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Carbon Capture, Utilization and Storage (CCUS) in Alaska: *Technical Considerations and Governance Opportunities*

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This research by CK Blueshift was commissioned by The Nature Conservancy in Alaska.

715 L Street, Suite 100

Anchorage, Alaska 99574

907-531-4239

alaska@tnc.org

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Executive Summary

This memo examines carbon capture, utilization, and storage (CCUS) through a high-level technical and governance framework and summarizes various considerations, risks, and case studies to provide a framework for understanding CCUS in Alaska. After providing an introduction to CCUS and relevant considerations, this memo summarizes research on existing state policies for CCUS in order to highlight any common lessons learned and evaluate considerations relevant to CCUS in Alaska.

Carbon sequestration is being considered globally to help reduce greenhouse gas emissions and mitigate climate change. However, these solutions also carry significant technical, environmental, economic, and social challenges that require careful consideration. States play a significant role in the development of the general policies and regulatory frameworks to ensure that carbon sequestration technologies and projects not only meet federal and market standards, but that they are developed in alignment with local and state-specific interests, circumstances, and objectives.

This review is divided into two main sections. The first segment of the report focuses on the technical considerations of CCUS, with specific review given to storing carbon underground, technological and logistical challenges, and potential environmental impacts. The second segment of the report focuses on regulating and governing CCUS by assessing regulatory frameworks in other states, providing context and information on CCUS governance frameworks being considered in Alaska, and additional areas of focus that may merit attention within the regulatory sphere for CCUS in Alaska. Key findings from the review are as follows:

- *Although CCUS and its potential has been researched for several decades, it remains a highly specialized and niche sector – and one that is not easy to understand – ripe with technical considerations.*
- *New financial incentives and tax credits available in the U.S., can provide an important boost to financial return for CCUS projects. However, initial demonstration projects have rendered mixed results, cautioning the industry of the importance of implementing appropriate project selection processes and individual project risk assessments.*
- *While many states implementing CCUS will benefit from the experience and frameworks that already exist in their oil and gas industry, it is important to recognize that conflicts of interest between economic interests and environmental protection have been difficult to manage in the oil and gas sector nationally. While CCUS is still emerging, regulatory frameworks where agency independence is ensured may be perceived more favorably.*
- *There are a variety of case studies – ranging from implemented projects to policies being implemented in other states – that can provide additional insight, information, context, and learning relevant to this emerging area in Alaska.*

Introduction to Carbon Capture, Utilization, and Storage (CCUS)

Carbon capture, utilization and storage is the process of capturing CO_2 emissions and pumping the CO_2 into rock formations deep underground. CCUS is one of many strategies that is being considered to reduce the concentration of CO_2 in the atmosphere. According to the Intergovernmental Panel on Climate Change (2022), such strategies, coupled with a transition away from fossil fuels, are essential components of any comprehensive strategy to limit the effects of global climate change.

Although the motivation to use CCUS for sequestering carbon to mitigate the effects of climate change is relatively new, there have been operational CCUS facilities around the world for nearly 50 years (McFarlane et al., 2019). Early uses of CCUS technology were focused on enhanced oil recovery (EOR), in which CO_2 is injected into the ground to reduce the viscosity of any oil that remains trapped in pore spaces; this helps to extract additional oil and gas from reservoir rocks. Because the CO_2 used at these sites is a commodity that enhances the productivity of depleted oil reservoirs, the goal of these sites is often to recover and recycle the CO_2, rather than to sequester it at depth for the long term (Perera et al., 2016). Nonetheless, several decades of experience using CO_2 for EOR has enabled technological advances that are directly relevant to CCUS.

CCUS includes three parts -- capturing CO_2, transporting it (if needed) to a storage location, and injecting it below ground for permanent storage. CO_2 can also be “utilized” for example by storing it in products such as concrete, though this is less common. At most CCUS sites, CO_2 is captured from industrial processes or power plants at the point of emission (*point source capture*), though some techniques capture CO_2 directly from the atmosphere (*direct air capture)*. In either case, CO_2 is compressed and heated so it has characteristics of both a liquid and a gas, what is known as a *supercritical* state (National Academies of Sciences, Engineering, and Medicine, 2019). In its supercritical state, CO_2 has a higher density than it does in its gas form, which both reduces the amount of storage space needed and helps prevent it from escaping back into the atmosphere. This supercritical CO_2 is then pumped into rock formations deep underground (reservoir rock) deemed suitable for storage.

