACB5DFE4B97BBE70476D [https://perma.cc/S3SK-NJC7].

[208] In addition to combustion, BECCS can also transfer biomass to energy as a liquid or gaseous fuel (ethanol or hydrogen). *See* ENERGY FUTURES INITIATIVE, SURVEYING THE BECCS LANDSCAPE 5 (2022) [hereinafter EFI BECCS LANDSCAPE REP.], https://energyfuturesinitiative.org/reports/surveying-the-beccs-landscape/ [https://perma.cc/CW2P-BMM9] (noting in addition to combustion, BECCS can also transfer biomass to energy as a liquid or gaseous fuel (ethanol or hydrogen)).

[209] *Power From Waste - The World's Biggest Biomass Power Plants*, POWER TECH. (July 1, 2020), https://www.power-technology.com/analysis/featurepower-from-waste-the-worlds-biggest-biomass-power-plants-4205990/ [https://perma.cc/N2RY-96US] (last visited Aug. 27, 2022).

[210] *See* EFI BECCS LANDSCAPE REP., *supra* note 208, at 1.

[211] EFI BECCS LANDSCAPE REP., *supra* note 208, at 1.

[212] Amber Broch, S. Kent Hoekman & Stefan Unnasch, *A Review of Variability in Indirect Land Use Change Assessment and Modeling in Biofuel Policy*, 29 ENV'T SCI. & POL'Y 147 (2013), https://www.sciencedirect.com/science/article/pii/S1462901113000208 [https://perma.cc/F5SM-7VJE].

these emissions tend to be lower than lifecycle emissions from fossil fuels.[213]

BECCS adds CCS to this equation.[214] When carbon from biomass combustion is sequestered, much of the carbon that has been pulled out of the air by plants or trees is now being permanently sequestered into the ground. Depending on the other lifecycle emissions factors (biomass production and sourcing, transportation, process, indirect land use effects), this can result in "negative emissions" on a lifecycle basis.[215] In short, BECCS can theoretically produce energy while permanently pulling GHGs out of the atmosphere.

BECCS power plants are still in early stages of demonstration of deployment. There are only a handful of projects in operation around the world, and most are small in scale.[216] The only large-scale project—Archer Daniels Midland's (ADM) Decatur, Illinois ethanol production facility—has "yet to achieve its full capacity . . . [and] still emits more CO_2 from fossil fuel combustion than it removes through BECCS."[217] BECCS is also expensive, costing over $100 per ton of CO_2 removed to deploy.[218] Furthermore the full lifecycle emissions of BECCS depend heavily on the specific project and supply chain—some projects can even result in net increases of GHGs on a lifecycle basis.[219]

To be cost effective, BECCS facilities will locate in areas that have an abundance of biomass fuel (*e.g.*, agricultural residues or forests) and appropriate geologic storage. In the U.S., "the Illinois basin, Gulf region,

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[213] *See, e.g.*, *Lifecycle Greenhouse Gas Results*, U.S. ENV'T PROT. AGENCY (2016), https://www.epa.gov/fuels-registration-reporting-and-compliance-help/lifecycle-greenhouse-gas-results [https://perma.cc/T36A-U86E] (last visited Aug. 27, 2022) (showing cellulosic ethanol and biodiesel with lower, but still significant, lifecycle GHG emissions as compared to gasoline and diesel).

[214] EFI BECCS LANDSCAPE REP., *supra* note 208, at 1.

[215] EFI BECCS LANDSCAPE REP., *supra* note 208, at 1.

[216] EFI BECCS LANDSCAPE REP., *supra* note 208, at 2.

[217] *Id*.

[218] Hilaire *supra* note 203, at 197; EFI BECCS LANDSCAPE REP., *supra* note 208, at 4 (reporting range of $20-$400 per ton of CO_2 removed). N.B. that IRA incentives will make BECCS more economically viable.

[219] Mathilde Fajardy & Niall Mac Dowell, *Can BECCS Deliver Sustainable and Resource Efficient Negative Emissions?*, 10 ENERGY ENV'T. SCI. 1389, 1389 (2017), https://pubs.rsc.org/en/content/articlelanding/2017/ee/c7ee00465f [https://perma.cc/B9XN-3YR5] (finding positive emissions in some situations); Gough et al., *supra* note 207, at 3 (citing studies finding net negative emissions, but noting LCA analyses are highly dependent on specific supply chain and that there are many uncertainties).

and western North Dakota have the greatest potential for near-term BECCS deployment."[220]

At the current time, BECCS and afforestation have been the only negative emissions technologies that have been widely modeled.[221] Current analyses find that BECCS has greater potential for annual CO_2 removals than afforestation.[222] For these reasons, many IPCC modelling scenarios consistent with achieving 1.5 or 2 degree limits anticipate large scale deployments of BECCS in the future.[223]

Yet the IPCC notes that there has been a "fervent debate on the large-scale deployment" of this "as yet unproven" technology.[224] One reason is because of the danger that the prospect of future large-scale deployment of BECCS (or any negative emission technology) could reduce the perceived need for dramatic near-term emission reductions.[225] It should be stressed that even with BECCS, dramatic near- and mid-term GHG emissions reductions are critical to limiting emissions to 2 degrees, not to mention 1.5 degrees.[226] BECCS can, however, "allow for a greater flexibility in the timing of mitigation policies."[227] A second major concern driving the debate is that BECCS presents a wide range of other concerns, including environmental concerns related to air, water, and soil pollution and impacts on food and water supplies.[228] This second concern is addressed below in Section IV.A.4.

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[220] Ejeong Baik et al., *Geospatial Analysis of Near-Term Potential for Carbon-Negative Bioenergy in the United States*, 115 PROCEED. NAT'L ACAD. SCI. 3290, 3290 (2018), https://www.pnas.org/doi/10.1073/pnas.1720338115 [https://perma.cc/C3A7-Y2PU].

[221] *IPCC 1.5 Rep. Full*, *supra* note 8, at 42; Hilaire et al., *supra* note 203, at 192 ("[I]t should be noted that in most mitigation scenarios, BECCS is the only explicit NET available.").

[222] Hilaire et al., *supra* note 203, at 198 ("[T]he annual removal rate of AR is around 0–10 $GtCO_2$/yr. whereas that of BECCS and DACCS is around 0–20 $GtCO_2$/yr.").

[223] Hilaire et al., *supra* note 203, at 198.

[224] *IPCC Working Group III*, *supra* note 8, at 3–15.

[225] This would mean that current generations are taking risks whose negative consequences would be borne by future generations if the promise of BECCS does not play out. Gough et al., *supra* note 207, at 3; Hilaire et al., *supra* note 203, at 196 ("The anticipated availability and use of NETs can be used as a reason to postpone near-term climate action.").

[226] EFI BECCS LANDSCAPE REP., *supra* note 208, at 5; Gough et al., *supra* note 207, at 3.

[227] Hilaire et al., *supra* note 203, at 195.

[228] *E.g.,* Jasmin Kemper, *Biomass and Carbon Dioxide Capture and Storage: A Review*, 40 INT'L J GREENHOUSE GAS CONTROL 401, 420 (2015); *see* discussion *infra* at Section IV.A.4.

2. Direct Air Capture With Carbon Sequestration (DACCS)

Direct air capture uses one of several technologies to directly capture carbon from the ambient air.[229] Capturing carbon from the air is difficult because CO_2 is "highly dilute[d]" in the atmosphere, as compared to more concentrated streams of CO_2 from combustion or industrial processes.[230]

There are currently two technological approaches: a liquid system where a chemical solution removes carbon from a passing air stream and using solid sorbent filters to extract CO_2. In both processes, the captured CO_2 can then be sequestered using CCS.[231] If the source of energy used for DACCS is itself carbon-free (e.g., renewable or nuclear), then DACCS does not produce GHG emissions.[232]

DACCS is currently very expensive. Cost estimates vary widely, but range between $100 and $1000 per ton,[233] although the recent IRA tax incentives for DACCS improve economic viability.[234] It also requires significant amounts of zero- or low-carbon energy. In contrast to BECCS, however, DACCS is unlikely to present the same level of pollution, land use, water, and food system impacts.[235] For these reasons, it is an attractive negative emissions technology; several countries around the world are actively incentivizing DACCS. There are direct air capture plants operating around the world, although most of these are small plants that sell CO_2 for use instead of sequestering it.[236] The first large-scale DACCS plant is now being constructed in Texas by Carbon Engineering and Occidental Petroleum.[237]

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[229] *Direct Air Capture*, INT'L ENERGY AGENCY [hereinafter IEA DAC WEBSITE], https://www.iea.org/reports/direct-air-capture [https://perma.cc/6U57-AKEW] (last visited Aug. 27, 2022).

[230] Bui et al., *supra* note 131, at 1127.

[231] IEA DAC WEBSITE, *supra* note 229.

[232] *IPCC Working Group III*, *supra* note 8, at 11–35 ("CCS can help maintain . . . fully negative emissions if the source is air capture.").

[233] Jonas Meckling & Eric Biber, *A Policy Roadmap for Negative Emissions Using Direct Air Capture*, 12 NATURE COMMC'N 2051, 2051–52 (2021), https://www.nature.com/articles/s41467-021-22347-1 [https://perma.cc/LAN3-88MT].

[234] *See* discussion *supra* at Section V.B.; *see also* Trent Jacobs, *Oxy Doubles Down on Low-Carbon Push Despite Delay With Direct Air Capture*, J. PETROLEUM TECH. (Mar. 1, 2023), https://jpt.spe.org/oxy-doubles-down-on-low-carbon-push-despite-delay-with-direct-air-capture [https://perma.cc/T72S-MWT3].

[235] Meckling & Biber, *supra* note 233, at 2051–52.

[236] IEA DAC WEBSITE, *supra* note 229.

[237] Jacobs, *supra* note 234.

It is expected to capture and sequester over one million tons of carbon per year.[238]

The same concerns that reliance on BECCS could lead to reduced action on necessary near-term GHG emission reductions also apply to DACCS.

D. Potential Role of CCS in Limiting Warming

In addition to analyzing the lifecycle GHG emissions of different CCS applications, scientists have modelled the role that CCS applications can play in limiting global warming to 2 or 1.5 degrees.[239]

In general, IPCC analyses of different "mitigation pathways" show that CCS technologies play a significant role in many of the modeled pathways for successfully limiting warming to 2 or 1.5 degrees.[240] The degree to which different CCS applications are used in successful pathways varies: pathways may rely on CCS from fossil fuel combustion, BECCS, or DACCS to differing degrees. Some mitigation pathways also demonstrate that it is possible to limit warming to 2 or 1.5 degrees without CCS, although such pathways require dramatic near-term reductions of energy demand and fossil fuel use.[241] Recent history suggests that it may be difficult to count on such a quick ramp up of global action; in the three years prior to the COVID-19 crisis, global GHG emissions declined only "a tenth of what achieving 1.5 degree limits would require."[242] The longer the world waits to make serious emission cuts, the more likely it is that some level of CCS deployment will be *necessary* for limiting warming.[243]

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[238] *Id.*; *DAC1*, INT'L ENERGY AGENCY, https://www.iea.org/reports/ccus-around-the-world/dac-1 [https://perma.cc/Z5FS-7MZ9].

[239] *IPCC Working Group III*, *supra* note 8, at 3–11.

[240] *IPCC Working Group III*, *supra* note 8, at 3–7, 3–19 (finding it "likely" that "limiting warming to 2°C or below involve[s] some amount of CDR" and that most likely CDR options are BECCS, DACCS, and afforestation; finding that in 1686 mitigation scenarios analyzed "there remains extensive use of both CDR and CCS in scenarios."); *see IPCC 1.5 Rep. Full, supra* note 8, at 14. 121 (finding that avoiding CCS possible only in scenarios with very low energy demand facilitating the rapid phase-out of fossil fuels); *see also* IEA CCUS REP., *supra* note 32, at 13 ("Reaching net zero will be virtually impossible without CCUS").

[241] *IPCC 1.5 Rep. Full*, *supra* note 8, at 121–22.

[242] *Global carbon emissions need to shrink 10 times faster*, STAN. EARTH MATTERS MAG. (Mar. 3, 2021), https://earth.stanford.edu/news/global-carbon-emissions-need-shrink-10-times-faster-0 [https://perma.cc/3KEV-69TT] (reporting findings that "Among the dozens of countries that reduced their emissions 2016-2019, carbon dioxide emissions fell at roughly one tenth the rate needed worldwide to hold global warming well below 2°C."); *IPCC 1.5 Rep. Full*, *supra* note 8, at 121–22.

[243] *See IPCC 1.5 Rep. Full*, *supra* note 8, at 121–22 ("[t]he longer the delay in reducing CO_2 emissions towards zero, the larger the likelihood of exceeding 1.5°C, and the heavier the implied reliance on net negative emissions after mid-century to return warming to 1.5°C.")

Limiting warming to 1.5 degrees, as opposed to 2 degrees, makes it even more likely that CCS deployment will be needed, especially as a form of negative emissions technology.[244] This is important to consider because allowing global warming above 1.5 degrees would almost certainly result in severe climate impacts. Coral reefs would face massive declines, extreme weather that was previously "unheard of" would become more common, and cities would flood from rising seas caused by melting glaciers.[245] Limiting warming to 1.5 degrees may also prevent dangerous "tipping points" —such as ice sheets sliding into the sea—that could trigger global feedback loops and accelerate warming.[246] Allowing warming of over 2 degrees is expected to trigger even more severe impacts to humans and the environment.[247]

It is important to note that while CCS may be a likely component of pathways that successfully limit warming, successful pathways almost all share in common other strategies that drive emission reductions. All successful pathways require substantial reductions of fossil fuel consumption and a "near elimination of coal use without CCS."[248] Similarly, all pathways rely on large-scale electrification of building, transportation, and industrial sectors, and on deployment of energy conservation measures.[249] These pathways also universally show a transition of the electricity system to nearly all low-carbon sources by 2050, and include large scale deployment of renewable energy.[250]

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[244] *IPCC 1.5 Rep. Full*, *supra* note 8, at 96. ("All analysed pathways limiting warming to 1.5°C with no or limited overshoot use CDR to some extent to neutralize emissions from sources for which no mitigation measures have been identified and, in most cases, also to achieve net negative emissions to return global warming to 1.5°C."). The IPCC report included four illustrative scenarios that would limit warming to 1.5 degree. Three of the four relied significantly on CCS. The fourth relied on substantial near-term reduction in energy demand and fossil fuel use, and used afforestation for carbon dioxide removal. *Id.* at 14.

[245] Lauren Sommer, *This is What the World Looks Like if We Pass the Crucial 1.5-Degree Climate Threshold*, NPR (Nov. 8, 2021), https://www.npr.org/2021/11/08/1052198840/1-5-degrees-warming-climate-change [https://perma.cc/T79G-NSZ2].

[246] *See* Hilaire et al., *supra* note 203, at 200.

[247] *IPCC Working Group III*, *supra* note 8, at 3–6.

[248] *IPCC Working Group III*, *supra* note 8, at 3–6 ("These pathways show an increase in low carbon energy, with 88% (69-97%) of primary energy coming from these sources by 2100." Findings with "high confidence.").

[249] *IPCC Working Group III*, *supra* note 8, at TS-52-53.

[250] *Id.*

In contrast, pathways that do not include a substantial reduction of fossil fuel use and model high levels of continued fossil fuel combustion are generally not successful in meeting temperature targets. For the sixth assessment report, the IPCC selected seven "illustrative pathways" to show how different combinations of strategies would or would not limit warming to 2 degrees.[251] An illustrative "moderate action" pathway with a high degree of fossil-fuel CCS and relatively little near-term action *fails* to meet the 2 degree temperature target.[252] Of the five illustrative pathways that *would* meet the 2 degree temperature target, *fossil-fuel* CCS plays only a modest role in two of those pathways and a negligible role in the other three (as described below, BECCS or DACCS plays a significant role in four pathways).[253] In sum, the IPCC pathways analysis shows that while CCS may be necessary to limit warming if the world does not aggressively cut emissions and energy demand in the near term, overreliance on CCS at the expense of near term reductions in fossil fuel use will likely fail to limit warming to 2 degrees.

