SETTING THE STAGE FOR DIRECT AIR CAPTURE IN WYOMING

C2ES CLIMATE *INNOVATION* 2050

by

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Both public and private sector actors are increasingly interested in direct air capture (DAC) and other carbon management technologies, driven in part by increased ambition of companies' carbon management commitments and significantly increased federal incentives for deployment. This has significant implications for Wyoming, whose long history of energy development has produced a legacy of communities with deep expertise in underground resources and reservoir management. Regulatory expertise and conditions like Class VI primacy create a smoother path to project permitting, creating a tremendous opportunity to build the nation's first generation of large-scale DAC facilities and lead the industry in its development. In May 2023, C2ES organized a roundtable bringing together policymakers, businesses, nonprofits, and other stakeholders in the region to explore this opportunity and the associated regulatory and technological challenges in Wyoming. This brief summarizes key takeaways from the discussion and offers recommendations for state and federal policymakers, to help grow this nascent industry in Wyoming and the nation.

INTRODUCTION

REGIONAL ROUNDTABLES

Efforts to accelerate the transition to the low-carbon economy of the future are accelerating across all sectors of the economy. To chart a pathway to sustainable, long-term prosperity, communities must be able to leverage their unique strengths and capitalize on emerging economic opportunities, while addressing barriers that are often poorly understood outside of their communities.

To that end, the Center for Climate and Energy Solutions (C2ES) is hosting a series of regional roundtables to bring together local, state, and federal policymakers; businesses of all sizes; community organizations and nonprofits; academics and issue experts; trade associations; investors; philanthropy; economic development organizations; and others. These conversations are meant to elevate the perspectives of a diverse set of stakeholders who are deeply embedded in their communities and uniquely positioned to speak to the needs of their states and regions. They are also meant to create opportunities to integrate local perspectives into state and federal policy decisions and, importantly, identify concrete steps to better align the long-term vitality of these communities with the urgent task of reaching economy wide net-zero emissions.

Our second roundtable of 2023, held in Laramie, Wyoming, took place in May and brought together approximately 55 participants, representing companies, nonprofits, government (including federal, state, local, and tribal governments), colleges and universities, and economic development organizations. This brief summarizes key takeaways from the discussion and—building on insights from the event and other conversations with local stakeholders—provides C2ES recommendations meant to support the development of direct air capture in the state in a way that achieves both climate and economic development goals.

FRAMING THE DISCUSSION IN WYOMING

With the existing energy expertise, favorable regulatory environment, and geology conducive to permanent sequestration, Wyoming is poised to be a leader in the development and deployment of engineered carbon dioxide removal technologies, and specifically direct air capture (DAC).

For more than a century, Wyoming has supplied much of the energy used by the rest of the United States. The state produces more coal than any other state, it is the largest producer of natural gas from federal leases, and it is the second-largest producer of crude oil from onshore federal leases. In total, Wyoming exports more than 90 percent of the energy it produces.[1] Wyoming is well-known for its "energy IQ:" its expertise in resource extraction, energy production, and other associated industries. Its workers have a long, proud legacy of serving the energy industry and possess crucial skills, such as mineral extraction, infrastructure construction, and operations and maintenance. In addition to fossil energy, Wyoming's share of renewables is growing rapidly, with wind power doubling since 2019 to account for 22 percent of the state's net electricity generation in 2022.[2] The state has also led the nation in supporting the development of carbon management technologies, like point-source carbon capture and sequestration. Its geography is conducive not only to fossil fuel extraction, but also permanent geologic sequestration. Carbon management could represent the state's next opportunity to utilize its natural resources and maximize the value of its pore space for carbon sequestration.

Mining and fossil fuel extraction are major contributors to Wyoming's gross domestic product and tax revenue, with a severance tax on mineral resources between 2 and 6 percent.[3] However, as demand for fossil fuels decreases and interest in renewables and carbon management technologies grow, the state seeks to diversify its economy and revenue stream. It has leveraged a tax on wind energy production of $1 per megawatt hour (MWh) since 2012 and supported other industries' growth in the state to reduce its dependence on natural resource revenues.[4]

Wyoming's state government and private sector have leaned in to the growing carbon management industry, supporting carbon capture, sequestration, and utilization (CCUS). Wyoming is one of only two states in the nation with Class VI primacy (the other is North Dakota). With Class VI primacy, state regulators—rather than the U.S. Environmental Protection Agency—approve permits for new Class VI wells for carbon dioxide geologic sequestration.[5] (Class VI wells are wells used to inject carbon dioxide into deep rock formations for long-term geologic storage.[6]) This makes it significantly easier for project developers to get approval to drill new Class VI wells in Wyoming than in other states. Additionally, Wyoming's regulations of pore space (i.e., the underground reservoirs where carbon can be sequestered) are clear, with ownership of pore space belonging to the owner of the surface land, although it may be transferred to another owner separately from the surface land.[7]

Governor Mark Gordon has been public in his support for carbon capture technology, seeing it as a way to support the state's coal industry while reducing carbon emissions, as well as an opportunity for communities with a legacy of supporting fossil fuel development to transition into carbon management. He favors a "net-negative" standard within the state that would require a percentage of all new electricity generated to be carbon negative.[8]

With the existing energy expertise, favorable regulatory environment, and geology conducive to permanent sequestration, Wyoming is poised to be a leader in the development and deployment of engineered carbon dioxide removal technologies, and specifically direct air capture (DAC).

THE U.S. CARBON DIOXIDE REMOVAL LANDSCAPE

Both the federal government and the private sector are interested in carbon dioxide removal technology. Corporations including Microsoft, Shopify, and Stripe have made ambitious, public commitments to become "carbon negative," removing more carbon dioxide each year than they emit.[9] For example, Stripe, Alphabet, Shopify, Meta, McKinsey, and other businesses collaborated to launch Frontier, an advance market commitment to purchase at least $1 billion of permanent carbon removal between 2022 and 2030.[10]

The federal government is also investing billions to incentivize private investment that can help grow a domestic carbon removal industry, supporting projects around the country. Most recently, the Inflation Reduction Act of 2022 (IRA) updated and enhanced the federal tax credit aimed at incentivizing carbon sequestration, Section 45Q of the U.S. Internal Revenue Code. From its establishment in 2008 to the 2022 passage of the IRA, it offered $50 per ton of carbon sequestered and $35 per ton of carbon utilized for enhanced oil recovery (EOR) and other uses.[11] Now, with the update from the IRA, the credit offers specific amounts for carbon captured through DAC of $180 per ton of carbon sequestered and $130 per ton of carbon utilized. Separately, for carbon captured from industrial and power generation facilities, the credit is $85 per ton for carbon sequestered and $60 per ton for carbon utilized.[12] The IRA also allows for direct pay and makes the credit transferrable, which makes the incentive more accessible to early-stage companies by making these projects more attractive to debt financing and reducing the need for tax equity investors who would usually charge higher rates of return to support these projects. Finally, it reduces the capture requirement for eligibility from 100,000 tons per year to 1,000 tons per year. Essentially, the enhanced 45Q tax credit makes the credit significantly larger, especially for DAC, and significantly easier for project operators to claim.

The Infrastructure Investment and Jobs Act of 2021 (IIJA, also known as the Bipartisan Infrastructure Law) is another recent law that includes incentives for DAC. It establishes a Regional DAC Hubs program through the Department of Energy's (DOE) Office of Clean Energy Deployment (OCED). The Bipartisan Infrastructure Law allocates $3.5 billion for four regional DAC Hubs, each intended to facilitate the deployment of DAC projects and required to have the capacity to capture and sequester or utilize at least one million metric tons of carbon dioxide annually.[13] Applications for the first round of funding, totaling $1.2 billion, were due in March 2023. In August 2023, DOE awarded $1.2 billion to one regional direct air capture hub each in Texas and Louisiana and announced its intent to award $99 million to 19 projects supporting feasibility and front-end engineering and design studies for potential DAC hubs across the nation.[14] Wyoming's Regional Direct Air Capture Hub will receive $12.5 million in DOE funding.