Interest in the CCUS industry in the United States has increased in recent years given ambitious greenhouse gas reduction targets, enabling policies at the federal level, and its appealing economic potential. In major oil producing states such as Alaska, Texas, Louisiana, New Mexico, North Dakota, and Wyoming among others, the availability of geologic storage capacity, infrastructure, and the experience gained by the oil and gas industry from CO_2 injection for enhanced oil recovery processes (EOR), may offer a unique advantage over other locations for the development CCUS.

However, successful development and implementation of CCUS activities will require adequate consideration of financial, technical, and regulatory issues. States can facilitate CCUS by providing regulatory clarity, supporting infrastructure planning efforts, and providing technology and infrastructure incentives (National Energy Technology Laboratory & Great Plains Institute, 2017, p. 7).

Storing Carbon Underground

Storage Site Suitability

Well-selected and managed geologic sites are likely to retain over 99% of injected CO_2 over 1,000 years (McFarlane, et al, 2019). The key considerations for site selection and characterization relate to understanding the properties of the reservoir rock (into which the CO_2 will be injected) and the caprock (the impermeable layer that will prevent the CO_2 from leaking). A suitable site needs space for CO_2 storage (high porosity), interconnected pores so that CO_2 can be easily injected (high permeability), and an intact caprock to prevent leakage once the CO_2 is injected. Finally, the temperature and pressure required to keep CO_2 in its supercritical state naturally occur at depths below approximately 800 meters (~2,600 ft), so locations below this depth are generally preferred for CCUS projects (U.S. Department of Energy, 2015). The most commonly suitable sites for CCUS are depleted oil and gas fields, deep saline aquifers, and shallow, un-mineable coal seams (National Energy Technology Laboratory, 2017; **Figure 1**).

Depleted oil and gas reservoirs are the most common sites for CCUS projects for several reasons. Oil and gas are usually found within porous and permeable rock formations that are capped by a less permeable layer above. These same properties that have stored hydrocarbons for millions of years are also conducive to trapping CO_2 injected by CCUS. Oil and gas reservoirs also tend to be very well characterized due to the extensive amount of research that goes into oil and gas exploration.

Deep saline aquifers are also attractive storage sites, as they have similar characteristics to oil and gas reservoirs. These aquifers occur in porous and permeable formations, which facilitates the injection of CO_2 into storage. However, since these reservoirs have not had oil and gas removed from them, there is typically less space to inject CO_2 into saline aquifers, and more work may be required to evaluate whether injection can occur without over-pressuring the aquifer (National Energy Technology Laboratory, 2017).

The third main storage location for CCUS projects, **coal seams**, rely on the chemical properties of coal, which can adsorb CO_2 and keep it trapped via chemical bonds that form along the surface of the coal. However, this technique remains substantially less common than CCUS in depleted oil and gas reservoirs or deep saline aquifers, and it is not considered further in this overview (National Energy Technology Laboratory, 2017).