With regards to hydrogen, the IPCC finds that "a common characteristic" of various country-specific net zero energy systems will be the "use of alternative energy carriers such as hydrogen . . . to substitute for fossil fuels in sectors less amenable to electrification."[254] To the degree that there are 100 percent renewable electricity systems, "it is anticipated that [these] systems will need to include alternative fuels such as hydrogen . . . ."[255] The IPCC 6th assessment report does not provide much detail on how deployment of blue versus green hydrogen might contribute to achieving temperature limits.[256] The IEA, however, anticipates that because of its lower costs and the widespread use of SMR technology, blue hydrogen will ramp up substantially in the near term to serve as a bridge to green hydrogen in the sustainable development pathway.[257]

BECCS and DACCS play at least a modest role in all but one of the illustrative IPCC two-degree pathways; BECCS plays a substantial role in the one two-degree scenario that prioritizes negative emission technologies.[258]

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[251] *IPCC Working Group III*, *supra* note 8, at 3-12–3-20.

[252] *Id*. at 3-18 to 3-23.

[253] *IPCC Working Group III*, *supra* note 8, at 3-12–3-23 (gradual strengthening of current policies (GS) and extensive use of net negative emissions (Neg) pathways).

[254] *IPCC Working Group III*, *supra* note 8, at TS-52.

[255] *IPCC Working Group III*, *supra* note 8, at TS-54.

[256] *IPCC Working Group III*, *supra* note 8, at TS-54 ("The future role of hydrogen and hydrogen derivatives will depend on how quickly and how far production technology improves, i.e., from electrolysis ("green"), bio gasification, and fossil fuel reforming with CCS ("blue") sources.").

[257] IEA HYDROGEN REP., *supra* note 169, at 38*; IPCC Working Group III*, *supra* note 8, at 6–90.

[258] *IPCC Working Group III, supra* note 8, at 3–47.

The IPCC finds it "likely" that "limiting warming to 2°C or below involve[s] some amount of CDR to compensate for residual GHG emissions remaining after substantial direct emissions reductions."[259]

When evaluating pathways that would achieve a 1.5 degree temperature target, negative emission technologies, including but not limited to BECCS and DACCS, play a larger role. When deployed together with ambitious efforts to cut carbon, NETs can make it feasible to achieve a 1.5 degree limit or provide a more gradual path toward achieving a 2 degree limit because they "effectively increase the available carbon budget . . . allowing for a temporary overshoot of the carbon budget in the near-term and removal of excess carbon later."[260] The IPCC concludes that "Carbon Dioxide Removal . . . is *necessary* to achieve net zero CO_2 and GHG emissions both globally and nationally, counterbalancing 'hard-to-abate' residual emissions. CDR is also an essential element of scenarios that limit warming to 1.5°C or likely below 2°C by 2100 . . . ."[261] Many modeled pathways rely on BECCS as the CDR technology, although some rely on afforestation or DACCS.[262] The IPCC notes that deployments of any of these technologies at scale has potential negative consequences.[263]

Several studies note that a substantial scale up of CCS will be needed for the level of NETs deployment envisioned in 1.5 degrees.[264] They also note that other CCS applications, including CCS capture from power plants

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[259] *IPCC Working Group III*, *supra* note 8, at 3–7 (finding with "high confidence" that; "CDR options in the pathways are mostly limited to BECCS, afforestation and DACCS. CDR through some measures in AFOLU can be maintained for decades but not in the very long term because these sinks will ultimately saturate").

[260] Hilaire et al., *supra* note 203, at 197 (Hilaire found this to be a conclusion of 13 studies in the climate literature).

[261] *IPCC Working Group III*, *supra* note 8, at TS-94 (emphasis added); *IPCC 1.5 Rep. Full*, *supra* note 8, at 14 (finding that all of the various pathways analyze for achieving the 1.5 degree limit used negative emissions technologies to some degree); Hilaire et al., *supra* note 203, at 192 (finding that even in a 2 degree limit scenario, 85 percent of modeled scenarios achieving the 2 degree limit that reflect more mainstream assumptions require substantial deployment of negative emissions technologies. Mainstream assumptions were ones where "no drastic GHG emission abatement, radical changes towards sustainable lifestyles, nor constraints on technological availability and climate policy timing are imposed"); *see also* Gough et al., *supra* note 207.

[262] *IPCC 1.5 Rep. Full*, *supra* note 8, at 96.

[263] *Id.*

[264] IEA CCUS REP., *supra* note 32, at 150, 153–54; Meckling & Biber, *supra* note 233, at 3–4.

and industrial facilities, EOR, and blue hydrogen can further develop and lower costs of CCS technology.[265]

A final climate consideration is that reliance on CCS in lieu of aggressive near-term action can increase the chance that the world triggers catastrophic "tipping" points and feedback loops. Our understanding of the impacts of global warming is uncertain. For example, we do not know what level of warming will cause glaciers and ice sheets to slide into the sea, which can cause a negative feedback loop and accelerate warming. The same is true in terms of the release of methane trapped in permafrost around the world, or the potential collapse of the amazon rainforest or coral reefs.[266] A recent study concludes that exceeding 1.5 degrees could trigger multiple tipping points.[267]

Over-reliance on CCS has the potential to increase the likelihood of reaching catastrophic tipping points for two reasons. First, a climate policy that aims to postpone near-term emission reductions because of the promise of negative emissions reductions in the future results in a higher rate of near-term GHG-emissions, and therefore makes it more likely that we will reach tipping points sooner.[268] Second, many CCS technologies risk higher near-term emissions of methane or hydrogen. Both of these gases have very potent climate forcing effects in the near term, but those effects are shorter lived. In the near term, methane has 85 times the climate-forcing effect as CO_2,[269] and hydrogen has 33 times the climate-forcing effect.[270] If CCS policies that rely on natural gas (such as natural gas power plants with CCS, natural gas processing with CCS, blue methane production) maintain or exacerbate current high levels of fugitive methane emissions, this could have substantial effects on near-term warming that could make tipping points more likely.

In sum, the IPCC analyses suggest that CCS will be needed to limit warming to 2 or 1.5 degrees absent significant near term reductions in fossil fuel use and energy demand. Within those generalizations, there are likely many different pathways to both 2 degree and 1.5 degree outcomes, with different degrees of reliance on various CCS applications. Few of

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[265] *See* IEA CCUS REP., *supra* note 32, at 150, 153–54; Meckling & Biber, *supra* note 233, at 3–4.

[266] Armstrong McKay et al., *supra* note 7, at 1.

[267] *Id*.

[268] Hilaire et al., *supra* note 203, at 200 ("Temperature overshoot associated with NET deployments increasing the risks of triggering climate tipping points."); *id*. (Hilaire found this to be a conclusion of 89 studies in the climate literature).

[269] *Methane and Climate Change*, INT'L ENERGY AGENCY, https://www.iea.org/reports/methane-tracker-2021/methane-and-climate-change [https://perma.cc/9K43-LVNZ] (last visited Apr. 17, 2023) (methane GWP-20 estimated at 84–87).

[270] Warwick et al., *supra* note 194, at 54.

those pathways rely on a high degree of fossil CCS—in fact, high global reliance on fossil fuel CCS likely leads to exceeding the two-degree temperature target. But CCS for hard-to-decarbonize sectors, enhanced EOR, and blue hydrogen *could* be a significant part of pathways that limit warming to 2 degrees or 1.5 degrees. Significant deployment of some of these technologies may also help scale CCS for potentially needed NETs usage in the future. At the same time, if policymakers seek to rely on CCS as opposed to taking aggressive action to directly reduce emissions, they risk triggering dangerous "tipping points" that could precipitate catastrophic climate harms.

IV. NON-CLIMATE CONSIDERATIONS: JUSTICE, POLLUTION, RESOURCE SCARCITY, AND ECONOMIC BENEFITS

While CCS applications provide varying degrees of climate benefits, they also create other potential harms and benefits not directly related to climate change. These factors present important considerations for state policymakers.

This section provides an overview of these harms and benefits. The potential harms include the potential for maintaining or exacerbating harms from extractive industries, potential water and subsoil contamination, increased and perhaps unsustainable demand for land and water, and induced earthquakes. Other potential benefits include economic flows to fossil fuel worker communities that may otherwise experience economic decline, reduction in stranded asset costs, reduction in the costs of energy transition, and reduction of some co-pollutants.

Two final factors that may be of interest to policymakers are the role of CCS in the developed versus developing world and the role of fossil fuel companies—many of which have a well-documented history of mischaracterizing climate change and opposing climate change policies—in implementing CCS.

A. Potential Drawbacks

1. Maintaining or Exacerbating Harms From Extractive Industries

A number of CCS applications described above rely on continued fossil fuel extraction. Natural gas power plants with CCS, natural gas processing with CCS, enhanced oil recovery, and blue hydrogen all rely on continued natural gas development. Adding CCS to coal-fired power plants also relies on continued coal extraction.

Extractive industries have a long and well-documented history of environmental and public health impacts, which are anticipated to persist even with the addition of CCS.[271] Many of these impacts disproportionately harm communities of color and low-income communities.[272]

For example, development of oil and gas wells emits dozens of hazardous air pollutants (HAPs) that increase health risks for people who live nearby.[273] This includes emissions of benzene, toluene, ethylbenzene, xylenes, N-hexane, formaldehyde, and acetaldehyde, all of which are volatile organic compounds.[274] These hazardous pollutants are known to cause cancer and to cause other severe health effects, including harms to the nervous and blood (hematological) systems.[275] When VOCs combine with nitrous oxides (NOx), another pollutant emitted by oil and gas development, they form ground-level ozone.[276] Ozone causes respiratory harms, aggravating

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[271] Hertwich et al., *supra* note 154, at 6278–79 (generally finding much higher particulate matter emissions, ecotoxicity, eutrophication, and land occupation for fossil fuel power plants with CCS as compared to renewables).

[272] *See* LESLIE FLEISCHMAN & MARCUS FRANKLIN, FUMES ACROSS THE FENCE-LINE: THE HEALTH IMPACTS OF AIR POLLUTION FROM OIL & GAS FACILITIES ON AFRICAN AMERICAN COMMUNITIES (2017), https://naacp.org/resources/fumes-across-fence-line-health-impacts-air-pollution-oil-gas-facilities-african-american [https://perma.cc/654A-RPJH]; David J. X. Gonzalez et al., *Historic redlining and the siting of oil and gas wells in the United States*, 33 J. EXPOSURE SCI. ENV'T EPIDEMIOL 76 (2023), http://www.nature.com/articles/s41370-022-00434-9 [https://perma.cc/8KYZ-GYQZ].

[273] *E.g.,* Diane A. Garcia-Gonzales et al., *Hazardous Air Pollutants Associated with Upstream Oil and Natural Gas Development: A Critical Synthesis of Current Peer-Reviewed Literature*, 40 ANN. REV. PUB. HEALTH 283, 284, 293–94, 296 (2019), https://doi.org/10.1146/annurev-publhealth-040218-043715 [https://perma.cc/9QPL-P5JJ]; Lisa M. McKenzie et al., *Ambient Nonmethane Hydrocarbon Levels Along Colorado's Northern Front Range: Acute and Chronic Health Risks*, 52 ENV'T. SCI. TECH. 4514, 4514 (2018), https://doi.org/10.1021/acs.est.7b05983 [https://perma.cc/A7W9-97PR]; John L. Adgate, Bernard D. Goldstein & Lisa M. McKenzie, *Potential Public Health Hazards, Exposures and Health Effects from Unconventional Natural Gas Development*, 48 ENV'T. SCI. TECH. 8307, 8307 (2014), https://doi.org/10.1021/es404621d [https://perma.cc/38WY-VD7S].

[274] Garcia-Gonzales et al., *supra* note 273, at 290–94.

[275] *Id*. at 293; *see also Health Effects Notebook for Hazardous Air Pollutants*, ENV'T PROT. AGENCY, https://www.epa.gov/haps/health-effects-notebook-hazardous-air-pollutants [https://perma.cc/FV5Z-DT5C] (*see* entries for benzene, toluene, ethylbenzene, xylenes, formaldehyde and acetaldehyde).

[276] *Ground-level Ozone Basics*, ENV'T PROT. AGENCY, https://www.epa.gov/ground-level-ozone-pollution/ground-level-ozone-basics [https://perma.cc/LY47-57V7] (last visited Mar. 14, 2023).

and likely causing asthma.[277] When exposure to VOCs and ozone is chronic and severe, it is associated with premature death.[278]

Recent studies have also indicated that oil and gas development impacts large numbers of people of color and vulnerable groups, including people living in poverty, children, the elderly, and those who have not attained a high-school level of education.[279] Jeremy Proville and his coauthors found that four oil and gas development areas in particular affect a high degree of intersecting vulnerable areas: Southern California (both near Los Angeles and in the Central Valley); Southwest Texas (including both the Permian Basin and Eagles Shale); Appalachia; and Northwest New Mexico (with a high prevalence of Native Americans).[280] All of these regions have substantial potential for geologic storage.[281]

Adding CCS technologies to combustion facilities may increase emissions of some conventional air pollutants and reduce others.[282] For example, one study found that Nitrous Oxide emissions would likely increase because CCS requires additional combustion of fossil fuels to account for the energy penalty.[283] The Environmental Defense Fund has also noted that the use of amine solvents may lead "to the presence and potential release of nitrosamines (a toxic carcinogen associated with the breakdown of amine solvents) [and] may pose serious hazards to workers and the public near capture facilities utilizing certain amine solvents in post-combustion capture processes."[284] At the same time, as noted in Section IV.B.3 below,

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[277] *Health Effects of Ozone Pollution*, EVN'T PROT. AGENCY, [hereinafter *Health Effects of Ozone Pollution*], https://www.epa.gov/ground-level-ozone-pollution/health-effects-ozone-pollution [https://perma.cc/HB44-NXS4] (last visited Aug 28, 2022).

[278] *Id.*; Karl M. Seltzer, Drew T. Shindell & Christopher S. Malley, *Measurement-based assessment of health burdens from long-term ozone exposure in the United States, Europe, and China*, 13 ENV'T. RSCH. LETTERS 104018, at 7–8 (2018), https://doi.org/10.1088/1748-9326/aae29d [https://perma.cc/2WXE-R896].

[279] Jeremy Proville et al., *The Demographic Characteristics of Populations Living Near Oil and Gas Wells in the USA*, 44 POPULATION ENV'T 1, 2, 8–9 (2022), https://doi.org/10.1007/s11111-022-00403-2 [https://perma.cc/329K-Y7RT].

[280] *Id.* at 11.

[281] *See* CARBON STORAGE ATLAS, *supra* note 52, at 110–11.

[282] ENV'T AGENCY, AIR POLLUTION IMPACTS FROM CARBON CAPTURE AND STORAGE (CCS) 7 (2011) [hereinafter EEA CCS Air Pollution Impacts], https://data.europa.eu/doi/10.2800/84208 [https://perma.cc/2WZ5-39V7].

[283] The report also found significant increases in ammonia emissions. *Id.*

[284] Gary T. Rochelle, *Air pollution impacts of amine scrubbing for CO_2 Capture*, PROC. OF THE 16TH GREENHOUSE GAS CONTROL TECH. CONF. (GHGT-16) 1 (2022), *available at* https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4281826 [https://perma.cc/MD55-

the emissions for other pollutants such as sulfur dioxide are likely to be reduced.[285] Any reductions of conventional pollutants at the capture point, however, would not reduce air pollution from upstream in the supply chain. In other words, CCS does not reduce air pollution associated with oil and gas wells and pipelines described above.

Therefore, many climate and environmental justice advocates have robustly opposed CCS. They have grounded their opposition in part on the principle that a just climate policy requires ensuring that the benefits of climate policies—including reduction of conventional health-damaging air pollution—are spread equitably across all communities. This principle requires in particular that conventional-pollution reduction benefits of climate policies should flow equitably to communities that have historically suffered disproportionate legacy pollution.[286]

In 2021, the White House Environmental Justice Advisory Council released a report stating that CCS, CCUS, and direct air capture were all "examples of the types of projects that will not benefit a community."[287] In 2021, over 500 environmental justice advocates and organizations sent a letter to U.S. and Canadian policymakers, arguing that "investing in carbon capture delays the needed transition away from fossil fuels and other combustible energy sources, and poses significant new environmental, health, and safety risks, particularly to Black, Brown, and Indigenous communities already overburdened by industrial pollution, dispossession, and the impacts of climate change."[288] Many of the same groups also criticized guidance on CCS policy issued by the White House Council on Environmental Quality as "a mechanism for fast-tracking the approval of massive CCS/CCUS and associated carbon dioxide permits in spite of significant opposition from the environmental justice community as well as the larger ecosystem of climate justice advocates."[289]

EACR] (citing EDF letter to CEQ). Rochelle finds that such emissions of nitrosamine and other air toxics "will likely be insignificant." *Id*. at 18.

[285] *Id*. at 41.

[286] *E.g.*, Jalonne Lynay White-Newsome, *A Policy Approach Toward Climate Justice*, 46 THE BLACK SCHOLAR 12 (2016), https://doi.org/10.1080/00064246.2016.1188353 [https://perma.cc/A5XN-3XRY].