The Bipartisan Infrastructure Law also created the Carbon Storage Validation and Testing Program, also administered by DOE.[15] For each fiscal year from 2022 through 2026, DOE will allocate $2.5 billion to develop new or expanded large-scale commercial carbon sequestration projects and the necessary supporting transport infrastructure. In May 2023, just before the roundtable in Wyoming, DOE announced it would award $40.5 million to the University of Wyoming for work on a "commercial, multi-source, large-scale carbon capture and storage hub" in the state.[16]

Similarly, the EPA proposed a new rule in May 2023 covering emissions from existing power plants, requiring all coal units that remain in operation by 2040 to begin capturing 90 percent of their carbon dioxide emissions by 2030.[17] If enacted as proposed, the rule could boost CCUS and raise developers' demand for permanent sequestration.

BOX 1: Policy Recommendations

Facilitate the geologic sequestration of carbon dioxide

- Wyoming's Department of Environmental Quality (DEQ) and the Bureau of Land Management (BLM) should develop a memorandum of understanding (MOU) for geologic sequestration of carbon dioxide to prevent subsurface conflicts among owners and prospective developers and guarantee that access rights are consistent across state, private, and federal lands.
- Congress should create categorical exclusions for certain activities (e.g., small well design and injection modifications) under the National Environmental Policy Act (NEPA) that can streamline geologic storage projects without compromising the safety or environmental impacts of these projects.
- State and federal agencies, including the Wyoming DEQ and BLM, should establish plans for corrective action on existing and legacy wells that can be repurposed for safe carbon injection and storage.
- State and federal agencies, along with academic institutions, should establish educational campaigns to create awareness about the process that project developers must go through to ensure the safety and integrity of carbon injection and storage operations, as well as the rigorous process that project developers must go through to be granted permits.
- State and federal agencies should explore ways to address long-term liability for stored carbon using a shared liability model similar to Wyoming's experience with the abandoned mine land (AML) program.

Support the expansion of a low-carbon energy system to ensure the integrity of DAC projects

- The Wyoming Energy Authority, working with utilities, should develop a plan for building an energy system that can respond to the increasing demand of low-carbon energy from major consumers, including DAC facilities.
- Wyoming should leverage existing infrastructure by adopting CCUS retrofits on existing fossil-based power plants to increase their competitiveness to export clean power to other states with net-zero targets and provide carbon-free power to DAC facilities in the state.
- Congress should enact permitting reform legislation that can enable expansion of power transmission and create economic opportunities for DAC developers instead of relying on developing "renewable islands" just to power these facilities.

Responsibly site DAC projects

- State agencies should identify low-impact sites, including previously industrially disturbed lands, and require project developers to prioritize these sites for their projects.
- Wyoming's DEQ should develop guidance that provides detailed information about how new projects can be sited efficiently, including considerations for land use, capacity, and conservation.
- State agencies should require project developers to demonstrate specific community benefits—such as job creation, workforce development programs, improved transportation or housing infrastructure, or access to renewable energy—in their project proposals.

BOX 1: Policy Recommendations *(continued)*

Maximize economic opportunities for developing a regional DAC hub in Wyoming

- The Wyoming Business Council should coordinate with the state's community colleges to characterize the benefits and risks of DAC projects to local communities, estimate job opportunities for local workforces, and develop training programs necessary to build needed competencies for the carbon management sector.
- The White House Council on Environmental Quality (CEQ) should develop an outreach plan to introduce local communities to Justice40 initiative and available tools such as the Climate and Economic Justice Screening Tool (CEJST) that can clarify the geographic spread of "disadvantaged communities" and help local stakeholders better evaluate the value propositions of new projects.
- Companies and governments should consult tribal nations early in the project development process and work collaboratively to explore economic development opportunities for tribal communities along the carbon management value chain (e.g., equipment manufacturing, capture facilities, pipelines, storage sites).
- Wyoming—in partnership with project developers, labor organizations, and community colleges—should develop apprenticeship programs that can support the transition of traditional fossil energy workers to carbon management jobs to take advantage of the existing skills of fossil energy workers.
- To attract and retain talent, Wyoming should offer funding to help local governments and developers coordinate housing, transportation, childcare, and other wraparound support for workers on carbon management projects, especially those that will be sited in areas remote from population centers.

BACKGROUND: CARBON DIOXIDE REMOVAL

It is important to differentiate between two terms that are often confused: "carbon removal" and "carbon reduction." Carbon removal refers to interventions that capture carbon dioxide from the atmosphere and store it in geological, land, or ocean reservoirs, or in long-lasting products. Carbon reduction, or mitigation, refers to interventions that prevent carbon dioxide from being released into the atmosphere by capturing it from point sources (e.g., industrial facilities, power generating facilities) and storing it in a similar manner. While carbon reduction activities (e.g., carbon capture and storage [CCS] and carbon capture and utilization [CCU]) share some components with carbon dioxide removal (CDR), they do not necessarily result in net-negative carbon dioxide emissions.

While there are different ways to categorize CDR solutions, they can be simply categorized according to their capture/removal mechanism—i.e., nature-based solutions and technological solutions.

Nature-based solutions: increase the biological uptake of carbon dioxide by increasing natural "sinks" or improving natural processes and land-use practices. Nature-based solutions combine the capture and storage processes within the natural carbon cycle.

Technological solutions: utilize separate processes to first capture the carbon dioxide and then store it in dedicated reservoirs or long-lived materials.

While nature-based solutions are largely affordable, ready now, and will be of importance in both the near and long term, technological solutions may be more scalable and more permanent. Given that potential, these technological solutions must continue to be developed and deployed. See Appendix A for a full list of both nature-based and technological solutions.

DIRECT AIR CAPTURE (DAC)

DAC is the direct removal of dilute carbon dioxide from ambient air via chemical bonding. Currently, two types of DAC are being scaled as CDR solutions: chemical liquid solvent DAC and chemical solid sorbent DAC. While there are technical differences between the two methods, they both operate via the removal of carbon dioxide from ambient air by contact with a basic solution (chemical liquid solvents) or a basic modified surface (chemical solid sorbents). Once fixated in a carbonate or carbamate bond, the carbon dioxide can then be liberated from the capture media through the application of heat, producing a high-purity carbon dioxide stream that can be transported to storage sites or industrial plants for utilization. See Figure 1 for a schematic of the DAC value chain.

Advantage: Siting flexibility and low land requirements

One of the main benefits of direct air capture is siting flexibility, which enables project development at locations that avoid competition with other land uses. Because DAC facilities do not require arable land, they can be sited in locations where they will have minimal impact on the surrounding ecosystem, such as brownfields. In addition to siting flexibility, DAC can provide much higher carbon dioxide removal per land area (Mt/acre) than afforestation/reforestation approaches. For example, a DAC facility capable of removing one million tons of carbon dioxide would occupy 1,730 acres (if powered by natural gas with carbon capture) and do the equivalent carbon removal work of 20 million trees, or a forest spanning 100,000 acres.[18]

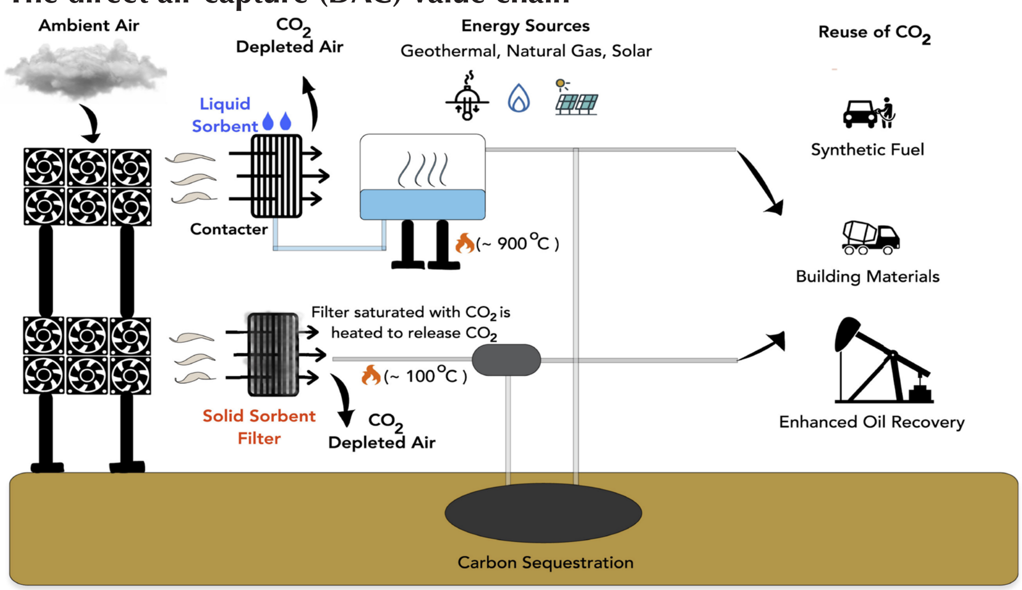
While the footprint of DAC facilities is relatively small, the footprint of the low-carbon energy sources needed to power the facilities could be substantial. For example, data from the National Academy of Sciences indicate that a DAC facility capable of removing one million tons of carbon dioxide powered solely by solar energy would require a land area of almost 14,500 acres (about 1.3 times the size of the city of Laramie, WY).[19] Other technologies, however, such as advanced nuclear, might be able to provide clean electricity for DAC facilities with a relatively small land footprint.