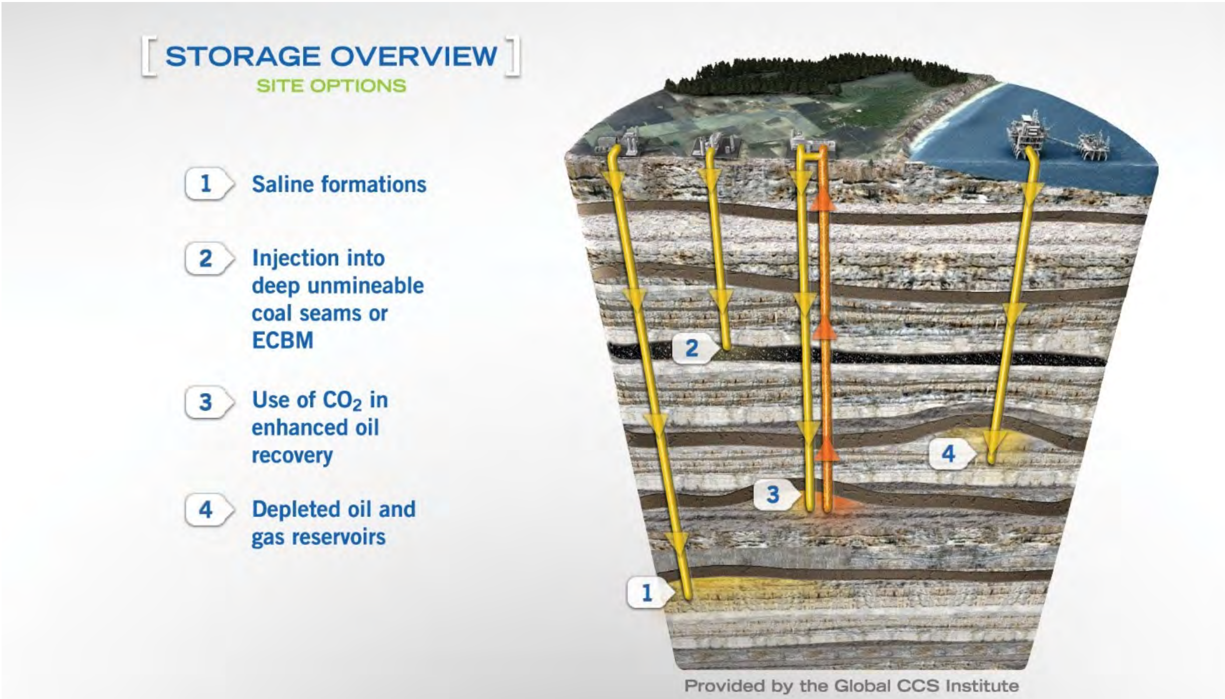

Figure 1. Schematic showing typical sites suitable for CCUS projects (*CCS Image Library*, n.d.)

CO2 Trapping Mechanisms

Once supercritical CO_2 is injected underground, it undergoes a series of trapping mechanisms that affect how and how long it is stored (e.g., Kelemen et al., 2019). Initially, sequestration relies on *structural or stratigraphic trapping,* meaning an impermeable layer of rock physically prevents the CO_2 from leaking upwards from the higher permeability reservoir rock where it was injected (see **Figure 1**). A number of *secondary trapping mechanisms,* such as those described below, lead to more permanent sequestration as they convert the supercritical CO_2 into even more stable forms (Kelemen et al., 2019; National Academies of Sciences, Engineering, and Medicine, 2019). These secondary trapping mechanisms are:

Solubility trapping, where CO_2 dissolves into the surrounding groundwater fluids,

Residual trapping, where CO_2 becomes trapped in small pore spaces between mineral grains,

Mineralization, where CO_2 reacts with minerals in the rock to create new materials.

These secondary trapping mechanisms are important for long-term sequestration success, but can take tens to even thousands of years to occur. Thus, the integrity of the structural trap – which holds CO_2 in the subsurface while these secondary trapping mechanisms occur – is of paramount importance to the success of any CCUS project.

Technological and Logistical Challenges with CCUS

Broadly, many of the technological challenges associated with CCUS are similar to the challenges associated with oil and gas development and extraction. These challenges are related to geologic site characterization; CO_2 transport from the source to the injection site; and post-injection monitoring.

Suitability of Reservoir

Because secondary trapping mechanisms can take decades or longer to occur, understanding the integrity of the structural trap is critically important to project success.

A common technological challenge is accurately assessing the suitability of the reservoir rock and caprock for CCUS. Similar to oil and gas exploration, seismic imaging is often used to map out the thickness and extent of the reservoir rock and the caprock; while samples of the rock from drill cores are used to characterize the porosity and permeability of the reservoir material and caprock directly. Even with extensive seismic imaging, however, it is not always possible to detect small faults that may cut through the caprock and potentially create conduits for leakage. Given the possibility that these conduits may be missed in the initial site characterization and selection phase, post-injection monitoring is critical to ensuring that CO_2 is not leaking from the project site.