[287] WHITE HOUSE ENV'T JUSTICE ADVISORY COUNCIL, JUSTICE40, CLIMATE AND ECONOMIC JUSTICE SCREENING TOOL, & EXECUTIVE ORDER 12898 REVISIONS: INTERIM FINAL RECOMMENDATIONS 576–87 (2021), https://www.epa.gov/environmentaljustice/whejac-justice40-climate-and-economic-justice-screening-tool-executive-order [https://perma.cc/F8FC-JUHF].

[288] Letter from Environmental Justice Advocates to President Joseph R. Biden and Policymakers from environmental justice advocates, Re: Carbon capture is not a climate solution, (July 19, 2021), https://www.ciel.org/wp-content/uploads/2021/07/CCS-Letter_FINAL_US-1.pdf [https://perma.cc/4D82-E8CB].

[289] *Environmental Justice Organizations post Comments on Carbon Capture and Storage to the White House Council on Environmental Quality*, INDIGENOUS ENV'T NETWORK

Advocates have been particularly concerned that CCS will maintain and exacerbate oil and gas impacts in communities that are already disproportionately harmed. In California's Central Valley, over 80 environmental justice and conservation organizations urged the EPA to deny all "pending and upcoming" permits for permanent carbon sequestration wells, arguing that such wells "resurrect or prolong the life of polluting industrial facilities in predominantly low-income neighborhoods of color that already experience some of the worst air quality in the country."[290] In New Mexico, both environmental justice and traditional environmental advocacy organizations succeeded in blocking passage of a hydrogen hub bill sponsored by Democratic Governor Michelle Lujan Grisham, in part because of concerns about how blue hydrogen would affect native communities in the San Juan Basin.[291] Communities in Louisiana have been similarly concerned about how CCS could maintain and exacerbate harms from concentrations of oil, gas, and petrochemical infrastructure to make Louisiana attractive to proponents of CCS.[292]

2. *Potential Water and Subsoil Contamination*

Another concern is the potential for contamination of groundwater by leaking CO_2 from sequestration, which can occur through "well leakage, fault leakage, and cap rock leakage."[293] CO_2 is generally injected in a supercritical state, where it is buoyant and tends to flow upward if it finds an available pathway.[294] If escaped CO_2 reaches a freshwater aquifer and dissolves, the "concentration of dissolved carbonate increases, which leads to

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(Apr. 18, 2022), https://www.ienearth.org/environmental-justice-organizations-post-comments-on-carbon-capture-and-storage-to-the-white-house-council-on-environmental-quality/ [https://perma.cc/2P3L-HWAB].

[290] *EPA Urged to Reject Carbon Capture Projects in Central California*, CENTER FOR BIOLOGICAL DIVERSITY (June 29, 2022), https://biologicaldiversity.org/w/news/press-releases/epa-urged-to-reject-carbon-capture-projects-in-central-california-2022-06-29/ [https://perma.cc/95SD-89SC].

[291] *Community, conservation groups unified in opposition to fossil gas hydrogen bills*, W. ENV'T L. CTR. (Feb. 7, 2022), https://westernlaw.org/community-conservation-groups-unified-opposition-fossil-gas-hydrogen-bills/ [https://perma.cc/A276-A9A4].

[292] Cate Bonacini, *Carbon Capture and Storage: An Expensive and Dangerous Plan for Louisiana*, CTR INT'L ENV'T L. (June 25, 2021), https://www.ciel.org/carbon-capture-and-storage-an-expensive-and-dangerous-proposition-for-louisiana-communities/ [https://perma.cc/8H5P-BTHP].

[293] Eldardiry & Habib, *supra* note 11.

[294] Class VI Final Rule, 75 Fed. Reg. at 77234.

significant increases in water acidity."[295] In some instances, the increased acidity "could cause leaching and mobilization of naturally-occurring metals or other contaminants from geologic formations into ground water (e.g., arsenic, lead, and organic compounds)."[296] Another potential source of contamination is the impurities in the stream of captured CO_2, which may include contaminants such as hydrogen sulfide or mercury.[297] Finally, large-scale injection of CO_2 could "force brine from the target formation into [fresh water aquifers], which could affect drinking water."[298]

A related concern is that escaped CO_2 could result in elevated CO_2 concentrations in the soil, potentially harming plants and animals, and affecting microbial populations.[299]

3. CO_2 Pipeline Safety, Asphyxiation Risks

CO_2 is commonly transported under pressure in a super-critical state.[300] If a pipeline ruptures, it "could lead to a massive and rapid release" where the CO_2 "vaporizes into a heavier than air gas and dissipates" and travels up to several kilometers.[301] Because the CO_2 is heavier than air and mildly toxic, it can displace oxygen and lead to illness, or in extreme cases, death by asphyxiation.[302] A February 2020 rupture of a pipeline carrying CO_2 in Satartia, Mississippi, sent at least 45 people to the hospital and created a crater 40 feet deep.[303]

A large leak of CO_2 could cause the asphyxiation of people, plants or animals. A 1986 rapid leak of naturally-occurring CO_2 trapped beneath Lake Nyos in Cameroon killed approximately 1,700 people and 3,500

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[295] Eldardiry & Habib, *supra* note 11, at 4.

[296] Class VI Final Rule, 75 Fed. Reg. at 77235.

[297] *Id.*

[298] JONES, *supra* note 21, at 16.

[299] Class VI Rule, 73 Fed. Reg. at 43497–98, (proposed Nov. 21, 2028) (to be codified at 40 C.F.R. 124).

[300] Wesley Matthews, *Pipeline and Hazardous Materials Safety Admin.*, *Failure Investigation Report–Denbury Gulf Coast Pipelines, LLC–Pipeline Rupture/Natural Force Damage*, US DEP'T OF TRANSP. 2 (May 26, 2022) [hereinafter Satartia Investigation Rep.], https://www.phmsa.dot.gov/news/phmsa-failure-investigation-report-denbury-gulf-coast-pipelines-llc [https://perma.cc/XBT3-YMSX].

[301] *Id.*; Mahgerefteh, *supra* note 11.

[302] Satartia Investigation Rep., *supra* note 300, at 2.

[303] Mike Soraghan & Anchondo Carlos, *Biden Releases Plan to Avoid "Dangerous" CO_2 Pipeline Failures*, E&E NEWS (May 27, 2022), https://www.eenews.net/articles/biden-releases-plan-to-avoid-dangerous-co2-pipeline-failures/ [https://perma.cc/M8WV-D2RW]. The pipeline ruptured because of rain-induced landslide. Satartia Investigation Rep., *supra* note 300, at 2.

livestock.[304] A similar release of CO_2 from the bottom of Lake Monoun, Cameroon, took place during the same decade.[305] The EPA concluded, however, that because geologic sequestration involves trapping CO_2 deep beneath many layers of rock, any leakage "would not be analogous."[306]

4. BECCS, Land and Food Security

Because BECCS requires large amounts of biomass fuel from plants and trees, it creates a substantial demand for land.[307] Competition created for usage of land—including growing food and natural habitat—puts pressure on water resources, and creates risk related to increased use of pesticides.[308] A number of studies found that large-scale deployment of BECCS would "bear the risk of triggering potentially irreversible changes in the Earth system through extensive land-use change, water use, alteration of biogeochemical flows and compromising biosphere integrity."[309] Several studies concluded that the demand for land makes large-scale deployment of BECCS infeasible.[310] One particular equity concern is that because BECCS would increase demand for agriculture land, it would raise food prices.[311]

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[304] Alexandra B. Klass & Sara E. Bergan, *Carbon Sequestration and Sustainability Symposium: Environmental Sustainability*, 44 TULSA L. REV. 237, 248 (2008).

[305] *Id*.

[306] Class VI Rule, 73 Fed. Reg. at 43498 (proposed Nov. 21, 2028) (to be codified at 40 C.F.R. 124).

[307] Vera Heck et al., *Biomass-based Negative Emissions Difficult to Reconcile with Planetary Boundaries*, 8 NATURE CLIMATE CHANGE 151, 153 (2018), http://www.nature.com/articles/s41558-017-0064-y [https://perma.cc/S3EN-YQU7]; Hilaire et al., *supra* note 203, at 190, 198–219 (cataloging analyses finding potential negative effects of BECCS on food, water, ecosystems).

[308] Heck et al., *supra* note 307, at 153.

[309] *Id*.; Hilaire et al., *supra* note 203, at 190, 198–219 (cataloging analyses finding potential negative effects of BECCS on food, water, ecosystems).

[310] Heck et al., *supra* note 307, at 153.

[311] Eldardiry & Habib, *supra* note 11, at 2 ("The deployment of BECCS increases food prices due to land competition between energy and food biomass feedstocks. However food prices would still be high without BECCS because other bioenergy-based mitigation technologies would increase in importance."); *IPCC 1.5 Rep. SPM*, *supra* note 5, at 21 (finding with high confidence that "1.5°C and 2°C modelled pathways often rely on the deployment of large-scale land-related measures like afforestation and bioenergy supply, which, if poorly managed, can compete with food production and hence raise food security concerns).").

5. *Water Scarcity*

CCS applications require significant amounts of water, which is used for both emissions scrubbing and cooling.[312] CCS technologies are therefore "expected to significantly introduce additional stresses on the sustainability of water systems."[313] As an example, thermoelectric power plants are already the largest source of water use in the United States, responsible for approximately 40 percent of all water withdrawals.[314] Adding CCS to a fossil fuel-fired power plant "almost double[s]" water withdrawals.[315]

6. *Earthquakes*

Much research has established that oil and gas development can cause seismic activity, or earthquakes.[316] In oil and gas development, this seismic activity often occurs from wastewater injection, although studies have also found that earthquakes likely occur due to EOR.[317] The resulting earthquakes can reach significant magnitudes, likely large enough to cause property damage.[318] One study found reduced property values after EOR-induced earthquakes; another study found increases in stress and anxiety among residents.[319] Several studies found similar potential for induced seismicity from CCS.[320] In addition to property damage, induced

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[312] Lorenzo Rosa et al., *Hydrological Limits to Carbon Capture and Storage*, 3 NAT. SUSTAINABILITY 658, 658 (2020), https://www.nature.com/articles/s41893-020-0532-7 [https://perma.cc/92LT-UG2Z].

[313] Eldardiry & Habib, *supra* note 11, at 2.

[314] *Water withdrawals by U.S. power plants have been declining*, ENERGY INFO. ADMIN. (Nov. 9, 2018), https://www.eia.gov/todayinenergy/detail.php?id=37453https://www.eia.gov/todayinenergy/detail.php?id=37453 [https://perma.cc/S6UK-HY77] (Water withdrawals by power plants have been declining due to the shift to natural gas-fired power plants—which are less water-intensive than coal-fired power plants—and renewable energy).

[315] Eldardiry & Habib, *supra* note 11, at 4.

[316] ALAN J. KRUPNICK & ISABEL ECHARTE, RESOURCES FOR THE FUTURE, INDUCED SEISMICITY IMPACTS OF UNCONVENTIONAL OIL AND GAS DEVELOPMENT, RESOURCES FOR THE FUTURE 2, 97–101 (2017), https://media.rff.org/documents/RFF-Rpt-ShaleReviews_Seismicity_0.pdf [https://perma.cc/H8N5-H9RH]; Cornelius Langenbruch & Mark D. Zoback, *How Will Induced Seismicity in Oklahoma Respond to Decreased Saltwater Injection Rates?*, 2 SCI. ADVANCES 1, 1 (2016).

[317] KRUPNICK & ECHARTE, *supra* note 316, at 2, 11; Wei Gan & Cliff Frohlich, *Gas Injection May Have Triggered Earthquakes in the Cogdell Oil Field, Texas*, 110 PROC. NAT'L ACAD. SCI. 18786, 18786 (2013).

[318] KRUPNICK & ECHARTE, *supra* note 316, at 14.

[319] *Id.* at 11, 14.

[320] Mark D. Zoback & Steven M. Gorelick, *Earthquake Triggering and Large-scale Geologic Storage of Carbon Dioxide*, 109 PROC. NAT'L ACAD. SCI. 10164 (2012), https://www.pnas.org/doi/10.1073/pnas.1202473109 [https://perma.cc/VN5P-W39J]; James P. Verdon & Anna L. Stork, *Carbon Capture and Storage, Geomechanics and Induced*

seismicity also has the potential to create gaps in the caprock seal for geologic reservoirs, which could lead to escaping CO_2.[321]

B. Potential Benefits

CCS technologies can also provide significant non-climate-related benefits. These external benefits are generally economic in nature, mainly consisting of economic opportunities for fossil-fuel worker communities and companies and potentially lower overall costs in the transition to low-carbon energy.

1. Benefits for Fossil Fuel Worker Communities

CCS technologies can provide economic benefits to communities dependent on fossil fuel extraction or on fossil fuel-powered industrial facilities. These benefits are especially salient because these communities might otherwise face economic decline given the necessity of dramatically reducing fossil fuel usage to limit warming to 2 or 1.5 degrees.[322]

For example, one study of stakeholder attitudes in the oil-and-gas community in the North Sea found that CCS could be part of a just transition where it "(a) makes a contribution to climate change imperatives; (b) helps to mitigate the economic and employment effects arising from declining or maturing industries; and (c) is undertaken in a manner that helps to redress (or at least does not increase) uneven vulnerabilities and inequalities in society."[323] A report commissioned by the Global CCS Institute highlighted the ways that CCS can mitigate the geographic and temporal disconnect between declining carbon-intensive economies and emerging low-carbon opportunities.[324] It states, "CCS enables existing industries to continue to make a sustained contribution to local economies while transitioning to a net-zero economy. Inefficient and uncompetitive industrial plants will still

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Seismic Activity, 8 J. ROCK MECH. & GEOTECHNICAL ENG'R 928 (2016), https://www.sciencedirect.com/science/article/pii/S1674775516301196 [https://perma.cc/74FB-F6CE].

[321] Zoback & Gorelick, *supra* note 320, at 10164; Verdon & Stork, *supra* note 320, at 928.

[322] *See* Floris Swennenhuis et al., *What Role for CCS in Delivering Just Transitions? An Evaluation in the North Sea Region*, 94 INT'L J. GREENHOUSE GAS CONTROL 102903 (2020), https://www.sciencedirect.com/science/article/pii/S1750583618307874 [https://perma.cc/T5KJ-6EUB]; ALEX TOWNSEND ET AL., *The Value of Carbon Capture and Storage (CCS)*, GLOB. CCS INST. 4 (2020).

[323] *See* Floris Swennenhuis et al., *supra* note 322, at 15.

[324] TOWNSEND et al., *supra* note 322.

close, but supporting the longevity of the most innovative firms will help achieve a fair transition."[325]

A number of studies have identified the economic benefits that CCS can bring to various locales. For example, the Rhodium Group analyzed potential economic impacts of retrofitting existing fossil fuel-fired power plants and industrial facilities among states participating in the Regional Carbon Capture Deployment Initiative.[326] The analysis found that CCS retrofits would bring 132 to 200 billion dollars in capital investments and sustain an average of 67,000 to 100,000 associated jobs per year for 15 years.[327] The Global CCS Institute similarly found that the level of CCS deployment outlined in IEA's Sustainable Development Scenario—approximately 2,000 CCS facilities—would create 100,000 jobs in 2050.[328]

2. Reduction of Costs and Stranded Assets

The IPCC notes that limiting warming to 2 or 1.5 degrees will necessarily strand existing fossil fuel assets, meaning the owners of in-ground fossil fuel resources or infrastructure (e.g., power plants, pipelines) will find the value of those assets dramatically decreased or depleted.[329] According to the IPCC, CCS can "reduc[e] potential stranded assets" by "allow[ing] fossil fuels to be used longer."[330] In the case of rate-regulated utilities, stranded asset costs are often passed onto ratepayers.[331] Avoiding stranded assets can therefore mitigate increased utility costs. The IEA also finds that for related reasons, CCS can potentially reduce the cost of transitioning to a low carbon electricity system.[332] "[I]f CCS is not used in the electricity generation sector, the capital investment needed to meet the same emissions constraints is increased by 40%."[333]

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[325] TOWNSEND et al., *supra* note 322, at 20.

[326] JOHN LARSEN ET AL., THE ECONOMIC BENEFITS OF CARBON CAPTURE INVESTMENT AND EMPLOYMENT ESTIMATES FOR REGIONAL CARBON CAPTURE DEPLOYMENT INITIATIVE STATES, RHODIUM GROUP (2020).