Advantage: Removal potential and scalability

One of the main advantages of DAC systems is that they have a much larger removal potential compared to other engineered removal solutions that are constrained by feedstocks (e.g., biomass for BiCRS) or nature-based solutions that are limited by land availability and biodiversity challenges. DAC facilities have few limits on their removal potential. As long as they have access to low-carbon electricity sources and access to suitable geologic sequestration sites (or utilization opportunities), they can remove many gigatons of carbon dioxide per year.

In addition to needing to be deployed safely and quickly, CDR solutions also need to be deployed at a scale that sequesters enough carbon dioxide to help stabilize global temperatures. While nature-based removals have limitations on scalability due to competition with other land uses, engineered CDR technologies (e.g., DAC) are generally more scalable because they can remove additional emissions without requiring a significantly greater facility-level land footprint. Companies looking to reduce their emissions, especially in hard-to-abate sectors (e.g., cement, steel, chemicals, heavy transport), can benefit from the scalability of engineered CDR technologies

FIGURE 1: The direct air capture (DAC) value chain



Source: Ozkan et al., 2022[1]

to reduce emissions that cannot be addressed through other mitigation efforts (e.g., cleaner energy substitution, energy efficiency, electrification of industrial processes) and reach their carbon-neutrality goals through high-quality, certified carbon offsets.

Advantage: Durability of carbon removal

Technologies like DAC offer durable carbon sequestration, providing effective, permanent carbon removal. Conversely, there are concerns about the potential for reversal of nature-based sequestration. For example, wildfires can release much of the carbon that had been stored during tree growth, negating the removal benefits associated with those forests. In contrast, engineered CDR utilizes separate processes for capturing carbon dioxide and for sequestering it in appropriate geological reservoirs or in long-lived materials (e.g., concrete, aggregate materials). This type of geologic storage has been proven to be safe, with decades of experience in carbon dioxide injection and storage operations demonstrating minimal risk of leakage or release.[20]

In geologic sequestration, carbon dioxide is injected into the pore space of the rock formation, and it can be kept there in a variety of ways: structural/buoyant trapping, residual trapping, solubility trapping, and mineral trapping.

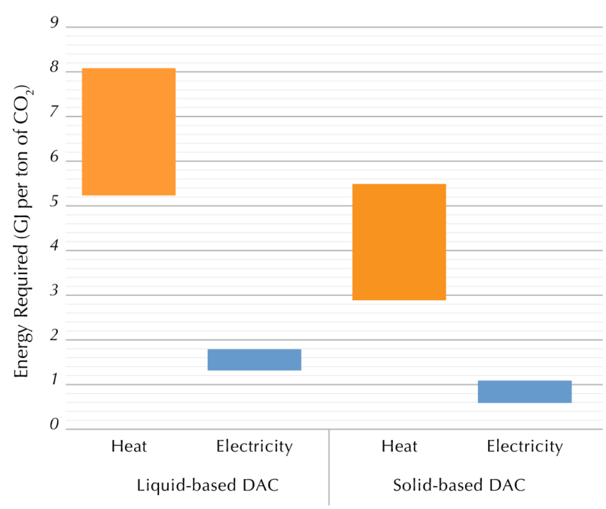
- **Structural/Buoyant trapping**: Similar to the way that naturally occurring oil and gas are trapped underground, the sequestered carbon dioxide can be held in place by layers of low-permeability rock ("caprock") on the top that prevent upward leakage, with porous rock on the sides and below containing fluid that is denser than the carbon dioxide, thereby trapping the carbon dioxide in between.
- **Residual Trapping**: Injected carbon dioxide initially displaces fluid in the rock formations, but as the carbon dioxide moves through the formation, the fluid returns, and some of the carbon dioxide is left behind and trapped in place by surface tension in the pore spaces.
- **Solubility trapping**: When carbon dioxide contacts with the formation fluids, mass transfer occurs as carbon dioxide dissolves into these fluids until equilibrium is reached.
- **Mineral trapping**: The injected carbon dioxide reacts with minerals in the rock and solidifies into carbonates over time, locking the carbon dioxide into the rock formation.

Challenge: Energy requirements

To achieve net carbon removal, the required energy for DAC must come from low-carbon sources. Otherwise, greater emissions will be produced in the operation of the carbon removal technology, eliminating its effectiveness and invalidating any related carbon credits in global carbon markets.

The energy needs of different DAC technologies vary greatly, with liquid solvent technologies requiring a higher operating temperature than solid-based DAC technologies. The liquid solvent system requires heat of up to nearly 900 degrees C (1,652 degrees F) for the calcination process—the decomposition of calcium carbonate into calcium oxide and carbon dioxide. The solid sorbent system, in contrast, only requires an operating temperature of 80–130 degrees C (176–266 degrees F).[21] The high temperature requirements of liquid-based DAC mean only a few low-carbon technologies (e.g., natural gas with carbon capture, nuclear) can provide an adequate amount of clean heat, whereas solid-based DAC's lower heat requirements can be powered by several clean energy technologies (e.g., heat pumps, solar thermal, geothermal). See Figure 2 for a comparison of the energy requirements for DAC systems.

FIGURE 2: Energy requirements for DAC systems



Source: C2ES, based on data from NASEM, 2019; Realmonte et al., 2019; Chatterjee and Huang, 2020; Krekel et al., 2018; Luis, 2016.[2]

Challenge: Water use

Water consumption in DAC systems is a function of the temperature and relative humidity of a given location. While both solid and liquid-based DAC systems use water in closed-loop systems where the water is continuously recycled, water loss still occurs—especially during the sorbent-air contacting process. For liquid-based DAC, capturing a ton of carbon dioxide requires 2–8 tons of water. For solid-based DAC, capturing a ton of carbon dioxide would require around 1.6 tons of water; however, depending on the humidity at the capture site some solid sorbent DAC systems can be water positive (i.e., produce more water than consumed).[22]

Challenge: Costs

In general, the more concentrated carbon dioxide is at the capture point, the less expensive it is to capture. This explains why the costs associated with DAC are much higher compared to point-source carbon capture.

Atmospheric carbon dioxide is much more dilute (412 parts per million, or 0.04 percent) than any industrial point source (e.g., 4–5 percent for natural gas combined-cycle flue gas, 12–15 percent for coal-fired flue gas, 14–33 percent for cement production).[23] This extremely low concentration of ambient carbon dioxide makes the cost of DAC higher compared to other capture/removal technologies. DAC cost estimates vary widely across the literature, typically ranging from $600–$1,000 per ton of carbon dioxide captured.[24] A 2021 assessment by the International Energy Agency, however, estimates the cost of DAC projects to range from $400–$700 per ton.[25] Additional deep cost reductions are expected in the coming decades with technological improvements, large-scale deployment, and increasing availability of low-cost, clean electricity. These developments could conceivably reduce the cost of early commercially viable DAC projects to $190–$230 per ton. Additionally, locational flexibility allows CDR facilities to reduce costs by co-locating with existing or planned carbon transport (i.e., pipelines) and storage infrastructure.