CO_2 Transport to Injection Site

A technological and logistical challenge associated with CCUS is how to transport CO_2 from sites where it is produced to sites where it can be stored effectively. The majority of existing CCUS sites are co-located with a CO_2 source, which allows CO_2 to be injected into the ground without requiring transport. However, if CCUS is to be scaled up to become a long-term climate solution, it will be necessary to develop compressors and pipelines to transport compressed gas. These pipes and compressors are designed to process a set volume of CO_2 and can perform poorly if they are run at less than full capacity or shut down periodically. Successfully operating a CCUS facility therefore requires a relatively consistent supply of CO_2 (National Energy Technology Laboratory, 2017).

Post-Injection Monitoring

A final set of technological considerations for CCUS surrounds post-injection monitoring to track the CO_2 plume and ensure it is not leaking (National Academies of Sciences, Engineering, and Medicine, 2019). Though there are well-established methods for monitoring, there can be challenges related to their cost and how to effectively implement them to spur timely adaptive management actions.

Because CCUS projects are deep beneath the surface, the most common methods used for monitoring and verification are remote geophysical techniques like gravity and seismic imaging. These methods use the distinct properties of CO_2 relative to surrounding fluids and rocks to create maps of where the plume is located through time. Although these methods are expensive, repeat gravity or seismic surveys can be used to create time-lapse images of where the plume is moving through time, which can provide valuable information to adaptively manage these projects (Furre et al., 2017).

Other monitoring methods for CCUS include the installation of monitoring wells to measure pressure, which can be used to determine where the CO_2 is migrating through time (Finley et al., 2013; National Academies of Sciences, Engineering, and Medicine, 2019). Pressure monitoring within the injection reservoir can be used to track lateral movement of CO_2, while monitoring in overlying geologic layers can determine whether there may be leakage into overlying materials (National Academies of Sciences, Engineering, and Medicine, 2019). Finally, surface monitoring using infrared light detectors can be used to determine whether any CO_2 may be escaping to the surface.

Case Study: Sleipner Project, Norway

One of the longest-lived CCUS sites in the world is the Sleipner project off the coast of Norway. The Sleipner gas field went online in 1996, and waste CO_2 was removed from the natural gas stream both to purify the final product and to meet strict national emissions taxes from the Norwegian government. This waste CO_2 was injected back into the high porosity, saline aquifer at Sleipner beginning in 1997, and this has continued at a rate of approximately 0.9 million metric tons (0.9 Mt) per year ever since. Thus, there has been more than two decades of monitoring to document the effectiveness of CCUS at the Sleipner site (Furre et al., 2017).

As of 2017, the CO_2 plume at Sleipner had been monitored by ten 3D seismic surveys and four gravity surveys, none of which have documented leakage of CO_2 from the reservoir. 3D seismic surveys have been the most efficient tool for monitoring the evolution of the CO_2 plume over time, and show CO_2 collecting in higher areas of the reservoir where the low-permeability caprocks are bowed upwards (Furre et al., 2017).

One of the main lessons learned from the Sleipner project is that monitoring should be conducted frequently and using a variety of techniques. In addition to 3D seismic, monitoring of pressure and temperature using borehole monitoring devices was shown to be effective at early characterization of CO_2 migration as injection was occurring. The experience from Sleipner also suggests that repeat 3D seismic monitoring should occur as soon as possible after injection begins, to document where the CO_2 plume is migrating early in the project. After these first surveys are complete and the plume behavior is better understood, the monitoring interval can be increased if no issues are detected.

Potential Environmental Impacts of CCUS Storage

Although the depth of reservoirs where CCUS occurs tends to limit the potential environmental risks of these projects, there are several potential environmental impacts associated with CCUS, if projects are not managed properly. These include the potential for seismic activity (induced seismicity); water quality issues associated with leakage of CO_2 into surrounding freshwater aquifers; and potential toxicity related to leakage of CO_2 to the surface.