[327] JOHN LARSEN ET AL., THE ECONOMIC BENEFITS OF CARBON CAPTURE INVESTMENT AND EMPLOYMENT ESTIMATES FOR REGIONAL CARBON CAPTURE DEPLOYMENT INITIATIVE STATES, RHODIUM GRP. 27 (2020).

[328] TOWNSEND et al., *supra* note 322, at 4.

[329] *IPCC Working Group III*, *supra* note 8, at TS-53 to TS-54.

[330] *Id.* at TS-53.

[331] *See* Catherine Morehouse, *Duke stranded gas assets could cost customers $4.8B, report finds*, UTILITY DIVE (Jan. 26, 2021), https://www.utilitydive.com/news/duke-stranded-gas-assets-could-cost-customers-48b-report-finds/593939/ [https://perma.cc/2WS9-A87G].

[332] Verdon & Stork, *supra* note 320, at 928 (citing Levina et al., 2013).

[333] *Id.*

3. *Reductions of Some Conventional Air Pollutions at the Point of Capture*

As described above in Section V.A.1, applying CCS is expected to reduce some conventional air pollutants—particularly sulfur dioxide—at the point of capture.[334] A 2022 study also found that CCS "will reduce significantly the effect of the power plant emissions on ambient levels of [fine particulate matter] PM2.5."[335] Moreover, researchers have developed processes that could be used to also reduce Nitrogen Oxide emissions.[336] As discussed above, however, these reductions would only occur at the point of capture. They would not reduce emissions occurring because of upstream fossil fuel extraction. Moreover, other technologies, such as renewable energies, are expected to achieve much higher degrees of conventional pollution reduction.[337]

C. *Other Factors*

1. *CCS as a Climate Strategy with Support in Conservative Communities*

Although CCS has faced skepticism or opposition from many segments of the public,[338] CCS is "among the very few climate solutions receiving strong political support in conservative, fossil-dependent states."[339] Some

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[334] EEA CCS Air Pollution Impacts, *supra* note 282, at 7; Rochelle, *supra* note 284, at 1.

[335] Rochelle, *supra* note 284, at 1. The EEA study also found that in certain scenarios particulate matter emissions could be reduced due to increased adoption of CCS. EEA CCS Air Pollution Impacts, *supra* note 282, at 10.

[336] Presentation of Env't Protect. Agency and Dept. of Energy, Carbon Capture and Storage 15 (on file with the author).

[337] *See* Hertwich et al., *supra* note 154, at 6279 (finding renewable technologies would produce much less particulate matter on a lifecycle basis than power plants with CCS).

[338] *E.g.,* Jacob A. E. Nielsen et al., *Community acceptance and social impacts of carbon capture, utilization and storage projects: A systematic meta-narrative literature review*, NCBI: 17 PLOS ONE (Aug. 2, 2022), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9345485/ [https://perma.cc/F7QB-W8PV] (skepticism "has been expressed by the lay public concerning storage risks, uncertainties and concerns regarding the long-term efficacy of CCUS in mitigating climate change.").

[339] Matt Bright & Ryan Fitzpatrick, *As Oil Retreats, Carbon Capture Must Advance*, THIRD WAY (May 11, 2020), https://www.thirdway.org/memo/as-oil-retreats-carbon-capture-must-advance [https://perma.cc/W9CS-T7K7] (last visited Mar. 15, 2023).

have argued that CCS can be an important way to engage these communities as part of the solution to climate change.[340]

2. *Need for CCS in the Developed World vs. Developing World*

Much of the current development of fossil fuel infrastructure takes place in the developing world. For example, over 200 coal-fired power plants are currently under development in Asia.[341] In contrast, no new coal plants have been built in the U.S. in the last decade.[342] This is largely driven by the lower costs of developing fossil fuel power in these countries.[343] It also reflects a longstanding argument by developing countries that developed countries—as the world's largest emitters on a historic basis need to reduce emissions first and more quickly to give developing countries an equitable opportunity to grow their economies using relatively cheap fossil fuels.[344]

These new power plants are designed for long, useful lives, and the electricity that they provide will be needed to serve the large, and relatively poor, populations in Asia. To limit warming to 2 or 1.5 degrees, these power plants will eventually need to be retrofitted with some form of CCS

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[340] *Id.*

[341] Sudarshan Varadhan & Aaron Sheldrick, *COP26 Aims to Banish Coal. Asia is Building Hundreds of Power Plants to Burn it*, REUTERS (Nov. 1, 2021), https://www.reuters.com/business/energy/cop26-aims-banish-coal-asia-is-building-hundreds-power-plants-burn-it-2021-10-29/ [https://perma.cc/JH9U-SY6J].

[342] But new natural gas fired power plants are being built. Sammy Roth, *Coal plants are closing across the West. Here are the companies sticking with coal*, L.A. TIMES (Feb. 5, 2020), https://www.latimes.com/environment/story/2020-02-04/coal-power-plants-western-us [https://perma.cc/UMX9-L4FZ].

[343] *See* Sudarshan Varadhan and Aaron Sheldrick, *COP26 aims to banish coal. Asia is building hundreds of power plants to burn it*, REUTERS (Nov. 1, 2021), https://www.reuters.com/business/energy/cop26-aims-banish-coal-asia-is-building-hundreds-power-plants-burn-it-2021-10-29/ [https://perma.cc/5YU2-ZBZW].

[344] Developed nations have relied on fossil fuel exploitation over the past 150 years to grow their economies and improve the quality of life for their citizens. As a result, the U.S., United Kingdom, and European Union countries are by far the largest cumulative emitters of GHGs—and those historic GHG emissions are still responsible for the bulk of the warming the earth is experiencing. At the same, time, developing countries—especially China and India—now also rank as the world's largest emitters (China is number one, the U.S. is number two). These developing countries have long argued that developed countries have a moral obligation to reduce emissions first and faster, while developing countries continue emitting for some period of time to continue to most cost-effectively try to improve the quality of life for their populations. *See generally* Eric A. Posner & Cass R. Sunstein, *Climate Change Justice*, 96 GEO. L.J. 1565, X (2007). China and India have both committed to reducing emissions, but their emissions are currently still growing. *China*, CLIMATE ACTION TRACKER, https://climateactiontracker.org/countries/china/ [https://perma.cc/55F4-G5BC] (last visited Sept. 13, 2022); *India*, CLIMATE ACTION TRACKER, https://climateactiontracker.org/countries/india/ [https://perma.cc/TZ49-ZD4R] (last visited Sept. 13, 2022).

or else they will need to be prematurely shut down.[345] However, CCS does not fully capture all emissions from a facility. In addition, coal-powered electricity generation has significant GHG emissions from other parts of the coal lifecycle that will need to be accounted for. These "residual" emissions from CCS applications will need to be offset in the future.

One consideration for U.S. policymakers is that while fossil fuel-based CCS can play a role in reducing emissions, a large amount of fossil fuel-based CCS will likely make it more difficult to reach net-zero levels within the necessary timeframes. U.S. policymakers may want to consider that developing countries are "baking in" a lot of new fossil fuel infrastructure, and that the U.S. may not have as much of a "need" for fossil CCS in comparison, given the other decarbonization options available.

3. Role of Fossil Fuel Companies

CCS can also provide a lifeline for fossil fuel companies. Indeed, major global oil and gas companies increasingly view CCS and hydrogen sectors as key to a continued viable business model. Major oil and gas companies like BP, Shell, and ExxonMobil have released plans to heavily expand CCS and blue hydrogen, usually as part of pledges to reduce GHG emissions.[346]

Many environmental advocates have expressed strong opposition to CCS in part because of the role that oil and gas companies play.[347] They

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[345] IEA CCS REP., *supra* note 32, at 21.

[346] *Our Climate Target*, SHELL (2021), https://www.shell.com/energy-and-innovation/the-energy-future/our-climate-target.html#iframe=L3dlYmFwcHMvY2xpbWF0ZV9hbWJpdGlvbi8https://www.shell.com/energy-and-innovation/the-energy-future/our-climate-target.html#iframe=L3dlYmFwcHMvY2xpbWF0ZV9hbWJpdGlvbi8 [https://perma.cc/6XLS-JUJ9] (setting milestone "to have access to an additional 25 million tonnes a year of carbon capture and storage (CCS) capacity by 2035" as a way to meet company climate targets); *ExxonMobil Announces Corporate Plans to 2027—Supports Approximately Doubling Earnings and Cash Flow Potential, Reducing Emissions*, EXXONMOBIL (Dec. 1, 2021), https://corporate.exxonmobil.com:443/News/Newsroom/News-releases/2021/1201_ExxonMobil-announces-plans-to-2027-doubling-earnings-and-cash-flow-potential-reducing-emissions [https://perma.cc/DGF9-BFMY] (announcing plans to increase CCS and hydrogen investments); *CCUS and Hydrogen*, BP, https://www.bp.com/en_us/united-states/home/who-we-are/advocating-for-net-zero-in-the-us/ccus-and-hydrogen.html [https://perma.cc/8YC3-ZPRY] (last visited Sept. 10, 2022).

[347] *E.g.*, Tim Donaghy, *8 Reasons Why We Need to Phase Out the Fossil Fuel Industry*, GREENPEACE USA (Nov. 21, 2021), https://www.greenpeace.org/usa/research/8-reasons-why-we-need-to-phase-out-the-fossil-fuel-industry/ [https://perma.cc/ZE4Y-KKGG]; Dana Drugmand, *Big Oil's Been Secretly Validating Critics' Concerns about Carbon Capture*,

point to a well-documented history of oil and gas companies knowingly misrepresenting the facts of climate change to stymy climate policies and to prolong a high-carbon business model.[348] Many of these misrepresentations serve as the basis for a number of fossil fuel lawsuits that have been filed by cities and states.[349] Democrats on the House of Representatives Committee on Oversight and Reform released a memorandum after a year-long investigation, finding that "[c]ontrary to their pledges, fossil fuel companies have not organized their businesses around becoming low-emissions, renewable energy companies . . . [t]hey are devoted to a long-term fossil fuel future."[350] These advocates argue that the history of fossil fuel company actions to impede and delay climate action, and their position to lead implementation of CCS, should be taken as another reason to steer climate policy away from CCS.[351]

V. FEDERAL REGULATIONS DON'T COMPREHENSIVELY ADDRESS RISKS, BUT IRA SUPERCHARGES INCENTIVES

Between 2021 and 2022, Congress enacted two pieces of legislation, the Inflation Reduction Act and Infrastructure Investment and Jobs Act, that together supercharge the incentive structure for CCS technologies.[352] The chief incentive instruments are the 45Q and 45V tax incentives, which ramp up to provide CCS project developers between 60 to 180 dollars-per-ton of CO_2 sequestered and provide similarly high levels of incentives for hydrogen projects.[353]

At the same time, the federal government has only created a partial regulatory structure to address risks, uncertainties, and potential harms of CCS.[354] This partial regulatory structure focuses mostly on protecting

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DESMOG (Feb. 13, 2023), https://www.desmog.com/2023/02/13/exxon-shell-bp-api-concerns-carbon-capture/ [https://perma.cc/B9BW-ERXU].

[348] *See* Donaghy, *supra* note 347.

[349] Chris McGreal, *Big Oil and Gas Kept a Dirty Secret for Decades. Now They May Pay the Price*, THE GUARDIAN (June 30, 2021), https://www.theguardian.com/environment/2021/jun/30/climate-crimes-oil-and-gas-environment [https://perma.cc/7MEL-MZKK].

[350] *Ahead of Hearing, Committee Releases Memo Showing Fossil Fuel Industry is Misleading the Public About Commitment to Reduce Emissions*, H. COMM. ON OVERSIGHT & REFORM (Sept. 14, 2022), https://oversight.house.gov/news/press-releases/ahead-of-hearing-committee-releases-memo-showing-fossil-fuel-industry-is [https://perma.cc/2CQ2-CFNX].

[351] Donaghy, *supra* note 347; *see* Drugmand, *supra* note 347.

[352] Inflation Reduction Act of 2022, Pub. L. No. 117-1679, 136 Stat. 1818 (codified as amended in scattered sections of U.S.C.); Infrastructure Investment and Jobs Act of 2021, Pub. L. No. 117-58, 135 Stat. 429 (2021) (codified as amended in scattered sections of U.S.C.).

[353] *See* discussion *infra* at Sections V.B.1 and V.B.2.

[354] *See, e.g.*, Federal Requirements Under the Underground Injection Control (UIC) Program for Carbon Dioxide (CO_2) Geologic Sequestration (GS) Wells, 75 Fed. Reg. 77230,

groundwater resources under the authority of the Safe Drinking Water Act (SDWA); though it also provides some protections against longer-term CO_2 leakage through GHG reporting requirements.[355] The 48Q and 45V tax incentive programs do establish some threshold qualification requirements: CCS projects must sequester a minimum amount of CO_2 annually; EOR projects must receive a permit specifically for permanent sequestration; and most significantly, hydrogen projects must meet a minimum cradle-to-grave lifecycle GHG standard.[356]

But these federal regulations and incentive requirements do not comprehensively address many of the other potential risks or harms of CCS. None of the federal regulations require CCS or EOR CCS projects to limit GHG emissions on a lifecycle basis. Moreover, existing federal regulations do not address potential environmental justice harms of CCS projects, such as maintaining or exacerbating air pollution from industrial uses.

A final piece of the puzzle, however, is that while increased federal incentives provide a huge boost for CCS projects, they may still not be sufficient to make such projects economically viable. Such projects may need additional support from state climate policies. California's Low-Carbon Fuel Standard provides one example of how state policies could make CCS policies viable—and how this provides states implementing such policies with leverage to decide whether and under what circumstances to authorize CCS.[357]

This section first describes the existing federal and state regulatory framework for CCS. It then details federal and state incentives. Finally, it discusses the role that state climate policies can play in shaping the deployment of CCS, focusing on California's CCS protocol for its Low-Carbon Fuel Standard (LCFS).

77235–36 (Dec. 10, 2010) [hereinafter Class VI Final Rule], http://www.gpo.gov/fdsys/pkg/FR-2010-12-10/pdf/2010-29954.pdf [https://perma.cc/4WBM-5ACJ] (noting that in response to proposed Class VI underground injection regulations EPA received a number of comments "indicating that the Agency should further explore environmental and regulatory issues beyond the scope of the proposed SDWA requirements for underground injection of CO_2 for GS.").

[355] *See* discussion *infra* at Section V.A.1.

[356] *See* discussion *infra* at Sections V.B.2–3.

[357] *See* discussion *infra* at Section V.C.

A. The Regulatory Framework

1. Federal Regulations

a. EPA Regulation of Underground Injection Wells

The federal regulations that most directly target CCS applications protect underground sources of drinking water from contamination. Part C of the Safe Drinking Water Act requires the EPA to establish minimum requirements for state underground injection control (UIC) programs and allows states to develop programs that meet these requirements.[358] If these programs are approved by the EPA, states then receive "primary enforcement responsibility" for the program.[359] If states do not submit a program, or if their program is not adequate, then the EPA is mandated to implement a federal program.[360]

The EPA has promulgated regulations for several different classes of underground injection wells, two of which are relevant here.[361] The EPA first established regulations for Class II wells, which are oil- and gas-related injection wells and include wells used for the injection of CO_2 for enhanced oil recovery.[362] In 2010, the EPA established Class VI, a new category covering wells used to permanently sequester CO_2 in geologic storage.[363] Oil and gas producers injecting CO_2 for EOR must apply for a Class VI well if they intend to permanently sequester CO_2 after active oil production is completed.[364] Because Class VI wells are intended to permanently sequester CO_2 (usually with higher volumes and higher pressures) and, therefore, present a greater risk of leakage and groundwater contamination, these regulations establish more stringent protections.[365]

For example, unlike Class II requirements, the Class VI regulations require that:

- well operators provide seismicity information, continuous monitoring of the injection pressure and CO_2 stream, monitoring of the CO_2 plume and pressure front, and monitoring of groundwater quality throughout the lifetime of the project;
- well operators provide post-injection site care and meet emergency and remedial response requirements;

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[358] 42 U.S.C. § 300h.
[359] 42 U.S.C. § 300h(b)(3).
[360] 42 U.S.C. § 300h(b)(4).
[361] 40 C.F.R. § 144.6.
[362] 40 C.F.R. § 144.6(b).
[363] Class VI Final Rule, 75 Fed. Reg., at 77230.
[364] *Id*. at 77244–45.
[365] *See id*. at 77234.