Figure 3 and Figure 4 below show the cost breakdown of both liquid and solid-based DAC systems using data from the National Academies of Sciences.[26] Note that these estimates are developed for a DAC system with a removal capacity of 1 million tons of carbon dioxide per year, assuming a plant life of 30 years and fixed charge factor of 12 percent.

FIGURE 3: Cost Breakdown of Liquid Solvent DAC Systems

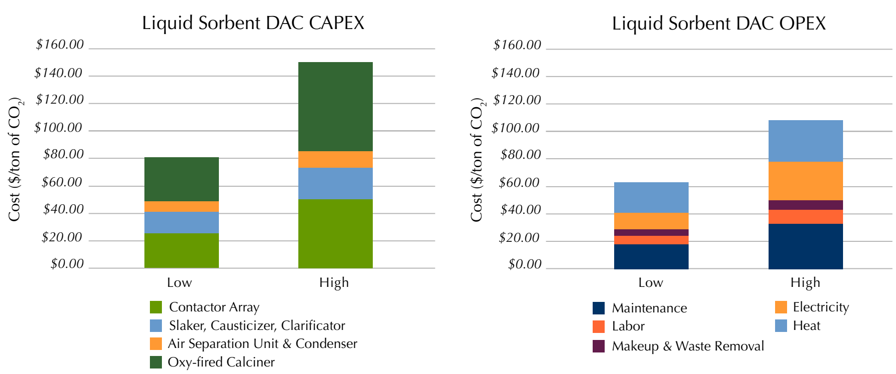
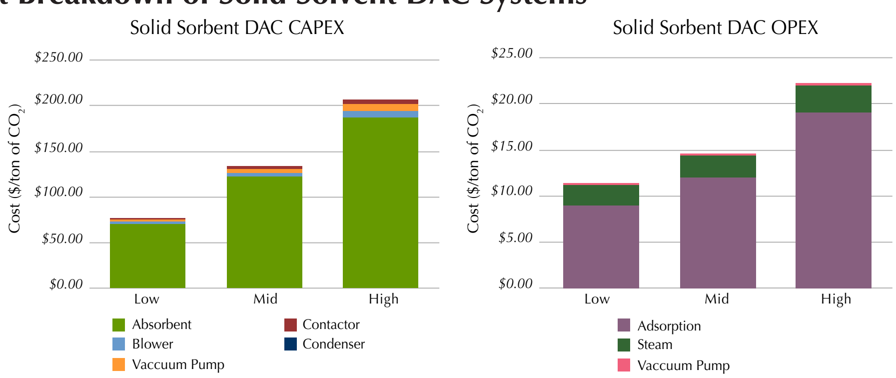


FIGURE 4: Cost Breakdown of Solid Solvent DAC Systems



THEMES FROM THE DISCUSSION

Throughout the full-day roundtable discussion, several key themes emerged. Much of the discussion centered on optimism that the technology could be deployed locally to Wyoming's advantage, particularly given the state's significant geologic sequestration potential and skilled workforce. That said, considering the high energy requirements to operate DAC projects, there was also significant discussion focused on building out low-carbon energy generation and the associated transmission infrastructure. Participants also identified opportunities to maintain strong conservation protections when siting projects, and considered how to best leverage Wyoming's strengths to grow the industry, attract investment, and build up its workforce.

MAXIMIZING ACCESS TO GEOLOGIC SEQUESTRATION

Roundtable participants expressed excitement about the sequestration potential in their state. According to the U.S. Department of Energy's National Energy Technology Laboratory (NETL), Wyoming has underground saline formations with a capacity to store 146–1,540 billion tons of carbon dioxide.[27] To put that in perspective, Wyoming's total, annual carbon dioxide emissions in 2020 was 63 million tons. In theory, the low estimate of Wyoming's saline storage potential would be enough to store the state's carbon dioxide emissions for more than 2,300 years. In addition to saline formations, Wyoming has unmineable coal seams and oil and gas reservoirs with an average carbon storage potential of 6.64 billion tons of carbon dioxide and 590 million tons of carbon dioxide, respectively.[28]

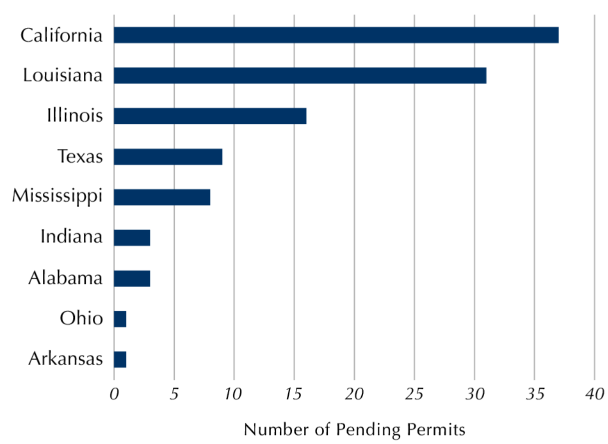
Although Wyoming has tremendous potential for geologic sequestration of carbon dioxide, participants highlighted that it can be challenging to navigate the regulatory landscape to commercialize carbon storage projects. According to a 2008 state law, the ownership of subsurface pore space belongs to the owner of the surface land in the state.[29] Since a large-scale carbon storage project would probably be developed across state, private, and federal lands, project developers need to make sure that they coordinate with these different landowners to have access rights. Also, making sure that these rights are consistent with each other would be necessary to allow projects to be developed in a uniform matter and according to a clear timeline.

One of the main roadblocks for developing permanent carbon storage projects in the United States is the uncertain and lengthy permitting process for Class VI injection wells. Class VI permits are required, under the EPA's Underground Injection Control (UIC) program, for the underground injection of carbon dioxide for the purpose of permanent geologic sequestration. As required by the Safe Drinking Water Act, EPA developed UIC program requirements to be adopted by states, territories, and tribes to protect underground sources of drinking water. However, only two states (North Dakota and Wyoming) currently have primary enforcement authority ("primacy") to permit Class VI wells under the UIC program; the EPA must review Class VI permits anywhere else.

Since the IRA was signed into law in August 2022, EPA has received an influx of applications for Class VI permits to benefit from the enhanced 45Q tax credit for carbon sequestration. There are currently 109 pending applications for Class VI permits at the EPA (Figure 5). However, the long permitting process for these wells could jeopardize the development of many projects by increasing financing costs and risking abandonment of these projects.

There are currently five pending applications for Class VI permits in Wyoming.[30] Although Wyoming

FIGURE 5: States with Pending Class VI Permits at the EPA

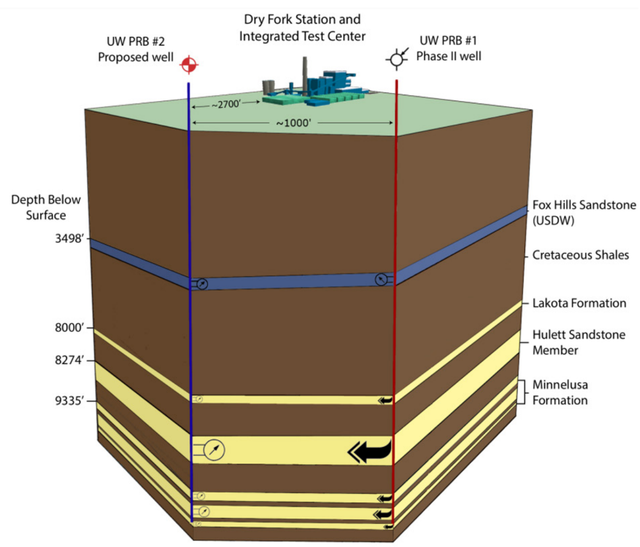


Source: U.S. Environmental Protection Agency, according to data last updated on July 12, 2023. Data does not include approved permits and withdrawn applications.[3]

was granted Class VI primacy in 2020, the state has not approved any permits yet. While primacy is helpful to streamline the permitting process, it is not a silver bullet. The federal government owns almost 50 percent of land in Wyoming, of which BLM owns more than 60 percent, or roughly 17.5 million acres.[31] Diverse land ownership within the state complicates the permitting process, as having a state permitting agency and a federal landowner requires more consultation and cooperation across these agencies. Creating a roadmap for large-scale carbon sequestration projects could help speed the permitting process.