Induced Seismicity

Induced seismicity has been observed at some CCUS project sites, including the In Salah project in Algeria and at the Decatur project in Illinois. When this does occur, it is related to the same factors that have been shown to create induced seismicity at hydraulic fracturing sites: because the supercritical CO_2 is injected at extremely high pressure, it can release stress along existing fault zones that allows them to slip. To date, the earthquakes created by CCUS projects have been very small, and not strong enough to be felt at the surface (National Academies of Sciences, Engineering, and Medicine, 2019). However, the potential for induced seismicity is also highly site specific and should be considered in the context of each location being screened for CCUS implementation.

Underground Leakage of CO_2 Impacting Water Quality

CCUS projects are intentionally designed to avoid freshwater aquifers and drinking water sources, but any leakage of CO2 from its target reservoir has the potential to create water quality issues in adjacent aquifers. CO2 is very unlikely to leak from a secure geological storage formation, though there is some risk that an engineering failure, such as a leak in the injection well casing, could contaminate ground water. When CO_2 dissolves in water it creates an acid that, in high enough concentrations, can lower the pH enough to make the water undrinkable. The increased acidity can also mobilize other toxins that may be present in the surrounding rock formations, including metals like arsenic and lead. Water quality monitoring of aquifers overlying CCUS facilities should be used to detect any changes in acidity and other toxins that could indicate leakage or engineering failures, so that the project can be adaptively managed to avoid further impacts.

To be an effective climate change mitigation tool, CCUS must be a part of a comprehensive strategy that includes replacing fossil fuels with renewable energy sources, while simultaneously sequestering carbon from other industrial processes and sources.

Case Study: Decatur Project, Illinois

The Illinois Basin-Decatur Project (IBDP) was a CCUS demonstration project in Decatur, Illinois, and was a collaboration between the US Department of Energy, Schlumberger, and Arthur Daniels Midland (ADM). The CO_2 used at the IBDP site was a byproduct of the conversion of corn to ethanol at the ADM facility. The IBDP began operation in 2011, injecting CO_2 into a deep saline aquifer within a regionally extensive sandstone formation at a depth of approximately 2,100 meters (Finley et al., 2013). Over approximately three years of operation, the IBDP injected approximately 1 Mt of CO_2 at a rate of approximately 1,000 metric tons/day.

Several types of monitoring were used at the IBDP to track and monitor the location of the injected CO_2 through time. Observational data included the following (Finley et al., 2013):

1) Pressure monitoring and fluid sampling in the sandstone aquifer and the overlying shale confining unit, at an observation well located approximately 300m from the injection site
2) Seismic monitoring at 31 depths within a nearby geophysical monitoring well; and
3) Three additional seismic sensors within the injection well itself.

After operations began in late 2011, CO_2 was documented in the observation well in March of 2012, which was sooner than expected. This rapid spread of CO_2 within the reservoir rock was attributed in part to the CO_2 plume being thinner than anticipated, and in part to the rock reservoir having a higher permeability than originally anticipated north of the injection site (Finley et al, 2013).

Secondary trapping mechanisms like mineralization can affect the porosity and permeability of the reservoir, which may affect long-term CCUS success at some sites.

Mineralogical testing also showed that some secondary trapping occurred at the IBDP, via dissolution of aquifer materials and precipitation of new minerals (Dávila et al., 2020). While these processes helped to more permanently sequester carbon in the subsurface via mineralization, the precipitation of new minerals into pore spaces also decreased the permeability of the aquifer. This type of reduction in permeability, if it occurs at other sites, could limit the rate at which CO_2 can be injected in similar settings, and should be considered as part of the long-term evaluation of future project performance.