- well operators provide information on seismic history and demonstrate confining zone is free of fractures; and
- wells be individually approved by permit, and cannot be allowed by rule.[366]

While primacy for Class II permitting has been delegated by the EPA to many states,[367] Class VI permitting has only been delegated to North Dakota and Wyoming.[368] The EPA is in the process of reviewing Louisiana's application, and Arizona, Texas, and West Virginia are in the pre-application stage.[369] The EPA has permitted two Class VI wells, and is currently processing 26 applications.[370] North Dakota has also issued two Class VI permits.[371]

CCS developers and proponents highlight the time to obtain a Class VI permit from the EPA as being a major impediment to the development of CCS projects, and point out that state primacy can greatly expedite this process.[372] "North Dakota has demonstrated the speed at which a state-run UIC program can approve a Class VI permit: the state approved [the most recent] application in 8 months, whereas the federal program has taken approximately 3-6 years."[373] Developers and proponents have also

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[366] JONES, *supra* note 21, at CRS-35-37.

[367] Forty states have primacy for Class II wells. JONES, *supra* note 21, at 12.

[368] Patrice Lahlum, *EPA's Class VI Well Program Key to Deploying CO_2 Geologic Storage*, GREAT PLAINS INST. (Feb. 17, 2022), https://betterenergy.org/blog/epas-class-vi-well-program-key-to-deploying-co2-geologic-storage/; Lauren A. Batchel, et al, *Carbon Capture, Utilization, and Storage: Class VI Wells and US State Primacy*, MAYER BROWN (June 9, 2022), https://www.mayerbrown.com/en/perspectives-events/publications/2022/06/carbon-capture-utilization-and-storage-class-vi-wells-and-us-state-primacy [https://perma.cc/6G68-Z3DH].

[369] Lauren A. Batchel, et al, *Carbon Capture, Utilization, and Storage: Class VI Wells and US State Primacy*, MAYER BROWN (June 9, 2022), https://www.mayerbrown.com/en/perspectives-events/publications/2022/06/carbon-capture-utilization-and-storage-class-vi-wells-and-us-state-primacy [https://perma.cc/6G68-Z3DH].

[370] *Class VI Wells Permitted by EPA*, U.S. ENV'T PROT. AGENCY, https://www.epa.gov/uic/class-vi-wells-permitted-epa [https://perma.cc/8PYM-AW3G] (last visited Sept. 11, 2022).

[371] Lauren A. Batchel, et al, *Carbon Capture, Utilization, and Storage: Class VI Wells and US State Primacy*, MAYER BROWN (June 9, 2022), https://www.mayerbrown.com/en/perspectives-events/publications/2022/06/carbon-capture-utilization-and-storage-class-vi-wells-and-us-state-primacy [https://perma.cc/6G68-Z3DH].

[372] *Id.*

[373] *Id.*

criticized the length of time it is taking the EPA to approve state primacy applications.[374]

b. GHG Reporting Requirements

The second set of federal regulations that directly address CCS projects are GHG emission reporting requirements promulgated by the EPA under the Clean Air Act.[375] At the same time that the EPA promulgated rules for Class VI wells under the SDWA, it also created GHG reporting requirements (referred to as subpart RR regulations) to cover projects that geologically sequester CO_2, including EOR projects that receive a Class VI SDWA permit.[376] These subpart RR reporting regulations require projects with a Class VI permit to develop site-specific monitoring, verification, and reporting (MVR) plans that must be approved by the EPA.[377]

The agency similarly established reporting requirements for other projects that inject CO_2 into the ground for other purposes, most notably for EOR facilities with a Class II permit (referred to as subpart UU regulations).[378] Unlike subpart RR regulations, these UU regulations do not require an MVR plan that must be approved by the agency.[379]

c. CAA Oil and Gas Methane Regulations

Given the importance of upstream methane emissions to the lifecycle GHG analysis of any CCS application that relies on oil and gas production, it is worth highlighting the Biden Administration's pending rules to reduce methane from existing oil and gas sources.[380] The rules are being promulgated under the authority of the Clean Air Act section 111, which mandates that the EPA set performance standards for categories of new sources.[381] In cases where pollution from categories of existing sources is not otherwise regulated, the EPA must require that states set such standards for existing

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[374] Brittany Bolen et al., *IRA-Driven Carbon Capture Needs Better Strategies*, BLOOMBERG LAW (Sept. 21, 2022), https://news.bloomberglaw.com/environment-and-energy/ira-driven-carbon-capture-needs-better-strategies [https://perma.cc/4ZZT-XS9H].

[375] Section RR, UU Reporting Rule, 75 Fed. Reg. 18576, 18580 (proposed Apr. 12, 2010) (to be codified at 40 C.F.R. pt. 98).

[376] Class VI Final Rule, 75 Fed. Reg. at 77235–36.

[377] Class VI Final Rule, 75 Fed. Reg. at 77235–36; 40 C.F.R. § 98.448 (2011).

[378] Class VI Final Rule, 75 Fed. Reg. at 77235; 40 C.F.R. § 98.441 (2022); 40 C.F.R. § 98.448 (2011).

[379] *See* 40 C.F.R. § 98.476 (2022).

[380] Standards of Performance for New, Reconstructed, and Modified Sources and Emissions Guidelines for Existing Sources: Oil and Natural Gas Sector Climate Review, 86 Fed. Reg. 63110 (proposed Nov. 15, 2021) (to be codified at 40 C.F.R. pt. 60).

[381] *Id.*; 42 U.S.C. § 7411.

sources.[382] These rules will require states to develop methane standards for existing oil and gas sources and are expected to significantly reduce upstream methane pollution—a critical step that may significantly improve the ability of CCS to achieve net lifecycle GHG benefits.[383] At the same time, the rules do not set absolute volumetric limits on upstream emissions; instead, the rules set performance standards for various pieces of equipment.[384] As of this writing, a final rule has not yet been adopted. Even when adopted, the effectiveness of the rule will be uncertain because it will be based on the standards different states establish and enforce and because of the difficulty of identifying or measuring all fugitive emissions.[385] In other words, while the rules are expected to achieve significant emission reductions, they will not absolutely limit methane emissions from oil and gas production, nor can they guarantee that a low overall rate of fugitive methane emissions can be achieved.

d. Federal Pipeline Regulations

After the deadly CO_2 release in Lake Nyos, in 1991 "federal regulators issued a minimalist final rule that mainly added the words 'and carbon dioxide' to existing federal minimum pipeline safety regulations developed for hazardous liquid petroleum pipelines."[386] According to a report by the Pipeline Safety Trust, the agency "opted to not issue standards specifically applicable to supercritical CO_2 pipelines" due to the limited number of such pipelines at the time.[387] In 2011, Congress enacted the Pipeline Safety, Regulatory Certainty, and Job Creation Act of 2011, mandating that the federal

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[382] 42 U.S.C. § 7411(d); *see* Gabriel Pacyniak, *Making the Most of Cooperative Federalism: What the Clean Power Plan Has Already Achieved*, 29 GEO. ENV'T L. REV. 301, 307–09 (2017).

[383] Emissions Guidelines for Existing Sources: Oil and Natural Gas Sector, 86 Fed. Reg. 63110, 63117, 63122–23 (proposed Nov. 15, 2021) (to be codified at 40 C.F.R. pt. 60).

[384] 86 Fed. Reg. at 63118–22.

[385] *See* Gabriel Pacyniak et al., Climate, Health, and Equity Implications of Large Facility Pollution Sources in New Mexico 15–16 (2023), https://www.psehealthyenergy.org/our-work/publications/archive/largest-emission-sources/ [https://perma.cc/636R-A67H] (describing why state oil and gas air pollution regulations, similar in structure to proposed federal regulations, will not achieve guaranteed emission reductions).

[386] RICHARD B. KUPREWICZ, ACCUFACTS' PERSPECTIVES ON THE STATE OF FEDERAL CARBON DIOXIDE TRANSMISSION PIPELINE SAFETY REGULATIONS AS IT RELATES TO CARBON CAPTURE, UTILIZATION, AND SEQUESTRATION WITHIN THE U.S. 3 (Accufacts, Inc. 2022), https://pstrust.org/wp-content/uploads/2022/03/3-23-22-Final-Accufacts-CO2-Pipeline-Report2.pdf [https://perma.cc/4ZY8-2AM8].

[387] *Id.*; *see* 49 C.F.R. § 195 (2022).

government “prescribe minimum safety standards for the transportation of carbon dioxide by pipeline in a gaseous state.”[388] In 2015, the Pipeline and Hazardous Materials Safety Administration (PHMSA) subsequently issued a report recommending such minimum safety standards,[389] but at the time no regulations were proposed.[390] In 2022, the PHMSA announced it was “[i]nitiating a new rulemaking to update standards for CO_2 pipelines” after a “CO_2 pipeline failure in Satartia, Mississippi in 2020 that resulted in local evacuations and caused almost 50 people to seek medical attention.”[391]

e. *Other Federal Regulations*

There are several other types of federal environmental requirements that could be triggered by CCS projects, but none of them are expected to comprehensively address the GHG or environmental harms noted above.

Perhaps most significant is the NEPA requirement that federal agencies —and third parties receiving federal funding or approvals[392]—consider environmental impacts of major actions and alternatives to those actions.[393] NEPA is important in part because it could conceivably be one tool for addressing environmental justice concerns of CCS projects. According to the EPA, under NEPA “[f]ederal agencies must consider environmental justice in their activities.”[394] In some recent court cases, environmental

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[388] 49 U.S.C. § 60102(i).

[389] OFF. OF PIPELINE SAFETY, PIPELINE AND HAZARDOUS MATERIALS SAFETY ADMIN., DEP’T OF TRANSP., PHMSA-2016-0049-0001, BACKGROUND FOR REGULATING THE TRANSPORTATION OF CARBON DIOXIDE IN A GASEOUS STATE 2–3 (2015), https://www.regulations.gov/document/PHMSA-2016-0049-0001.

[390] Kuprewicz, *supra* note 386, at 4.

[391] *PHMSA Announces New Safety Measures to Protect Americans From Carbon Dioxide Pipeline Failures After Satartia, MS Leak*, PIPELINE HAZARDOUS MATERIALS AND SAFETY ADMIN. (May 26, 2022), https://www.phmsa.dot.gov/news/phmsa-announces-new-safety-measures-protect-americans-carbon-dioxide-pipeline-failures [https://perma.cc/639M-L9W5].

[392] *See* 40 C.F.R. § 1508.1(g)(2) (2022).

[393] 42 U.S.C. § 4332; 40 C.F.R. §§ 1500-1508 (2022).

[394] *The Environmental Justice and National Environmental Policy Act*, U.S. ENV’T PROT. AGENCY, https://www.epa.gov/environmentaljustice/environmental-justice-and-national-environmental-policy-act [https://perma.cc/KQ4F-WWAT] (last visited Sept. 30, 2022); *see* 40 C.F.R. § 1508.1(g) (2022) (defining effects broadly to include social, economic); Clifford J. Villa, *No “Box to Be Checked”: Environmental Justice in Modern Legal Practice*, 30 N.Y.U. ENV’T. L.J. 157, 182–88 (2022) (cataloging cases where federal courts required adequate NEPA analysis); *but cf.* NINA M. HART & LINDA TSANG, Cong. Rsch. Serv., LSB10590, ADDRESSING ENVIRONMENTAL JUSTICE THROUGH NEPA 4 (2021) (courts have played a limited role in reviewing environmental justice analyses in NEPA cases, one court foreclosed all environmental justice review).

justice advocates have successfully used NEPA to force agencies to consider disproportionate pollution impacts on communities of color.[395]

But while NEPA could serve as a tool for requiring consideration of impacts related to CCS—including environmental justice harms—federal actions related to CCS projects are unlikely to trigger NEPA. First, courts have so far declined to find that receipt of federal tax credits triggers NEPA, meaning that the award of 45Q or 45V tax credits for CCS and hydrogen projects will also likely not trigger NEPA.[396] Second, courts have also found that the EPA's approval of a SDWA permit does not trigger NEPA analysis, meaning that the act of approving a Class VI permit for permanent CO_2 sequestration is also exempt from NEPA requirements.[397] If an EOR CCS project is located on federal lands pursuant to a federal oil and gas lease, however, the approval of the permit to drill the oil well will be subject to NEPA requirements.[398]

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[395] *E.g.*, Friends of Buckingham v. State Air Pollution Control Bd., 947 F.3d 68, 92 (4th Cir. 2020) ("environmental justice is not merely a box to be checked"); Vecinos Para el Bienstar de la Comunidad de Costera v. Fed. Energy Reg. Comm'n, 6 F.4 1321, 1330–31 (D.C. Cir. 2021) (finding FERC's EJ analysis arbitrary).

[396] Federal actions under NEPA include projects that are significantly controlled by the federal government or third-party actions that have the potential to restrict federal consideration of alternatives for federal components of the project. Southwest Williamson County Community Ass''n v. Slater, 173 F.3d 1033 (6th Cir. 1999); In two challenges brought to tax credit awards or tax credit permits, courts dismissed both suits for lack of standing. Fla. Audubon Soc. v. Bentsen, 94 F.3d 658 (D.C. Cir. 1996) (D.C. Circuit ruled en banc that environmental group failed to show particularized harm caused by failure of the IRS to create an EIS on the effects of tax credit for ethyl tertiary butyl ether (ETBE) fuel additive); Appalachian Voices v. Bodman, 587 F. Supp. 2d 79 (D.D.C. 2008) (environmental groups lacked standing as the injury was not fairly traceable to tax credit programs).

[397] Class VI Final Rule, 75 Fed. Reg. at 77236 (citing Western Nebraska Resources Council v. US EPA, 943 F.2d 867, 871–72 (8th Cir. 1991)). This exemption falls under a court-made doctrine finding that agencies need not comply with NEPA if they are implementing another statute that also requires environmental considerations that are "functional equivalents" of the NEPA process. State of Ala. ex Rel. Siegelman v. U.S. E.P.A., 911 F.2d 499, 504 (11th Cir. 1990). It is worth noting that while SDWA requires consideration of impacts to drinking water, EPA's administrative adjudicators have declined to consider other environmental impacts such as surface spills that would be required under NEPA. *In Re: Windfall Oil & Gas, Inc.*, 2015 WL 3782844, at *31 (Env. App. Bd. 2015) ("the UIC permitting process is narrow in its focus and the Board's review of the UIC permit decisions extends only to the boundaries of the UIC permitting program, which is limited to the protection of underground sources of drinking water.").

[398] *Applications for Permits to Drill*, BUREAU OF LAND MGMT., https://www.blm.gov/programs/energy-and-minerals/oil-and-gas/operations-and-production/permitting/applications-permits-drill [https://perma.cc/P4ZW-LCDU] (last visited Mar. 14, 2023).

CCS projects may trigger other federal environmental obligations, but these are not likely to comprehensively address concerns about cumulative air pollution, disparate pollution burdens, or increased earthquakes.[399] For example, CCS facilities that include fossil fuel combustion will likely trigger one or more Clean Air Act permitting requirements, but these requirements have not succeeded in preventing industrial pollution hot spots to date.[400]

Depending on location, CCS projects may also jeopardize endangered species or harm critical habitats of such species, which could trigger Endangered Species Act requirements.[401] CCS projects may also trigger National Pollutant Discharge Elimination System permit requirements for discharge of process wastewater or stormwater.[402] While these are both important environmental protections, neither would address the lifecycle GHG, disparate air pollution, or seismicity concerns articulated above.

CO_2 can indirectly cause hazardous contamination of groundwater, and therefore, CCS projects could potentially be subject to regulation of hazardous waste regulation under the Resource, Conservation, and Recovery Act (RCRA).[403] The EPA, however, has conditionally exempted Class VI well injection of CO_2 from the RCRA.[404]

Finally, Congress and the executive branch have sought to streamline CCS permitting under these various statutes.[405] The White House Council on Environmental Quality has released a report and guidance that both include recommendations on how federal agencies can better coordinate permitting.[406] These recommendations include encouraging agencies to "consider developing programmatic environmental reviews, such as tiered documents or programmatic environmental impact statements (PEISs) under NEPA, or programmatic biological opinions under the ESA, where such

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[399] *See generally* Appendix A, WHITE HOUSE COUNCIL ON ENV'T QUALITY, REPORT TO CONGRESS ON CARBON CAPTURE, UTILIZATION, AND SEQUESTRATION (2021) [hereinafter CEQ CCS PERMITTING REP.], https://www.whitehouse.gov/wp-content/uploads/2021/06/CEQ-CCUS-Permitting-Report.pdf [https://perma.cc/HBJ8-TXCS].

[400] *See, e.g.*, Ann E. Carlson, *The Clean Air Act's Blind Spot: Microclimates and Hotspot Pollution*, 65 UCLA L. REV. 1036 (2018).

[401] CEQ CCS PERMITTING REP., *supra* note 399, at app. A.