To demonstrate the feasibility of secure, permanent, large-scale carbon storage, Wyoming has been working on the design and development of two test wells. Over the last six years, the Wyoming CarbonSAFE project performed tests for seismicity, porosity, permeability, and fluid chemistry; the project has also collected 625 feet of core samples from nine different geological formations for analysis (see Figure 6).[32] These two wells were designed from the beginning to meet Class VI wells standards to allow for sharing lessons learned and transfer of methodologies to future projects.

FIGURE 6: Schematic cross section of the CarbonSAFE study area



This graphic shows where deep underground carbon storage operations would take place in Wyoming (typically more than 8,000 feet depth), far from oil and gas operations in the upper formations and completely isolated from water-bearing zones that usually occur at shallow depths (less than 4,000 feet depth).

Source: University of Wyoming School of Energy Resources

Policy Recommendations:

- Wyoming's Department of Environmental Quality and the Bureau of Land Management should develop a memorandum of understanding for geologic sequestration of carbon dioxide to prevent subsurface conflicts among owners and prospective developers and guarantee that access rights are consistent across state, private, and federal lands.
- Congress should create categorical exclusions for certain activities (e.g., small well design and injection modifications) under the National Environmental Policy Act that can streamline geologic storage projects without compromising the safety or environmental impacts of these projects.
- State and federal agencies, including the Wyoming DEQ and BLM, should establish plans for corrective action on existing and legacy wells that can be repurposed for safe carbon injection and storage.
- State and federal agencies, along with academic institutions, should establish educational campaigns to create awareness about the process that project developers must go through, to ensure the safety and integrity of carbon injection and storage operations and the rigorous process that project developers must go through to be granted permits.
- State and federal agencies should explore ways to address long-term liability for stored carbon using a shared liability model similar to Wyoming's experience with the abandoned mine land program.

EXPLORING THE ENERGY REQUIREMENTS FOR DAC PROJECTS

DAC facilities require significant amounts of energy in the form of both electricity and heat, which presents one of the main challenges to deploying this technology at scale. Regardless of the technology, the average energy requirement for DAC is 80 percent in the form of heat and 20 percent in the form of electricity.[33] Both forms of energy present different challenges for deploying DAC.

In Wyoming and globally, there is limited availability of low-carbon electricity, which is necessary to make DAC carbon negative. Participants pointed out that to manage this constraint, DAC project developers must also act as clean energy developers to guarantee sufficient clean energy to power their facilities and access the carbon credit markets so crucial to project economics.

Decarbonizing heat is even more challenging than electricity, as most high-heat technologies depend on

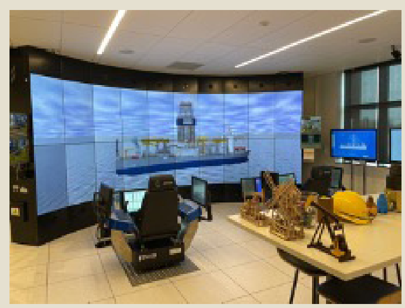
BOX 2: First public demonstration of well drilling and carbon injection operations

As part of the roundtable in Wyoming, C2ES organized a site visit to the Drilling and Completions Simulation Laboratory at the University of Wyoming where roundtable participants had the chance to see the first public demonstration of Class VI well drilling and carbon injection operations. This interactive learning experience used real data from CarbonSAFE* wells in Wyoming modeled specifically for our event.

At this state-of-the-art simulation facility, participants had the chance to experience different stages of project development along the carbon management value chain. From Class VI well drilling to carbon dioxide injection operations, participants used the facility's physical modeling and virtual reality capabilities to see how carbon management projects can be deployed with the highest safety and environmental integrity standards. This visit showcased numerous opportunities for skills transfer between Wyoming's well-established energy sector and the emerging carbon management sector.

While the conversation on skills transferability is a common theme for many emerging sectors, it is not always clear what these jobs are and how workers in legacy energy industries can prepare themselves for these future jobs. Through this simulation, the University of Wyoming highlighted specific jobs (e.g., drillers, wireline operators, geologists, reservoir engineers, coiled tubing operators) that energy workers can easily identify and relate to when they consider job opportunities in carbon management. What makes carbon management a unique sector for workforce transition is that it offers almost one-to-one replacement opportunities for workers in energy communities in Wyoming and across the country.

Dr. Tawfik Elshehabi, Director of the Drilling and Completions Simulation Laboratory and a Senior Lecturer of Energy and Petroleum Engineering at the University of Wyoming, provides an overview of well drilling and carbon injection operations to the roundtable participants.



Roundtable participants also had the chance to tour the University of Wyoming School of Energy Resources where we learned about the school's work on advancing energy technologies and policies to grow and support Wyoming's robust energy sector using the latest technologies and research. It was a great opportunity to learn about Wyoming's energy legacy and the school's strategy for positioning Wyoming as a global leader in energy education, research, and outreach.

* The Carbon Storage Assurance Facility Enterprise (CarbonSAFE) is an initiative funded by the U.S. Department of Energy (DOE) with the ultimate goal of ensuring carbon storage complexes will be ready for large-scale deployment of carbon management technologies.

fossil fuels to reach necessary temperatures. Overcoming this challenge would probably require DAC facilities to be co-located with low-carbon heat sources (e.g., geothermal power plants, a slip-stream of steam from nuclear power plants), since it is technologically impossible to transport heat over long distances.[34]

In addition to clean energy generation, distribution presents additional constraints in the state. Unlike other states with deregulated power sectors, electric utilities in Wyoming manage their own generation and distribution systems. This market design makes it harder for new facilities, like DAC, to get their power from a specific source if these utilities do not have it in their generation portfolio. Also, the scale of the new power generation needed for large DAC projects would require new transmission lines that already face significant delays and permitting challenges.

Another challenge for scaling clean power in Wyoming is the generation capacity limit for net metering, where renewable projects are connected to the power grid and can sell surplus electricity back to the utility. Facilities that use solar, wind, biomass or hydropower to fuel a DAC system can send back surplus electricity to the grid, but the generation capacity of these facilities cannot legally exceed 25 kilowatts.[35] This means that large renewable energy projects would not be able to connect to the grid—which might create a business model where microgrids or industrial power zones are developed just to serve DAC facilities. However, the efficiency (and climate utility) of developing such "renewable islands" just to capture carbon emissions from the atmosphere could be questionable.

Expanding the state's clean energy generation capacity is one method for overcoming DAC-related energy constraints. However, Wyoming can also leverage its existing infrastructure by adopting CCUS retrofits on fossil-based power plants to enable them to provide carbon-free power for DAC projects. This would guarantee that dispatchable power is available 24/7 so DAC facilities can optimally operate. However, because the projects are motivated by an interest in reducing carbon emissions, some DAC developers and investors might not be willing to associate their projects with fossil energy (even if the emissions are captured).

Recognizing that 90 percent of Wyoming's energy products are exported to markets outside the state's borders, the Wyoming Energy Authority has announced their strategy for a net-zero energy mix that can respond to the increasing demand for low-emissions energy.[36] Their "all-of-the-above" approach supports renewable energy and emerging technologies such as hydrogen, CCUS, geothermal, and small modular nuclear reactors. DAC is included as potential major energy consumer that can fit well into this energy strategy.

Policy Recommendations:

- The Wyoming Energy Authority, working with utilities, should develop a plan for building an energy system that can respond to the increasing demand of low-carbon energy from major consumers, including DAC facilities.
- Wyoming should leverage existing infrastructure by adopting CCUS retrofits on existing fossil-based power plants to increase their competitiveness to export clean power to other states with net-zero targets and provide carbon-free power to DAC facilities in the state.
- Congress should enact permitting reform legislation that can enable expansion of power transmission and create economic opportunities for DAC developers instead of relying on developing "renewable islands" just to power these facilities.

SITING CONSIDERATIONS OF DAC PROJECTS

Protecting Wyoming's natural environment requires smart siting of new projects. Wildlife conservation is one of the most important issues across socio-political demographics in Wyoming and can offer common ground for constructive conversations about climate solutions. To successfully deploy DAC (and other new technologies) in Wyoming, project developers need to ensure the siting and construction of their facilities actively consider land use and conservation. Projects that take these factors into consideration are more likely to get support from local communities, avoid permitting delays, and ultimately succeed.