Surface Leakage of CO_2 and Toxicity

In the event of an engineering failure (e.g., a pipeline failure, fractured casing, or other failure), significant escape of CO_2 during injection has the remote potential to create toxicity to humans and animals. The natural concentration of CO_2 in the atmosphere is approximately 400 parts per million (ppm). Health effects from CO_2 inhalation begin to occur at concentrations of ~50,000 ppm (5%) and acute toxicity can occur at concentrations exceeding 100,000 ppm (10%) (Permentier et al., 2017). Slow leakage of CO_2 from a CCUS site is highly unlikely to create concentrations near these levels, especially in well-ventilated outdoor areas; but an accident at the injection site could potentially create short lived and localized toxic conditions.

Scaling CCUS

A final, indirect environmental impact of CCUS is related to how it is scaled and implemented. As noted by the Intergovernmental Panel on Climate Change, to stave off the worst effects of climate change carbon removal will likely be necessary to offset residual emissions that cannot be otherwise eliminated by 2050. However, to meet these goals CCUS must be used in addition to, and not as a substitute for, reducing fossil fuel use. In particular, there is some concern around CCUS being used primarily to extract additional fossil fuels via EOR, rather than as an independent means of extracting CO_2 from the atmosphere (Lebling et al., 2022).

Regulating and Governing CCUS

Currently, 30% of states in the U.S. now have some degree of CCUS legislation, a trend that is expected to continue increase in the near term. This section explores lessons learned in relation to the major issues relevant to CCUS as well as now they are currently being examined in Alaska. While the analysis is not exhaustive of all the United States, we have attempted to highlight major trends and provide relevant examples of state legislation where CCUS is significant.

Authorities

Successful implementation of proposed CCUS policies at the state level requires that the enabling legislation clearly identify the authority(ies) that will oversee and the implement proposed CCUS programs including the development of a detailed regulatory framework around CCUS projects in accordance with the enabling legislation and federal Underground Injection Control (UIC) program requirements.

CCUS Authorities in Other States

Many of the CCUS regulatory frameworks at the state level have been largely influenced by models which have been in place in the oil and gas industry for decades. In this context, the most common regulatory authorities at the state level are usually oil and gas commissions or state environmental agencies. In some states, a single agency will be designated to exercise full oversight over CCUS programs and projects while other states split this authority between two different agencies. Agency capacity, internal expertise, and efficiency are important considerations in determining which agencies should serve such purposes.

However, the role played by oil and gas commissions as de facto environmental regulators can give rise to some concerns since these agencies may prioritize the protection of the right to capture minerals over limiting environmental harms (Righetti, 2019). Potential conflicts of interest between the industry's economic interest on one side, and environmental compliance on the other side, have been apparent in the oil and gas sector. While the CCUS industry is still emerging and is not expected to result in significant environmental degradation, regulatory frameworks where agency independence is ensured may be perceived more favorably. Preventing conflicting interests, functional overlap between agencies, and the undermining of environmental laws are key considerations.

Proposed CCUS Authorities in Alaska

Under the legislation proposed in 2023, oversight and authority over CCUS projects in Alaska would be split between two agencies: (1) the Alaska DNR; and (2) the Alaska Oil and Gas Conservation Commission (AOGCC). DNR would have the main authority over carbon storage exploration licenses and carbon storage leases on state land. AOGCC would be expected to have authority over well and carbon storage permits (see discussion on primacy) and to determine and collect fees.

The AOGCC is an independent, quasi-judicial agency of the State of Alaska composed of three commissioners appointed by the governor and confirmed by the legislature in joint session. Since it was first created, the AOGCC has undergone a series of changes and transfers with the state's agencies and divisions. Most recently, the commission was transferred to the Department of Commerce, Community and Economic Development by Gov. Dunleavy in 2019.[1] The AOGCC oversees oil and gas drilling, development and production, reservoir depletion and metering operations on all lands subject to the state's police powers. The commission acts to prevent waste, protect correlative rights, improve ultimate recovery, and protect underground freshwater. It administers the UIC program for EOR and underground disposal of oil field waste in Alaska.[2] These are generally Class II wells for which Alaska has state authority (see section below on primacy). Finally, the AOGCC serves as an adjudicatory forum for resolving certain oil and gas disputes between owners, including the state.[3] Under Section 31 of the proposed legislation, the AOGCC would be responsible for permitting and oversight, establishing fees, issuing certificates of completion, among others functions and activities.