[402] *Id.*

[403] RCRA establishes comprehensive protections for the generation, transport, and disposal of hazardous waste. 42 U.S.C. §§ 6922–25.

[404] 40 C.F.R. § 261.4(h); *see* CEQ CCS PERMITTING REP., *supra* note 399, at 60.

[405] Carbon Capture, Utilization, and Sequestration Guidance, Council on Environmental Quality, 87 Fed. Reg. 8808 (Feb. 16, 2022); CEQ CCS PERMITTING REP., *supra* note 399, at 40.

[406] 87 Fed. Reg. at 8808; CEQ CCS PERMITTING REP., *supra* note 399.

analyses can facilitate more efficient and effective environmental reviews of multiple projects while maintaining strong community engagement."[407]

In addition, the Utilizing Significant Emissions with Innovative Technologies (USE IT) Act—enacted as part of a 2020 appropriations law—made CCS infrastructure eligible for a "permitting review process created under Fixing America's Surface Transportation Act (FAST-41)."[408] This voluntary process requires agencies to create a timeline for permitting processes, supervised by a Federal Permitting Improvement Steering Council seeking to provide additional transparency and certainty in project development timelines.[409] The process does not change any substantive permitting requirements. At least one CCS project has used the process, although critics have questioned whether it is effective in speeding up permitting reviews.[410]

There are several other federal laws that would likely bear on CCS permitting that are not discussed here because they do not bear on addressing climate and other harms mentioned above.[411]

2. *State Regulatory Framework*

States also have significant regulatory authority over CCS projects. As described above, the key permit for geologic sequestration of CO_2 is the federal SDWA Class VI permit. The SDWA employs a familiar federalist structure, allowing states to regulate underground injection more stringently than required by the federal "floor."[412] While states may apply for and receive primacy for a Class VI program, only two states have received primacy to date.[413]

States also exercise broad authority under their general police power over the regulation of subsurface economic activity on state-owned and

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[407] 87 Fed. Reg. at 8809; CEQ CCS PERMITTING REP., *supra* note 399, at 40.

[408] CEQ CCS PERMITTING REP., *supra* note 399, at 31.

[409] *Id.*

[410] Ethan G. Shenkman & Sarah Grey, *CEQ Recommends Carbon Capture Policy Fixes to Congress for the Path Ahead | Advisories*, ARNOLD & PORTER (July 22, 2021), https://www.arnoldporter.com/en/perspectives/advisories/2021/07/ceq-recommends-carbon-capture-policy [https://perma.cc/8TF5-DKLE].

[411] For example, sub-seabed CO_2 injection may be subject to regulation under the Marine Protection, Research, and Sanctuaries Act (MPRSA) or the Outer Continental Lands Act. Class VI Final Rule, 75 Fed. Reg. at 77236–37.

[412] 42 U.S.C. § 300g–2(a)(1).

[413] *See* discussion *supra* at Section V.A.1.

privately-owned land within a state, including oil and gas drilling.[414] States use this authority to prevent waste of mineral resources, protect the correlative rights of mineral rights holders, and "protect the public health, safety, and welfare" of residents.[415] The states of California, Maryland, New York, Oregon, Vermont, and Washington have even banned hydraulic fracturing over concerns about harms to health and welfare,[416] and such bans have withstood legal challenges to date.[417]

Several states have enacted CCS-specific laws to address barriers to CCS project development.[418] Among other issues, these often seek to transfer liability from the developer to the state after a certain period, establish a fund for long-term management and monitoring of CCS facilities, clarify legal rules for subterranean pore space ownership, and clarify the relationship of mineral rights to CO_2 storage rights.[419]

Until recently, states have not used their police power to establish health and welfare protections specifically related to CCS. The exception is

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[414] JOHN LOWE ET AL., CASES AND MATERIALS ON OIL AND GAS LAW 703 (7th ed. 2018).

[415] These state mineral rights management statutes were often enacted in the early parts of the 1900s and have long withstood a variety of legal challenges. *Id.* at 699, 703.

[416] Chloe Marie, *Oregon and Washington Enact Hydraulic Fracturing Bans*, CTR. FOR AGRIC. & SHALE L. (July 19, 2019), https://aglaw.psu.edu/shale-law-in-the-spotlight/oregon-and-washington-enact-hydraulic-fracturing-bans/ [https://perma.cc/E47K-LKNH]; *California denies most fracking permits ahead of 2024 ban*, AP NEWS (Nov. 24, 2021), https://apnews.com/article/climate-business-environment-and-nature-california-gavin-newsom-1671bce1013b33ba9013b8c06ac2c645 [https://perma.cc/DS7T-3EZV].

[417] Constitutional challenges against fracking have generally argued that fracking is either preempted by federal law, is a regulatory taking, or violates due process. *See* Eric Schlabs, *Legal Challenges to Fracking Regulation*, REG. REV. (Aug. 18, 2015), https://www.theregreview.org/2015/08/18/schlabs-fracking-regulation/ [https://perma.cc/7ZEG-3HJC]; State hydraulic fracturing bans have been unsuccessfully challenged on such grounds, but courts have not ruled on the merits. *E.g.*, Morabito v. New York, 803 F. App'x 463, 467 (2d Cir.), *as amended* (Feb. 27, 2020), *cert. denied*, 141 S. Ct. 244 (2020), *reh'g denied*, 141 S. Ct. 886 (2020) (dismissed by district court on grounds of sovereign immunity); Yaw v. Del. River Basin Comm'n Del. Riverkeeper Network, 49 F.4th 302 (3d Cir. 2022) (district court dismissed for lack of standing); *cf.* Minnesota Sands, LLC v. Cnty. of Winona, 940 N.W.2d 183 (Minn. 2020), *cert. denied sub nom.,* Minnesota Sands, LLC v. Cnty. of Winona, Minnesota, 141 S. Ct. 1054 (2021) (county ban of mining not a regulatory taking); *see generally* Kevin J. Lynch, *Regulation of Fracking Is Not a Taking of Private Property*, 84 U. CIN. L. REV. 39 (2018).

[418] HOLLY JAVEDAN, REGULATION FOR UNDERGROUND STORAGE OF CO_2 PASSED BY U.S. STATES, https://sequestration.mit.edu/pdf/US_State_Regulations_Underground_CO2_Storage.pdf [https://perma.cc/3YBP-4QHL].

[419] *Id.*; Ben Reiter, *States look to attract CCS projects through laws shifting long term CO_2 storage liabilities*, NIXON PEABODY LLP (May 2, 2022), https://www.nixonpeabody.com/insights/articles/2022/05/02/states-look-to-attract-ccs-projects-through-laws-shifting-long-term-co2-storage-liabilities [https://perma.cc/D2NQ-X9LF]; *see also* Joseph Schremmer, *Pore Space Property*, 2021 UTAH L. REV. 1 (2021), https://dc.law.utah.edu/ulr/vol2021/iss1/1 [https://perma.cc/5M7G-6X8Y].

California, which in 2022 enacted the first state law in the nation to expressly require the development of a Carbon Capture, Removal, Utilization, and Storage Program.[420] Among other elements, the law requires the state's Air Resources Board to evaluate the "efficacy, safety, and viability" of CCS technologies, and to ensure that all CCS technologies "minimize . . . co-pollutant emissions," local water and air pollution from related construction and transportation, and "seismic impacts."[421] Many details of these protections remain to be established through regulation.[422] Notably, the City of New Orleans also enacted a resolution banning CCS in the city.[423]

B. The Incentive Framework

Federal tax incentives have arguably been the most important component of federal climate policy to date. Federal tax credits for wind and solar power plants have been a critical factor in driving tremendous growth in renewable energy deployment and displacing fossil fuel power plants.[424] The Inflation Reduction Act has dramatically increased tax incentives for CCS applications, opening the door for rapid acceleration of CCS deployment if other barriers can be overcome. In addition, tax credits for CCS set qualifications that require CCS projects to sequester a minimum amount of CO_2. With the exception of the hydrogen tax credits, however, these incentives do not require minimum lifecycle GHG standards.

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[420] S.B. 905, 2022 Leg., Reg. Sess. (Cal. 2022).

[421] S.B. 905, 2022 Leg., Reg. Sess. (Cal. 2022).

[422] *See id.*

[423] City Council of New Orleans Res. No. R-22-219 (May 19, 2022), available at https://www.all4energy.org/uploads/1/0/5/6/105637723/r-22-219_ccs_ban.pdf [https://perma.cc/X8NX-HHY7].

[424] The other factors are state renewable portfolio standards and the rapidly decreasing costs of natural gas due to fracking and horizontal drilling. TRIEU MAI ET AL., IMPACTS OF FEDERAL TAX CREDIT EXTENSIONS ON RENEWABLE DEPLOYMENT AND POWER SECTOR EMISSIONS, at i, iv (Nat'l Renewable Energy Lab'y 2016), https://www.nrel.gov/docs/fy16osti/65571.pdf [https://perma.cc/D4YT-VUSR].

1. CCS–45Q Tax Credits

The primary incentive driving CCS projects is the 45Q tax credit, first enacted in 2008.[425] Congress recently made major changes increasing the amount and flexibility of the credit in the IRA.[426]

After the IRA, tax incentives for CCS are nearly equal to reported dollar-per-ton CCS deployment costs;[427] although, only if specified wage and apprenticeship requirements are met.[428] Developers of industrial- or power plant-CCS projects can receive a credit value of $85/metric ton CO_2 sequestered in geologic formations, and $60/metric ton for CO_2 stored through EOR (these values increase to account for inflation beginning in 2027).[429] DAC project developers can receive a credit value of up to $180/ metric ton for CO_2 sequestered in geologic formations, and $130/metric ton for CO_2 stored through EOR (increasing with inflation in 2027).[430]

The 45Q tax credit allows developers to recover the credit during the first 12 years that their project is in operation, based on tons of CO_2 that they permanently sequester.[431] The IRA extended the deadline by which facilities must begin construction to qualify to January 1, 2033.[432] The legislation also provided additional flexibility for how developers can access and assign the benefit. Developers can elect to use "direct pay," which allows them to receive a tax refund without raising tax equity for their project.[433] Developers may also elect to transfer their credits annually to an unrelated taxpayer.[434] Taken together, these changes dramatically increase the level of the financial incentive and remove transactional and administrative barriers to using these subsidies.

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[425] The credit now applies to all carbon oxides, not just CO_2. Emergency Economic Stabilization Act of 2008, Pub. L. No. 110-343, 122 Stat. 3767 (2008) (codified as amended at 26 U.S.C. § 45Q).

[426] Pub. L. No. 117-169, 136 Stat. 1926, at § 13104 (2022).

[427] CCS is often estimated to cost over $100 dollars per ton, although estimates vary dramatically depending on the application. *See* discussion *supra* accompanying note 152.

[428] These requirements, which were lobbied for by labor and community groups, provide developers with a 5 times multiplier to base credits. Pub. L. No. 117-169, 136 Stat. 1926, at § 13104(d)(1) (2022).

[429] Carbon Capture and Use projects can also qualify for credits. *See id.* § 13104(c).

[430] *See id*. § 13104(c)-(d).

[431] JONES, *supra* note 21, at 21–22.

[432] H.R. 5376, 117th Cong. § 13104(a) (2022).

[433] *Inflation Reduction Act Provides Boost and Benefits to Carbon Capture Utilization and Storage Industry*, BAKER & HOSTETLER LLP (Aug. 23, 2022), https://www.bakerlaw.com/alerts/inflation-reduction-act-provides-boost-benefits-carbon-capture-utilization-storage-industry [https://perma.cc/CXA7-YR8F].

[434] *Id*.

The 45Q tax credits also establish minimum requirements for qualifying projects. Qualifying projects must sequester a minimum amount of CO_2 annually: 18,750 metric tons per year for power plants, and 12,500 metric tons per year for other facilities.[435] Notably, the IRA significantly lowered these thresholds.[436] Power plants with CCS must be "designed" to capture seventy-five percent of CO_2 produced, although there is no requirement that they actually achieve this level.[437]

Projects must also meet regulatory requirements for "permanent geologic storage" intended to ensure that CO_2 "does not escape into the atmosphere."[438] The IRS determined, however, that receiving a SDWA permit (Class II or VI) and complying with subpart RR GHG reporting requirements would be sufficient.[439] In short, qualifying for the tax credit does not require any higher level of "permanent geologic storage" certification than is otherwise required by the SDWA regulations. The CCS credits do not require projects to meet any minimum lifecycle GHG emission standard to qualify.

2. *Hydrogen–45V Tax Credit*

In addition, the IRA also created new tax incentives for "clean hydrogen" in section 45V of the tax code, which provide an increasing amount of revenue per kilogram (kg) of "qualified clean hydrogen" produced depending on the lifecycle GHG emissions.[440]

Importantly, the 45V credit does establish a minimum lifecycle GHG standard. To qualify, the hydrogen produced must have lifecycle emissions of no more than four kilograms of CO_2e per kilogram of hydrogen. Hydrogen with lifecycle emissions at the lowest qualifying level can receive a tax incentive of 60 cents per kilogram of clean hydrogen produced (adjusted for inflation after 2022) if prevailing wage and apprenticeship requirements

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[435] The threshold for DAC facilities is 1,000 metric tons per year. Pub. L. No. 117–169, § 13104(a).

[436] *Inflation Reduction Act Provides Boost and Benefits to Carbon Capture Utilization and Storage Industry*, BAKER & HOSTETLER LLP (Aug. 23, 2022), https://www.bakerlaw.com/alerts/inflation-reduction-act-provides-boost-benefits-carbon-capture-utilization-storage-industry [https://perma.cc/CXA7-YR8F].

[437] 26 U.S.C. § 45Q(d)(2).

[438] *Id.* at § 45Q(f)(2).

[439] 26 C.F.R. § 1.45Q-3.

[440] 26 U.S.C. § 45V(a).

are met. At the "cleanest" level—less than 0.45 kg CO_2e—producers can receive a three dollar credit.[441]

Notably, it is unclear whether *blue* hydrogen in many regions could qualify for even the lowest credit level because of its high upstream methane emissions. The DOE assessed that at the four kg/CO_2e threshold, blue hydrogen could likely only meet that level when achieving "~95% carbon capture and sequestration" and "and ensuring that upstream methane emissions do not exceed 1%."[442] Many oil and gas producing regions in the U.S. are assessed to have higher methane leak rates than one percent. The EPA estimated the national leak rate for natural gas production to be 1.5%.[443] Many independent analyses find this to be conservative; an alternative independent assessment found the national leak rate to be 2.3%.[444] Some regions are assessed to have much higher leak rates. For example, in the Permian basin—which spans Texas and New Mexico and is the busiest oil producing region in the country—multiple analyses have found leak rates ranging from 2.7% to as high as 9.4%.[445] One possible exception is in the Marcellus Shale region in Appalachia, where several studies have found leak rates lower than one percent.[446]

Because green hydrogen does not have the same kind of upstream GHG emission intensity, green hydrogen powered by renewable energy is not

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[441] *See id.* § 45V(b)(2)(C).

[442] This analysis assumed that the steam methane reformation process was powered by electricity that "represents the average U.S. grid mix." It is possible that blue methane using a cleaner grid mix—or dedicated renewable energy—would meet the standard. U.S. DEP'T OF ENERGY, CLEAN HYDROGEN PRODUCTIONS STANDARD (CPHS) DRAFT GUIDANCE 3 (2022) [hereinafter Clean Hydrogen Draft Standard], https://www.hydrogen.energy.gov/pdfs/clean-hydrogen-production-standard.pdf [https://perma.cc/RQP6-FMXV].

[443] Yuanlei Chen et. al., *Quantifying Regional Methane Emissions in the New Mexico Permian Basin with a Comprehensive Aerial Survey*, 56 ENV'T. SCI. & TECH. 4317, 4318 (2022), https://doi.org/10.1021/acs.est.1c06458 [https://perma.cc/3ZU2-KQPP].

[444] *Id.*; Ramon A. Alvarez et. al., *Assessment of methane emissions from the U.S. oil and gas supply chain*, 361 SCIENCE 186, 186 (2018), https://www.science.org/doi/10.1126/science.aar7204 [https://perma.cc/U5DV-76NK].

[445] Yuzhong Zhang et al., *Quantifying Methane Emissions from the Largest Oil-Producing Basin in the United States from Space*, 6 SCIENCE ADVANCES 1, 1 (2020), https://www.science.org/doi/10.1126/sciadv.aaz5120 [https://perma.cc/XG8T-G22J] (finding 2.7% leak rate in the Permian Basin); Chen et al., *supra* note 443, at 4317 (finding 9.4% leak rate in New Mexico Permian Basin and describing two studies that found leak rates between 3–4%).