The main concerns around the siting of new projects in Wyoming are related to impacts on water resources, ungulate habitat, migratory birds, and sagebrush habitat. By focusing development on low-impact sites and previously industrially-disturbed lands, project developers can reduce conflicts and lower risks for their projects.

One of the available tools that can help with siting these projects in Wyoming is the Brightfields Energy Siting Initiative (BESI), a mapping tool developed by

The Nature Conservancy to place new projects on previously disturbed lands (see Figure 7).[37] This tool offers a unique collection of data about existing infrastructure, disturbed areas, site characterizations, and areas of conservation value that can help project developers mitigate siting impacts.

In addition to the ecological and physical siting impacts, developers should also consider their proximity to communities, and whether associated benefits like job creation, workforce development programs, improved revenue for transportation or housing infrastructure, and access to renewable energy could also bring positive impacts to communities.

Policy Recommendations:

- State agencies should identify low-impact sites, including previously industrially disturbed lands, and require developers to prioritize these sites for their projects.
- Wyoming's DEQ should develop guidance that provides detailed information about how new projects can be sited efficiently, including considerations for land use, capacity, and conservation.
- State agencies should require project developers to demonstrate specific community benefits—such as job creation, workforce development programs, improved transportation or housing infrastructure, or access to renewable energy—in their project proposals.

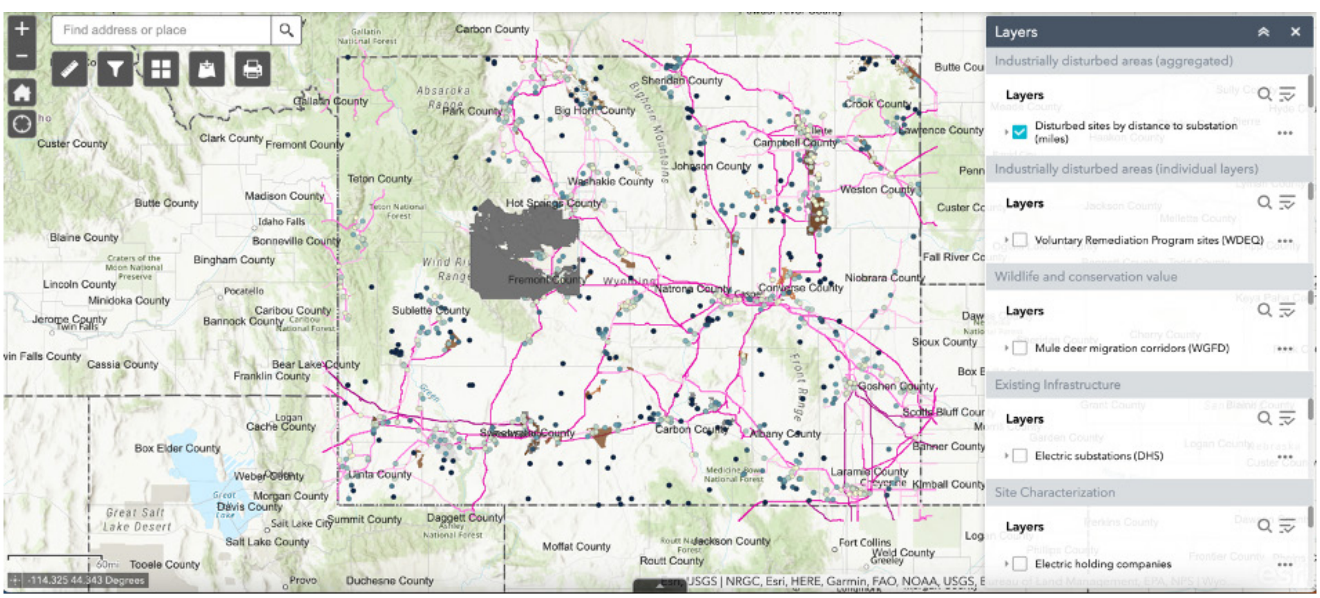
IDENTIFYING ECONOMIC OPPORTUNITIES FOR DEVELOPING A REGIONAL DAC HUB

Wyoming has a history of supporting new energy technologies, and DAC can offer a business model that is aligned with the state's energy legacy. For decades, Wyoming businesses have been extracting resources from the ground and selling energy products to other states. Roundtable participants emphasized that DAC is the next step in that traditional natural resource utilization model where emissions from these energy products are captured and stored underground or utilized to make low-carbon products.

It might be clear how DAC project developers can benefit from working in Wyoming (e.g., suitable geology, supportive policy, skilled workforce), but it is less clear how local communities would benefit from hosting these projects. Highlighting specific benefits for towards local communities early in the planning process can help build the local support that will be essential for the success of these projects.

The main source of revenue for DAC projects is the enhanced 45Q tax credit that offers $130 per ton of carbon dioxide and $180 per ton of carbon dioxide for utilization and storage, respectively. However, these enhanced values of the tax credit depend on fulfilling prevailing wage and apprenticeship requirements. Otherwise, projects developers would receive only 20 percent of the enhanced value ($26 per ton of carbon dioxide for utilization and $36 per ton of carbon dioxide

FIGURE 7: Brightfields Energy Siting Initiative (BESI) map tool



for storage) which would not be sufficient for developers to breakeven. This has already prompted DAC developers to engage with local communities about opportunities for creating new good-paying jobs and programs to train local workers to participate in developing these projects. Communities and local policymakers hoping to attract DAC projects can also engage proactively with developers to gain these benefits.

DAC can also create a new opportunity for Wyoming to access emerging markets by offering carbon removal services and credits to companies that want to meet their net-zero (or even net-negative) emissions goals. In addition to energy companies and point-source emitters, these companies can include financial institutions, information technology, automotive, and retail. Other forms of carbon utilization present economic benefits to the state. For instance, there are growing global markets for low-carbon fuels, particularly sustainable aviation fuels (SAF), where captured carbon can be used as a feedstock.

Wyoming can also leverage future growth in the state's DAC industry by attracting DAC equipment manufacturers (e.g., pumps, contactors, condensers, adsorbents). Expanding the state's DAC ecosystem can draw more project developers to the state to take advantage of lower transportation costs and low supply chain disruption risk as global demand increases for this equipment.

Efforts to bolster the economic benefits of deploying DAC can contribute to Wyoming's continued leadership in the energy sector, diversifying and boosting the competitiveness of the state's energy industry, and enhancing the resilience of the state's economy.

Policy Recommendations:

- The Wyoming Business Council should coordinate with the state's community colleges to characterize the benefits and risks of DAC projects to local communities, estimate job opportunities for local workforces, and develop training programs necessary to build needed competencies for the carbon management sector.
- The White House Council on Environmental Quality should develop an outreach plan to introduce local communities to Justice40 initiative and available tools such as the Climate and Economic Justice Screening Tool that can clarify the geographic spread of "disadvantaged communities" and help local stakeholders better evaluate the value propositions of new projects.
- Companies and governments should consult tribal nations early in the project development process and work collaboratively to explore economic development opportunities for tribal communities along the carbon management value chain (e.g., equipment manufacturing, capture facilities, pipelines, storage sites).

WORKFORCE DEVELOPMENT AND JOB OPPORTUNITIES

As the low-carbon economy grows, including the carbon management sector, it is critical to prepare the workforce for changes in skills and competencies required in emerging industries, including DAC. This training, and the economic opportunities it will create, should be made available to local communities, particularly those most heavily burdened by historic pollution and/or most heavily impacted by the low-carbon transition. It is equally important to ensure that the current workforce can utilize and transfer relevant skills and competencies into new jobs in these emerging industries. Many of the skills in the oil and gas workforce, for example, could be put to good use in the carbon removal sector, including the operation and maintenance of carbon dioxide pipelines, drilling and completion of injection wells, geological surveying and sampling, and monitoring and safety of geologic sequestration. DAC and other carbon management projects could facilitate a transition that allows workers and companies alike to leverage existing knowledge and capacity building. It is essential that state and local governments and DAC project developers work together to ensure a just and well-managed transition in which the existing skilled workforce can participate in building a net-zero (or even net-negative) future.

Policy Recommendations:

- Wyoming—in partnership with project developers, labor organizations, and community colleges—should develop apprenticeship programs that can support the transition of traditional fossil energy workers to carbon management jobs to take advantage of the existing skills of fossil energy workers.
- To attract and retain talent, Wyoming should offer funding to help local governments and developers coordinate housing, transportation, childcare, and other wraparound support for workers on carbon management projects, especially those that will be sited in areas remote from population centers.

CONCLUSION

Wyoming's legacy of leadership in the energy industry over the past century positions the state to also be a leader in the emerging carbon management sector, particularly by utilizing its existing natural resources for geologic storage and employing its skilled workforce in the development of direct air capture projects. Significant regulatory advantages over other states like Class VI primacy and transparent pore space ownership regulations, paired with recent federal incentives, can help Wyoming jumpstart its DAC industry in the coming years. However, in order to truly maximize this opportunity, state and federal policy must lend additional support for the build-out and integration of low-carbon energy generation, harmonization of pore space access rights, and integration of workforce and community development into all project development.

C2ES Resources

Regional Roundtables
https://www.c2es.org/accelerating-the-us-net-zero-transition/regional-roundtables/

Engineered Carbon Dioxide Removal: Scalability and Durability
https://www.c2es.org/document/engineered-carbon-dioxide-removal-scalability-and-durability/

Decarbonizing Louisiana's Industrial Sector: Community-Centric Approaches
https://www.c2es.org/document/decarbonizing-louisianas-industrial-sector-the-importance-of-community-centric-approaches/

Investing in West Virginia's Future: Aligning Climate and Economic Development
https://www.c2es.org/document/investing-in-west-virginias-future-aligning-climate-and-economic-development/

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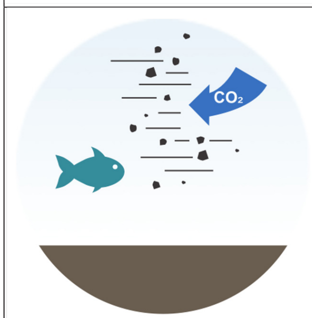
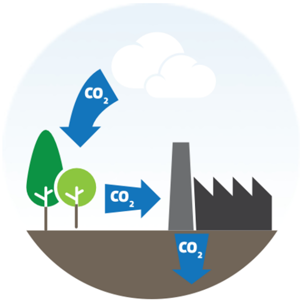
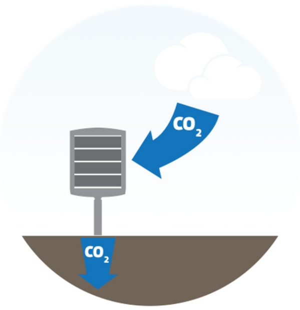
APPENDIX A: DIFFERENT APPROACHES FOR CARBON DIOXIDE REMOVAL (CDR)

	**Afforestation and reforestation** *Type: Nature-based* Afforestation refers to the process of planting trees and forests in areas that historically did not have forests, while reforestation refers to the process of replanting trees in areas where existing forests have been depleted.
	**Biochar** *Type: Technological* Biochar is a charcoal-like substance produced via pyrolysis (i.e., the thermal decomposition of organic material in the absence of oxygen). Biochar production converts biomass that might otherwise decay into a form that is relatively resistant to decomposition. When added to the soil, biochar stores carbon in a stable form that prevents it from leaking into the atmosphere.
	**Soil Carbon Sequestration** *Type: Nature-based* Soil carbon sequestration refers to the process of removing carbon dioxide from the atmosphere by changing land management practices in a way that increases the carbon content of the soil. Since the level of carbon in soil is a balance of carbon inputs (e.g., from leaf litter, residues, roots, manure) and carbon losses (mostly through respiration, increased by soil disturbance), practices that either increase inputs or reduce losses can promote soil carbon sequestration.
	**Enhanced Weathering** *Type: Nature-based* Enhanced weathering refers to accelerating natural rock chemical breakdown by spreading large amounts of crushed minerals (e.g., pulverized silicate) onto warm and humid land areas to help absorb carbon dioxide from the air.
	**Ocean Alkanization** *Type: Nature-based* Ocean alkalinization refers to adding carbonate-containing minerals (alkaline solutions) to enhance the ocean's natural carbon uptake.

	**Biomass with carbon removal and storage (BiCRS)** *Type: Technological* Biomass with carbon removal and storage (BiCRS) is the process of using biomass to generate energy, capturing the released carbon dioxide, and storing it in underground geologic formations (or potentially utilizing it to make long-lasting products). This technology is sometimes referred to as bioenergy with carbon capture and storage, or BECCS.
	**Direct Air Capture (DAC)** *Type: Technological* Direct air capture (DAC) involves the direct removal of diluted carbon dioxide from ambient air via chemical bonding. Carbon dioxide is removed from ambient air by contact with a basic solution (chemical liquid solvents) or a basic modified surface (chemical solid sorbents). The carbon dioxide, now fixated in a carbonate or carbamate bond, can then be liberated from the capture media through the application of heat, producing a high-purity carbon dioxide stream that can be transported to storage sites or industrial plants for utilization.

Source: Adapted from Mercator Research Institute on Global Commons and Climate Change (MCC), MCC Policy Brief No. 2 – Carbon Removal (Berlin: MCC, 2021), https://www.mcc-berlin.net/fileadmin/data/C18_MCC_Publications/MCC_Policy_Brief_Carbon_Removal_EN.pdf.

ENDNOTES

1 U.S. Energy Information Administration, "Wyoming: State Profile and Energy Estimates," last updated May 18, 2023, accessed June 23, 2023, *https://www.eia.gov/state/analysis.php?sid=WY*.

2 U.S. Energy Information Administration, "Profile Overview: Wyoming," accessed June 23, 2023, *https://www.eia.gov/state/?sid=WY#tabs-5*.

3 Wyoming Department of Revenue, *2022 Annual Report* (Cheyenne, WY: Wyoming Department of Revenue, 2022), *https://drive.google.com/file/d/1dFXkMrJN7tru18O_sOh_zMR1Qceu_iWV/view*.

4 In 2012, coal, oil, and natural gas made up 60 percent of the total local and state assessed valuation and 33 percent of the state's gross domestic product; in 2022, those figures dropped to 40 percent and 15 percent, respectively. Governor Mark Gordon, *Wyoming State Budget 2023-2024 Supplemental* (Cheyenne, WY: Wyoming Office of the Governor, 2022), *https://drive.google.com/file/d/1vqxBauOpA1QgcDZopbmx7_uMw2XFQBAw/view*.

5 U.S. Environmental Protection Agency, "Class VI – Wells used for Geologic Sequestration of Carbon Dioxide," accessed June 23, 2023, *https://www.epa.gov/uic/class-vi-wells-used-geologic-sequestration-carbon-dioxide*.

6 U.S. Environmental Protection Agency, "Class VI – Wells used for Geologic Sequestration of Carbon Dioxide."

7 Wyoming Enrolled Act No. 18 (2008), *http://legisweb.state.wy.us/2008/Enroll/HB0089.pdf*.

8 Mead Gruver, "Governor of top coal-mining state sets carbon-negative goal," *AP*, March 2, 2021, *https://apnews.com/article/joe-biden-technology-business-science-mark-gordon-d87892cc65ee90d156488060151eb680*.

9 Brad Smith, "Microsoft will be carbon negative by 2030," *Official Microsoft Blog,* January 16, 2020, *https://blogs.microsoft.com/blog/2020/01/16/microsoft-will-be-carbon-negative-by-2030/*; Dayna Winter, "Carbon Removal: How Shopify is Leading the Charge on Corporate Responsibility," *Shopify*, Feb 17, 2023, *https://www.shopify.com/blog/carbon-removal*; Peter Reinhardt, "Charm Delivers Stripe's Carbon Removal Purchase Ahead-of-Schedule," *Charm Industry*, April 19, 2021, *https://charmindustrial.com/blog/charm-delivers-stripe-s-carbon-removal-purchase-ahead-of-schedule*.

10 See Frontier, "An advance market commitment to accelerate carbon removal," accessed June 23, 2023, *https://frontierclimate.com/*.