[446] Zachary R. Barkley et al., *Quantifying Methane Emissions from Natural Gas Production in North-Eastern Pennsylvania*, 17 ATMOSPHERIC CHEMISTRY & PHYSICS 13941, 13943 (2017), https://acp.copernicus.org/articles/17/13941/2017/ [https://perma.cc/N8NE-HBTG].

expected to have a problem achieving the minimum lifecycle emission if it is powered by renewable energy.[447]

3. Hydrogen Hub

Another significant incentive is the eight billion dollars in the Bipartisan Infrastructure Law to support at least four regional "hydrogen hubs."[448] The law defines the hubs to be "a network of clean hydrogen producers, potential clean hydrogen consumers, and connective infrastructure located in close proximity," and intends for the hub program to "demonstrate the production, processing, delivery, storage, and end-use of clean hydrogen."[449]

The law also requires the Department of Energy to develop a standard for "clean hydrogen" set at a "carbon intensity equal to or less than 2 kilograms of carbon dioxide-equivalent produced at the site of production per kilogram of hydrogen produced."[450] Notably, this legislative floor for "clean hydrogen" articulates a carbon intensity standard based only on the GHG emissions at the site of production.[451] In other words, the statutory minimum does not require consideration of lifecycle emissions, including critical upstream methane emissions.

The law does, however, allow the DOE to set a more ambitious standard, so long as the agency considers technological and economic feasibility.[452] The DOE recently issued draft guidance proposing a minimum clean hydrogen standard that is a cradle-to-grave *lifecycle* GHG standard, as opposed to a "site of production" only standard.[453] The standard was proposed at the same level as the minimum threshold for the 45V clean hydrogen tax incentive standard: four kg CO_2e per kilogram of hydrogen produced.[454]

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[447] Green hydrogen has no problem meeting the requirements when renewable energy is produced on-site to power the electrolyzers. At the time of this writing, there was a debate as to under what circumstances green hydrogen could qualify when using grid energy. Ricks et al., *supra* note 175, at 014025; Catherine Clifford, *Inside the fierce debate over clean hydrogen, with $100 billion in federal subsidies on the line*, CNBC (Mar. 3, 2023), https://www.cnbc.com/2023/03/03/clean-hydrogen-industry-future-depends-on-ira-tax-credit.html [https://perma.cc/KQ7R-8S98].

[448] 42 U.S.C. § 16161 (a)-(b).

[449] 42 U.S.C. § 16161 (a)-(b).

[450] 42 U.S.C. § 16166(a)-(b).

[451] 42 U.S.C. § 16166(a)-(b).

[452] 42 U.S.C. § 16166(a)-(b).

[453] Clean Hydrogen Draft Standard, *supra* note 442, at 4.

[454] Clean Hydrogen Draft Standard, *supra* note 442, at 4.

Hydrogen hubs will need to "*demonstrably aid achievement* of, but . . . not necessarily . . . meet," the final clean hydrogen production standard.[455]

DOE announced that it is planning to fund six to ten hydrogen hubs at a total of six to seven billion dollars in its first (and potentially only) round of awards.[456]

4. Other Incentives and Funding

There are a number of other federal incentives that CCS developers may be able to take advantage of. The DOE's Loan Program Office has made $8.5 billion available for loan guarantees that can be used for commercial scale fossil CCS projects through its Advanced Fossil Energy Projects Solicitation.[457] The DOE is directly funding five CCS projects through its Carbon SAFE initiative, which seeks to "characterize, permit, and construct commercial-scale CO_2 storage complexes with capacity to safely and securely store greater than fifty million metric tons of CO_2."[458] Congress has authorized the USDA Rural Utilities Service Electric Program to provide loans for the development of power plants with CCS.[459] Coal-fired power plants can also take advantage of the Section 48A program, which provides tax credits to coal-fired power plants that sequester 70 percent of total CO_2 emissions.[460]

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Table 1 below demonstrates how the combined federal regulatory and incentive structure for CCS only provides partial protections from the climate and non-climate harms, risks, and uncertainties described in Sections IV and V.

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[455] DEP'T OF ENERGY, REGIONAL CLEAN HYDROGEN HUBS FUNDING OPPORTUNITY ANNOUNCEMENT at 14 (2022), [hereinafter H2Hubs FOA], https://oced-exchange.energy.gov/Default.aspx#FoaId4dbbd966-7524-4830-b883-450933661811 [https://perma.cc/S94Y-WPHS] (scroll down to documents, select "Full Funding Opportunity Announcement").

[456] *Id*. at 6.

[457] CEQ CCS Permitting Rep., *supra* note 399, at 46.

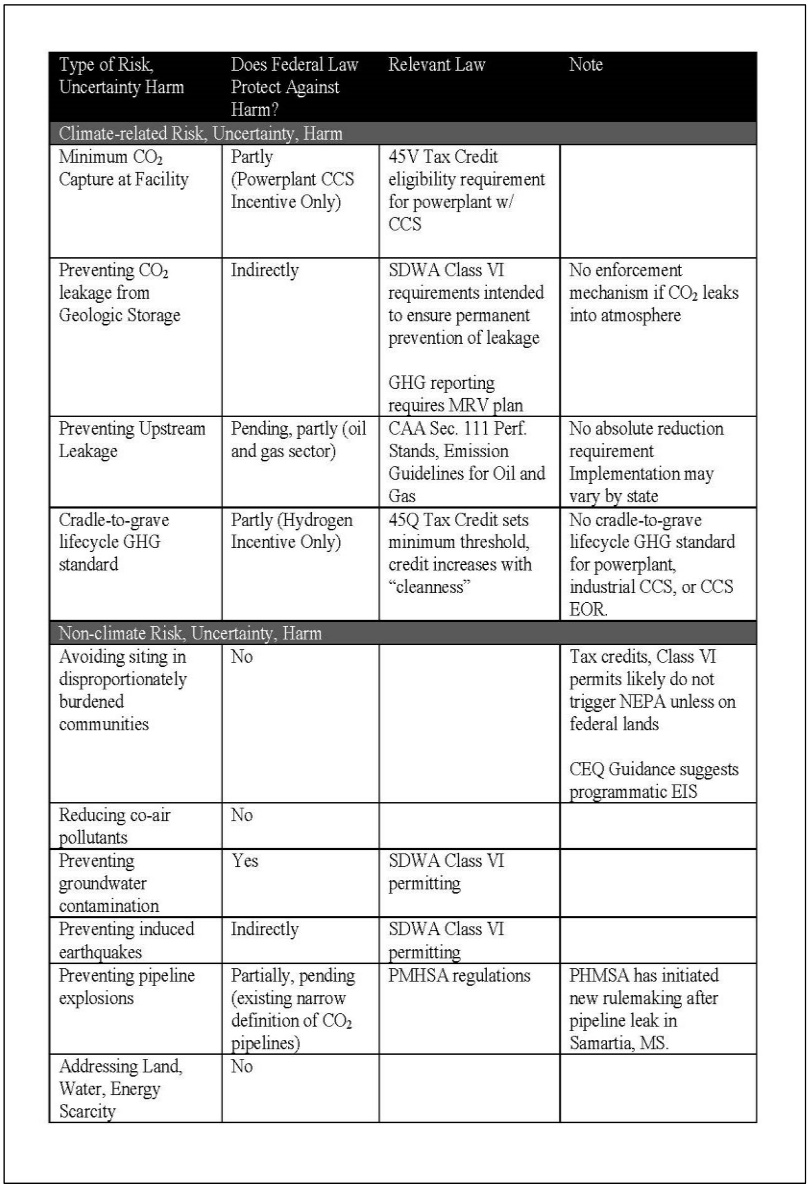
[458] *Id*. at 44.

[459] *Id*. at 47.

[460] 26 U.S.C. § 48A.

TABLE 1

SUMMARY OF REGULATORY COVERAGE OF FEDERAL POLICIES



Type of Risk, Uncertainty Harm	Does Federal Law Protect Against Harm?	Relevant Law	Note
Climate-related Risk, Uncertainty, Harm			
Minimum CO_2 Capture at Facility	Partly (Powerplant CCS Incentive Only)	45V Tax Credit eligibility requirement for powerplant w/ CCS	
Preventing CO_2 leakage from Geologic Storage	Indirectly	SDWA Class VI requirements intended to ensure permanent prevention of leakage GHG reporting requires MRV plan	No enforcement mechanism if CO_2 leaks into atmosphere
Preventing Upstream Leakage	Pending, partly (oil and gas sector)	CAA Sec. 111 Perf. Stands, Emission Guidelines for Oil and Gas	No absolute reduction requirement Implementation may vary by state
Cradle-to-grave lifecycle GHG standard	Partly (Hydrogen Incentive Only)	45Q Tax Credit sets minimum threshold, credit increases with "cleanness"	No cradle-to-grave lifecycle GHG standard for powerplant, industrial CCS, or CCS EOR.
Non-climate Risk, Uncertainty, Harm			
Avoiding siting in disproportionately burdened communities	No		Tax credits, Class VI permits likely do not trigger NEPA unless on federal lands CEQ Guidance suggests programmatic EIS
Reducing co-air pollutants	No		
Preventing groundwater contamination	Yes	SDWA Class VI permitting	
Preventing induced earthquakes	Indirectly	SDWA Class VI permitting	
Preventing pipeline explosions	Partially, pending (existing narrow definition of CO_2 pipelines)	PMHSA regulations	PHMSA has initiated new rulemaking after pipeline leak in Samartia, MS.
Addressing Land, Water, Energy Scarcity	No		

C. State Climate Policy Markets for CCS

States have led the development and implementation of climate regulatory programs in the United States, including renewable and zero-carbon electricity standards, GHG cap programs, and fuel standards.[461] In some cases—as with renewable energy mandates—these state programs create markets for certain technologies even beyond their borders. Where such policies drive the development of technologies, states can have leverage to set eligibility requirements.

One state program, California's Low Carbon Fuel Standard (LCFS), is beginning to create a financial incentive for some types of CCS applications and is setting more rigorous climate requirements in the process.[462] California's LCFS sets a declining annual carbon intensity standard for high-carbon transportation fuels.[463] Every year, California producers and importers of transportation fuels must meet the carbon intensity standard in aggregate based on all of the fuel that they have offered for sale.[464] The carbon intensity of a fuel is assessed on a lifecycle basis.[465] Regulated entities can meet the carbon intensity standard by lowering the aggregate carbon content of their fuels, or by procuring credits from producers of low-carbon fuels.[466] For example, a California producer of gasoline and diesel could comply with the standard by reducing the carbon intensity of their production processes, by entering the market with new low-carbon fuels (like advanced biofuels), or by purchasing credits from other low-carbon fuel producers (like advanced biofuel producers).[467]

Because fuels are assessed on a lifecycle basis, the carbon intensity score of a fuel is based on its carbon emissions involved in production, processing, refining, transportation, and end-use (e.g., combustion).[468] If fuel producers can reduce the carbon intensity of their fuel at any stage, they can earn a lower carbon intensity score. For producers of fuels that are below the carbon-intensity standard, this means that their fuels generate more "credits" that can be offered for sale to high-carbon fuel producers (e.g. petroleum fuel producers).[469]

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[461] *See generally* Arroyo et al., *supra* note 23.

[462] *See generally* Cal. Air Res. Bd., Low Carbon Fuel Standard Basics 1 [hereinafter LCFS Basics], https://ww2.arb.ca.gov/resources/documents/lcfs-basics [https://perma.cc/L2ZV-RW3L] (last visited Oct. 3, 2022).

[463] *See* CAL. HEALTH & SAFETY CODE § 38560; 17 CAL. CODE REG. § 95481 (2023).

[464] LCFS Basics, *supra* note 462, at 5–6; 17 CAL. CODE REG. § 95485 (2023).

[465] LCFS Basics, *supra* note 462, at 5–6; 17 CAL. CODE REG. §§ 95485, 95488.3 (2023).

[466] *See* LCFS Basics, *supra* note 462, at 5–6.

[467] *See generally id.*

[468] 17 CAL. CODE REG. § 95488.3 (2023).

[469] LCFS Basics, *supra* note 462, at 11.

In 2018, California promulgated a CCS protocol for its LCFS.[470] This allows fuel producers to get credit for reducing the carbon intensity of their fuels based on the carbon sequestered in the fuel production process, so long it meets protocol requirements.

California LCFS credit prices have historically been relatively high, selling for approximately $175 to $200 per metric ton of CO_2 equivalent in recent years.[471] These high prices created an effective financial incentive for development of new low-carbon fuel markets.[472] For the same reason, now that the protocol is finalized, the LCFS is expected to incentivize lower-carbon fuels that make use of CCS.[473] Several biofuel projects that use CCS have been announced that plan to combine revenue from the 45Q tax credit and California's LCFS to make them profitable.[474]

To qualify, CCS projects must apply for and receive a permanence certification before they can receive any credits.[475] Key to the certification is a monitoring plan that requires at least 100 years of post-injection monitoring.[476] CCS projects must contribute between eight and sixteen percent of the credits they generate to a "buffer account" to maintain the environmental integrity of the credits in the case of CO_2 leakage.[477] In

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[470] *See generally* Cal. LCFS CCS Protocol, *supra* note 71.

[471] Although as of this writing LCFS credit prices have dropped to a little over $100 per metric ton. *See* CAL. AIR RES. BD., MONTHLY LCFS CREDIT TRANSFER ACTIVITY REPORT FOR JULY 2022 (2022) (comparing monthly average for July versus annual averages 2019–2021).

[472] *See* JULIE WITCOVER, STATUS REVIEW OF CALIFORNIA'S LOW CARBON FUEL STANDARD, (U.C. Davis Inst. of Transp. Stud. 2018), https://escholarship.org/uc/item/445815cd [https://perma.cc/DB93-6WFF] (describing growth of biofuel market to meet LCFS); Stephanie Kelly & Jarrett Renshaw, *Plotting future, U.S. biofuel industry seeks federal clean fuel program from Biden*, REUTERS (Nov. 20, 2020, 4:16 PM), https://www.reuters.com/article/us-usa-biofuels-carbon-exclusive-idUSKBN28100O [https://perma.cc/76XL-2RGE].

[473] Deepika Nagabhushan, *California's CO_2 Reduction Program Opens Doors to CCS*, CLEAN AIR TASK FORCE (Nov. 10, 2018), https://www.catf.us/2018/11/californias-co2-reduction-program/ [https://perma.cc/RC3U-BV68].

[474] Carlos Anchondo, *Company announces Colo.'s first commercial CCS projects*, ENERGYWIRE (May 12, 2022, 7:39 AM), https://subscriber.politicopro.com/article/eenews/2022/05/12/company-announces-colo-s-first-commercial-ccs-projects-00024173 [https://perma.cc/7LP3-22U2]; Geiver, *supra* note 26.

[475] Cal. LCFS CCS Protocol, *supra* note 71, at 31.

[476] *Id.* at 103.

[477] ALEX TOWNSEND & IAN HAVERCROFT, THE LCFS AND CCS PROTOCOL: AN OVERVIEW FOR POLICYMAKERS AND PROJECT DEVELOPERS, GLOB. CCS INST. 4 (2020), https://www.globalccsinstitute.com/wp-content/uploads/2019/05/LCFS-and-CCS-Protocol_digital_version-2.pdf [https://perma.cc/ST6S-3GJJ].

general, California's CCS protocol requirements go beyond EPA Class VI well requirements.[478]

Oregon also implemented a similar Clean Fuel Standard program,[479] and Washington is in the process of implementing one.[480] Neither program has a CCS protocol at this time.

In addition to a LCFS, California also operates a cap-and-trade program that requires aggregate emission reductions from a wide range of sources throughout the economy, including both stationary sources and providers of petroleum transportation fuels.[481] Some have speculated that California may adopt a CCS protocol for the cap-and-trade program in the future.[482]

Similarly, in recent years, at least 13 states have enacted 100 percent zero-carbon electricity standards for at least their largest electric utilities.[483] These policies require electricity suppliers to supply consumers with electricity from zero-carbon generating sources by some year in the future (set between 2040 and 2050).[484] These standards usually begin as renewable portfolio standards, meaning that in early years, an increasing percentage of electricity must be from renewable sources.[485] But in the out years—usually between 2035 and 2045—they switch to requiring the incremental portion of electricity to come from zero-carbon sources.[486] These zero-carbon sources could be renewable, nuclear, or geothermal energy, or, in some cases, fossil fuel sources with CCS.[487] As with California's LCFS,

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[478] *Id*. at 17.

[479] OR. REV. STAT. § 468A.265 (2021); OR. ADMIN R. 340-253-0000 (2022).

[480] Act of May 18, 2021, ch. 317, 2021 Wash. Sess. Laws 2662; WASH. REV. CODE. § 70A.535.005 (2021).

[481] CAL. AIR RES. BD., OVERVIEW OF EMISSIONS TRADING PROGRAM (2015), https://ww2.arb.ca.gov/our-work/programs/cap-and-trade-program/about [https://perma.cc/VH48-GMYK].

[482] Nagabhushan, *supra* note 473; EJEONG BAIK ET AL., AN ACTION PLAN FOR CARBON CAPTURE AND STORAGE IN CALIFORNIA: OPPORTUNITIES, CHALLENGES, AND SOLUTIONS 82 (Energy Futures Initiative, Stan. Precourt Inst. for Energy, Stan. Earth Stan. Ctr. for Carbon Storage 2020), https://static1.squarespace.com/static/58ec123cb3db2bd94e057628/t/5f91b40c83851c7382efd1f0/1603384344275/EFI-Stanford-CA-CCS-FULL-10.22.20.pdf [https://perma.cc/JJK5-XY3Q].

[483] *Table of 100% Clean Energy States*, CLEAN ENERGY STATES ALLIANCE, https://www.cesa.org/projects/100-clean-energy-collaborative/guide/table-of-100-clean-energy-states/ [https://perma.cc/8SW5-2FDF] (last visited Oct 3, 2022).

[484] *See* Arroyo, *supra* note 23, 397–401.

[485] *See e.g.*, NMSA 1978 § 62-16-4(A) (2004, as amended in 2019) (requiring 80 percent renewable-supplied electricity by 2040).

[486] *Id.* (requiring 100 percent zero-carbon source-supplied electricity by 100%).

[487] Lee Beck & Jennifer Lee Gordon, *The devil's in the details: Policy implications of "clean" vs. "renewable" energy*, UTILITY DIVE (Mar. 14, 2019), https://www.utilitydive.com/news/the-devils-in-the-details-policy-implications-of-clean-vs-renewable/550441/.

these standards could create markets for power plants with CCS applications in the future.[488]

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In sum, the IRA has supercharged the federal incentives for CCS and hydrogen. However, federal regulations and tax incentive criteria only provide partial protections against the risks, harms, and uncertainties related to CCS. In particular, federal regulations establish standards to protect against drinking water contamination by leaking CO_2 and require a 50-year monitoring and verification plan as part of GHG reporting regulations. Hydrogen tax credits also require projects to meet a minimum lifecycle GHG standard, and award higher credit amounts for "cleaner" projects. But federal regulations or incentive requirements do not establish lifecycle standards for non-hydrogen CCS projects, do not address environmental justice concerns about site location nor disparate pollution impacts, and do not directly address concerns about induced seismicity nor impacts of CCS on water or food scarcity.

States have considerable authority to regulate CCS projects, although states have largely not used this authority to specifically address health and welfare effects of CCS; California recently enacted the first legislation to do so. States implementing climate policies, such as a low-carbon fuel standard, may also be able to set the terms for qualifying CCS projects if they choose to allow them to qualify.

VI. CONSIDERATIONS FOR STATE POLICYMAKERS

Against this backdrop of federal policy that accelerates CCS deployment but does not fully address risks, uncertainties, and harms, states are poised to play a key role in completing the regulatory picture. As described above, states generally have broad authority to regulate exploitation of subsurface resources, likely extending far enough to allow limiting or even banning CCS applications where there is a strong public interest.[489]

Moreover, given the polarized nature of the country and a variety of political factors, many political analysts do not expect another opportunity

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[488] Wendy B. Jacobs & Michael Craig, *Legal Pathways to Widespread Carbon Capture and Sequestration*, 47 ENV'T. L. REP. 11022, 11024 (2017).

[489] *See* Lynch, *supra* note 417.

for federal climate legislation in the near future.[490] If they are correct, federal CCS regulation will remain constrained to existing legal authority.[491]

The combination of supercharged federal incentives, partial federal regulation, and robust state legal authority means that states are in a powerful position to shape how and to what degree the deployment of CCS plays out in the near term. States with robust climate policies can establish standards for CCS projects that supply fuel or electricity to the state, and to the extent that their mandates help finance CCS project development, out-of-state projects may choose to comply with these incentives to quality for the state's regulatory program. This dynamic is already occurring with the California LCFS.

This is not surprising, as states have historically taken the lead in developing climate policy in the U.S in the absence of robust federal climate policy.[492] Many scholars have also demonstrated how state innovations have served as models for subsequent federal laws,[493] and how innovations by some states have become widely adopted by others.[494]

As this Article has shown, CCS may be both a critical tool for addressing climate change—and providing economic benefits to fossil fuel communities —while also being a tool that has very significant drawbacks, risks, and uncertainties. It is notable that environmental justice communities have strongly opposed CCS deployments, largely based on concerns that CCS technologies will maintain or exacerbate historic harms from fossil fuel communities and based on concerns that the net GHG benefits of CCS will not materialize.

This Article concludes with brief thoughts on the principles and tools states might consider to establish a robust framework for regulating CCS while addressing climate and equity principles. Given the focus of this Article on describing the state of science and the state-federal regulatory dynamic, this section is only a starting point for further exploration.

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[490] *See* Leber, *supra* note 22.

[491] Though there are arguably significant steps the federal government can take to better protect against CCS risks, uncertainties, and harms, including under NEPA and RCRA, but that is beyond the scope of this Article.

[492] *See, e.g.*, Arroyo et al., *supra* note 23.

[493] *E.g., id*., Kirsten H. Engel, *Harnessing the Benefits of Dynamic Federalism in Environmental Law*, 56 EMORY L.J. 159, 182–84 (2006); Ann E. Carlson, *Iterative Federalism and Climate Change*, 103 NW. U. L. REV. 1097, 1099, 1102 (2009).

[494] Barry G. Rabe et al., *State Competition as a Source Driving Climate Change Mitigation*, 14 N.Y.U. ENV'T L.J. 1, 12–43 (2005).

A. Consider Whether to Do It at All, and if Doing It, When to Do It and Where to Do It?

CCS will likely be a component of the climate solution to some degree, and effective use of CCS will likely require near-term demonstration and commercial scaling. But that does not mean that all states need to open the gates for all CCS projects, or to open them all at once, or even to open them at all. Given the risks, uncertainties, and drawbacks identified above, as well as potential climate and economic benefits, state policymakers may want to consider taking time to develop a comprehensive approach to CCS policy. Colorado provides an example, as the state convened a task force to consider the role of CCS in the state's climate policies and recently released recommendations.[495]

Policymakers may also consider proactively pausing CCS implementation or limiting the types of CCS projects that may address concerns related to risks and drawbacks. A number of states and the federal government have implemented "study periods" for other technologies, such as oil and gas development using horizontal fracturing.[496] This time can be used to develop a comprehensive policy approach involving multiple stakeholders.

B. Seek Out Input From Environmental Justice (EJ) and Impacted Communities

In recent years, a growing number of voices have drawn attention to and developed the idea of what it means to achieve a "just transition" to a zero-carbon world.[497] This concept, and the related concepts of "environmental

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[495] *Colorado Carbon Capture, Utilization and Sequestration Task Force Releases Recommendations on the Role of Carbon Capture in Meeting State Climate Goals*, COLORADO ENERGY OFFICE (Feb. 3, 2022), https://energyoffice.colorado.gov/press-releases/colorado-carbon-capture-utilization-and-sequestration-task-force-releases [https://perma.cc/DE53-6VT7].

[496] *E.g.*, Naveena Sadasivam, *New York State of Fracking: A ProPublica Explainer*, PROPUBLICA, (July 22, 2014), https://www.propublica.org/article/new-york-state-of-fracking-a-propublica-explainer [https://perma.cc/6YP5-RZ8M].

[497] *E.g.*, Julian Brave NoiseCat, *No, climate action can't be separated from social* justice, THE GUARDIAN (June 11, 2019), https://www.theguardian.com/commentisfree/2019/jun/10/no-climate-action-cant-be-separated-from-social-justice [https://perma.cc/YZX2-8XAM]; Darren McCauley & Raphael Heffron, *Just transition: integrating climate, energy and environmental justice*, 119 ENERGY POLICY 6 (2018), https://www.sciencedirect.com/science/article/pii/S0301421518302301 [https://perma.cc/F3M7-U2CA]; J. Mijin Cha et al., *Environmental Justice, Just Transition, and a Low-Carbon Future for California*, 50 ENV'T L. REP. 10216 (2020).

justice" and "climate justice," maintain that climate solutions should address the harms of legacy pollution that are already disparately affecting communities of color and low-income communities; that policymakers should take active steps to mitigate burdens caused by climate change policies, especially those that fall on poorer people and minority communities; and that all people should be able to access the economic opportunities created by the shift to a cleaner economy.[498] A key value of these movements is procedural justice—the idea that affected communities should have a meaningful opportunity to be involved in policymaking.[499] In keeping with the idea that state policymakers can consider developing a CCS policy, policymakers should also consider how to incorporate the perspectives of people that are likely to be most impacted by CCS policies.

C. Do Not Allow CCS to Displace Action on Other Zero-Emission Technologies

The IPCC and IEA are clear that any climate benefits of CCS applications only accrue to the extent that they do not displace other efforts to decarbonize the economy; for example, by continuing to reduce reliance on fossil fuels and to shift to a low-carbon electricity grid.[500] State policymakers should consider how to design policies that do not displace these efforts. For instance, CCS may be one option to provide firm power to support an electricity grid with a high degree of renewables (and again, there are other viable options), but a pathway that results in a large number of fossil fuel power plants with CCS will likely not achieve the needed GHG reductions after residual lifecycle emissions are taken into account. Policymakers should consider how to ensure that their policies prioritize aggressive decarbonization of the power sector, transition to renewable energy, electrification of the economy, and promotion of energy efficiency, and only incentivizes CCS as a supplement to these core policies. For example, state policy makers may want to limit the degree to which CCS can be used to meet state clean electricity mandates to ensure that fossil power plants with CCS can only be used, if at all, to supply needed firm power after most of the grid has transitioned to renewables or nuclear energy.

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[498] McCauley & Heffron, *supra* note 497, at 4; Cha et al., *supra* note 497, at 10217.

[499] Robert R. Kuehn, *A Taxonomy of Environmental Justice*, 30 ENV'T L. REP. (2004).

[500] *See* IEA CCUS REP., *supra* note 32.

D. Set Rigorous Standards for "Clean" CCS Projects

Perhaps the chief shortcoming of the federal CCS regulatory and tax incentive regime is the failure to set minimum lifecycle GHG standards for power plant and industrial CCS projects and for EOR with CCS. Requiring lifecycle emissions standards for CCS would prevent projects with high upstream emissions from weakening the effectiveness of state climate policies. States should consider setting such standards for compliance with their climate programs.

E. Set Rigorous, Binding Upstream Standards for Methane and Hydrogen

A chief reason why CCS projects using natural gas may not provide *any* net GHG benefit is because of the upstream methane emissions associated with natural gas production.[501] Similarly, the benefits of hydrogen as an energy carrier can be undermined by hydrogen leakage from transmission and distribution.[502] States should consider using their authorities to set rigorous emission reduction and monitoring standards for both methane and hydrogen. Regarding methane, Colorado, New Mexico, and California all provide examples of such standards,[503] and all states will be required to develop their own standards once the EPA finalizes methane emission guidelines for the oil and gas sectors.[504]

F. Limit or Disincentivize CCS Projects that Harm Environmental Justice Communities

If states allow CCS, they should consider allowing only those projects that either do not create EJ concerns or mitigate them. This could be achieved in a variety of ways, including using EJ mapping to identify disfavored

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[501] *See* discussion *supra* at Section III.B.3.

[502] *Id.*

[503] *See* Jon Goldstein, *Lessons from New Mexico and Colorado's leading methane rules*, ENV'T DEFENSE FUND (May 5, 2022), https://blogs.edf.org/energyexchange/2022/05/05/lessons-from-new-mexico-and-colorados-leading-methane-rules/ [https://perma.cc/NR4V-Y47T].

[504] *EPA's Proposal to Reduce Climate-and Health-Harming Pollution from the Oil and Natural Gas Industry: Overview*, EPA.GOV, https://www.epa.gov/system/files/documents/2021-11/2021-oil-and-gas-proposal.-overview-fact-sheet.pdf [https://perma.cc/HT9R-H4FD] (last visited Nov. 2, 2022).

areas,[505] creating more robust laws to consider surface effects,[506] or creating restrictions on CCS projects sitting next to residential areas,[507] among others.

G. If Allowing CCS in Climate Programs, Require Rigorous Climate Accounting and Consider EJ Factors

California's CCS protocol is expected to drive the development of biofuel projects that use CCS.[508] These projects, whether in state or out of state, will need to meet California's more rigorous CCS requirements.[509] To the extent that states are considering ways to allow credit for CCS in clean fuel, cap-and-trade, or clean electricity mandates, they should similarly consider only allowing projects to qualify if they meet rigorous climate standards. States should also consider adding equity requirements to these standards; for example, by ensuring that projects take robust steps to reduce local air pollution.

H. Send Revenue to Impacted Communities

There are a variety of ways for states to generate revenue from climate programs that include CCS. These ways include cap-and-trade allowance auctions, aggregator programs in a Clean Fuel Standard, and impact fees, among others.[510] To the extent that states promote CCS as part of their climate solution, states should consider implementing revenue-generating policies to help mitigate some of the harms that CCS may cause or exacerbate in effected communities.

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[505] *See, e.g.*, Tiffany Eng & Marybelle Nzegwu, CALENVIROSCREEN: A CRITICAL TOOL FOR ACHIEVING ENVIRONMENTAL JUSTICE (California Environmental Justice Alliance 2018), https://caleja.org/wp-content/uploads/2018/08/CEJA-CES-Report-2018_web.pdf [https://perma.cc/Z6KP-7Z72].

[506] Mark Squillace, *Managing Unconventional Oil and Gas Development as If Communities Mattered*, 40 VT. L. REV. 525 (2016).

[507] *E.g.,* Taryn Luna., *California lawmakers OK buffer zones between new oil wells and homes, schools*, L.A. TIMES (Aug. 31, 2022), https://www.latimes.com/california/story/2022-08-31/california-lawmakers-ok-buffer-zones-between-new-oil-wells-and-homes-schools [https://perma.cc/GR6S-XJYJ].

[508] *See* discussion *supra* at Section V.C.; Nagabhushan, *supra* note 473.

[509] *See* Energy Futures Initiative & Stanford University, *supra* note 482, at 20.

[510] *See, e.g.*, *Auction Information*, CAL. AIR RES. BD., https://ww2.arb.ca.gov/our-work/programs/cap-and-trade-program/auction-information [https://perma.cc/ET22-FX9K] (last visited Oct. 4, 2022); J. Peter Byrne & Kathryn A. Zyla, *Climate Exactions*, 75 MD. L. REV. 758 (2016).

VII. CONCLUSION

Absent dramatic near-term reductions of energy demand and fossil-fuel use, CCS applications of various types will likely be necessary to limit warming to 2 degrees, and especially to limit warming to 1.5 degrees. Limiting warming to 1.5 degrees may be more important given alarming science about the potential for triggering climate tipping points. At the same time, CCS applications are at an early stage of deployment in the context of permanent geologic sequestration. The overall lifecycle GHG reduction benefit of such applications depends on factors such as the overall long-term capture rate at the facility and the ability to reduce GHG emissions from across the supply chain, especially upstream and in hydrogen transport. CCS policies also have other risks and drawbacks, including risk of groundwater contamination, pipeline hazards, and induced earthquakes. Perhaps most significantly, environmental justice advocates have strongly criticized many CCS application for perpetuating or exacerbating disparate harms from oil and gas extraction. CCS can also offer benefits, however, including potentially helping fossil fuel worker communities achieve a just transition and lowering overall costs to the public in an economic transition.

The IRA has supercharged incentives for CCS projects, but federal policies only partially protect against CCS risks, uncertainties, and harms. Most significantly, federal policies do not establish lifecycle GHG standards for power plant and industrial CCS or for EOR with CCS. Neither do they directly address environmental justice impacts, induced seismicity, or concerns about land and food scarcity. Against this backdrop of partial federal regulations, states have broad legal authority to address federal regulatory gaps through state climate policies. These may include comprehensive planning processes to determine whether and how to use CCS as a part of a climate solution. They can also include gathering input from affected communities, setting rigorous lifecycle standards, requiring reductions in upstream emissions, requiring or incentivizing projects to reduce environmental justice harms, and sending revenue to impacted communities.