11 Inflation Reduction Act (2022) §13104.

12 Clean Air Task Force, *Carbon Capture Provisions in the Inflation Reduction Act of 2022* (Washington, D.C.: Clean Air Task Force, 2022), *https://cdn.catf.us/wp-content/uploads/2022/08/19102026/carbon-capture-provisions-ira.pdf*.

13 U.S. Department of Energy Office of Clean Energy Demonstrations, "Regional Direct Air Capture Hubs," accessed June 23, 2023, *https://www.energy.gov/oced/regional-direct-air-capture-hubs*; U.S. Department of Energy Office of Fossil Energy and Carbon Management, "Funding Notice: Bipartisan Infrastructure Law: Regional Direct Air Capture Hubs," accessed June 23, 2023, *https://www.energy.gov/fecm/funding-notice-bipartisan-infrastructure-law-regional-direct-air-capture-hubs*.

14 U.S. Department of Energy Office of Fossil Energy and Carbon Management, "Project Selections for FOA 2735: Regional Direct Air Capture Hubs – Topic Area 1 (Feasibility) and Topic Area 2 (Design)," Accessed September 12, 2023, *https://www.energy.gov/fecm/project-selections-foa-2735-regional-direct-air-capture-hubs-topic-area-1-feasibility-and*.

15 U.S. Department of Energy Office of Clean Energy Demonstrations, "Carbon Storage Validation and Testing," accessed June 23, 2023, *https://www.energy.gov/oced/carbon-storage-validation-and-testing*.

16 University of Wyoming, "UW Lands $40.5M From Department of Energy for New CarbonSAFE Project," *University of Wyoming News*, May 18, 2023, *https://www.uwyo.edu/news/2023/05/uw-lands-40.5m-from-department-of-energy-for-new-carbonsafe-project.html*.

17 U.S. Environmental Protection Agency, "New Source Performance Standards for Greenhouse Gas Emissions From New, Modified, and Reconstructed Fossil Fuel-Fired Electric Generating Units; Emission Guidelines for Greenhouse Gas Emissions From Existing Fossil Fuel-Fired Electric Generating Units; and Repeal of the Affordable Clean Energy Rule," Federal Register EPA-HQ-OAR-2023-0072, *https://www.federalregister.gov/documents/2023/05/23/2023-10141/new-source-performance-standards-for-greenhouse-gas-emissions-from-new-modified-and-reconstructed*.

18 Stevens *et al., The Footprint of Energy: Land Use of US Electricity Production*, (STRATA, 2017).

19 National Academies of Sciences, Engineering, and Medicine (NASEM), Negative Emissions Technologies and Reliable Sequestration: A Research Agenda (Washington, DC: The National Academies Press, 2019), *https://doi.org/10.17226/25259*.

20 "Permanence and Safety of CCS," National Energy Technology Laboratory, accessed May 16, 2023, *https://netl.doe.gov/coal/carbon-storage/faqs/permanence-safety*.

21 Noah McQueen et al., "A review of direct air capture (DAC): scaling up commercial technologies and innovating for the future," Progress in Energy 3 (April 2021): 1-22, *https://iopscience.iop.org/article/10.1088/2516-1083/abf1ce*.

22 National Academies of Sciences, Engineering, and Medicine (NASEM), Negative Emissions Technologies and Reliable Sequestration: A Research Agenda (Washington, D.C,: The National Academies Press, 2019), *https://doi.org/10.17226/25259.*

23 "Trends in Atmospheric Carbon Dioxide," National Oceanic and Atmospheric Administration, accessed March 19, 2022, *https://gml.noaa.gov/ccgg/trends/*; "Point Source Carbon Capture from Power Generation Sources," National Energy Technology Laboratory, accessed March 19, 2022, *https://netl.doe.gov/carbon-capture/power-generation*; Xiaoxing Wang and Chunshan Song, "Carbon Capture From Flue Gas and the Atmosphere: A Perspective," Frontiers in Energy Research 8, no. 560849 (2020): 1-24, *https://doi.org/10.3389/fenrg.2020.560849*.

24 Fuss et al., "Negative emissions—Part 2. Costs, potentials and side effects," Environ. Res. Lett. **13** 063002 (2018) *https://doi.org/10.1088/1748-9326/aabf9f.*

25 International Energy Agency Greenhouse Gas R&D Programme, *IEAGHG Technical Report: Global Assessment of Direct Air Capture Costs*, (Cheltenham, UK: IEA, 2021).

26 National Academies of Sciences, Engineering, and Medicine (NASEM), Negative Emissions Technologies and Reliable Sequestration: A Research Agenda (Washington, DC: The National Academies Press, 2019), *https://doi.org/10.17226/25259*.

27 U.S. Department of Energy, National Energy Technology Laboratory, Carbon Storage Atlas, 5th ed., 2015, *https://www.netl.doe.gov/sites/default/files/2018-10/ATLAS-V-2015.pdf*.

28 Numbers represent an average between the low and high estimates for each medium. U.S. Department of Energy, National Energy Technology Laboratory, Carbon Storage Atlas, 5th ed., 2015, *https://www.netl.doe.gov/sites/default/files/2018-10/ATLAS-V-2015.pdf.*

29 WY House Bill No. HB 0089, 2008, *https://wyoleg.gov/2008/Enroll/HB0089.pdf*.

30 Wyoming's Department of Environmental Quality, Class VI applications, accessed June 12, 2023, *https://deq.wyoming.gov/water-quality/groundwater/uic/class-vi/*.

31 Carol Hardy Vincent and Laura A. Hanson, Federal Land Ownership: Overview and Data, (Congressional Research Service, 2020), *https://crsreports.congress.gov/product/pdf/R/R42346/18*.

32 University of Wyoming, Wyoming CarbonSAFE project, *https://www.uwyo.edu/cegr/research-projects/wyoming-carbonsafe.html*.

33 National Academies of Sciences, Engineering, and Medicine (NASEM), Negative Emissions Technologies and Reliable Sequestration: A Research Agenda (Washington, DC: The National Academies Press, 2019), *https://doi.org/10.17226/25259*.

34 Wilcox *et al.*, "Cost Analysis of Direct Air Capture and Sequestration Coupled to Low-Carbon Thermal Energy in the United States", Environmental Science & Technology (2020) *54* (12), 7542-7551 *https://doi.org/10.1021/acs.est.0c00476*.

35 Wyoming Statutes §§ 37-16-101 through 104 *https://wyoleg.gov/statutes/compress/title37.pdf*.

36 Wyoming Energy Authority, Wyoming Energy Strategy, accessed June 20, 2023 *https://wyoenergy.org/wp-content/uploads/2023/02/WEA-Energy-Strategy-General-Audience.pdf*.

37 The Nature Conservancy, BESI: Brightfields Energy Siting Initiative, 2022 *https://www.nature.org/en-us/newsroom/wyoming-brightfields-energy-siting/*.

FIGURE ENDNOTES

1 Ozkan et al., "Current status and pillars of direct air capture technologies," iScience 25, no. 4 (2022): 103990, *https://doi.org/10.1016/j.isci.2022.103990*.

2 National Academies of Sciences, Engineering, and Medicine (NASEM), Negative Emissions Technologies and Reliable Sequestration: A Research Agenda (Washington, DC: The National Academies Press, 2019), *https://doi.org/10.17226/25259*; Realmonte, G., Drouet, L., Gambhir, A. et al., "An inter-model assessment of the role of direct air capture in deep mitigation pathways," *Nat Commun* **10**, 3277 (2019). *https://doi.org/10.1038/s41467-019-10842-5*; Chatterjee, S., Huang, KW, "Unrealistic energy and materials requirement for direct air capture in deep mitigation pathways," *Nat Commun* **11**, 3287 (2020). *https://doi.org/10.1038/s41467-020-17203-7*; Krekel et al., "The separation of CO2 from ambient air – a techno-economic assessment," Appl. Energy 218, 361–381. *https://doi.org/10.1016/j.apenergy.2018.02.144*.

3 U.S. Environmental Protection Agency, Inventory of Class VI Wells Permitted by EPA, accessed July 19, 2023, *https://www.epa.gov/uic/class-vi-wells-permitted-epa*.

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