In conjunction with Gov. Dunleavy (Alaska Governor's Office, 2023), DNR has been a major proponent of deployment and implementation of CCUS projects in Alaska. The Alaska DNR has also formed part of the Alaska CCUS workgroup, which was formed in July of 2022 to

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[1] See: https://www.commerce.alaska.gov/web/aogcc/AboutUs/History.aspx

[2] AS 31.05

[3] https://www.commerce.alaska.gov/web/aogcc/aboutus.aspx

accelerate commercial CCUS projects within the state.[4] Under Section 14 of the proposed legislation, DNR would be responsible for carbon storage exploration licensing and leases. Under Sections 31 and 36, DNR would also be responsible for administering storage facilities and stored carbon transferred to the state after completion. Together, DNR and the AOGCC are expected to issue the regulations necessary to implement the proposed legislation.

In addition to the AOGCC and DNR, the Alaska Department of Environmental Conservation (DEC) is a relevant authority for purposes of implementing CCUS in the state. DEC's mission is to conserve, protect and improve Alaska's natural resources and environment and control water, land, and air pollution to enhance the health, safety, and welfare of the people of the state and their overall economic and social well-being.[5] Under the proposed legislation, the AOGCC would be required to consult with the Alaska DEC on certain matters such as the issuance of a carbon storage permit and the issuance of a certificate of completion.

Class VI Well Primacy

Under Section 1421 of the Safe Drinking Water Act, the Environmental Protection Agency (EPA) is required to develop UIC program requirements that prevent underground injection which may endanger drinking water sources.[6] Accordingly, the EPA has developed a series of UIC program requirements that are designed to be adopted by states, territories, and tribes. The UIC permit program regulates underground injection by six classes of wells. Class VI wells are used for injection of carbon dioxide (CO_2) into underground subsurface rock formations for long-term storage, or geologic sequestration.

There are no federal requirements in relation to the agency that should be selected to exercise primacy over UIC Programs. From the EPA's perspective, states are in the best position to identify the appropriate agency to oversee Class VI wells, and in some states both the traditional oil and gas agency and the traditional environmental protection agency may administer some Class VI requirements. (EPA, 2014)

Class VI Well Primacy in Other States

Unless a state has gained primary enforcement authority also known as "primacy", the permitting of UIC wells is done by the EPA. States can develop their own state level UIC programs, which shall meet the minimum requirements set by the EPA and receive authorization to implement and oversee UIC programs in that jurisdiction. Under the EPA's UIC program and its regulations, all underground injections in any state are unlawful and subject to penalties unless authorized by the EPA under a permit or a rule.[7]

As of late 2023, only two states (North Dakota and Wyoming) have primacy for Class VI wells under the EPA's UIC program and one other state is awaiting EPA approval (Louisiana). With the passage of the Bipartisan Infrastructure Law, the EPA announced that it is

[4] See: https://ine.uaf.edu/carbon

[5] https://dec.alaska.gov/commish/dec-history/

[6] Safe Drinking Water Act, 42 U.S.C. 300f *et seq.*

[7] See: https://www.epa.gov/uic/primary-enforcement-authority-underground-injection-control-program-0

developing a new $50 million grant program that will support states, Tribes and territories in developing and implementing UIC Class VI programs. This newly available funding is expected to have a noticeable impact and increase the number of states that seek and obtain primacy for Class VI wells.

Proposed Class VI Well Primacy in Alaska

Alaska anticipates becoming one of the very few states in the U.S. that have obtained Class VI well primacy.

Obtaining primacy over Class VI wells is a relatively complex and time-consuming process. Currently, very few states have primacy authority over Class VI wells (see section on state comparison below). However, primacy can enable states to better manage permitting and overcome application backlogs that have existed within the EPA over time. An analysis of this issue by Alaska's DNR and other collaborators recommended the obtention of Class VI primacy to support efficient and wide-spread development of CCUS projects within the state. (DNR, 2022)

Although the enabling legislation for CCUS remains pending in the legislature, SB 48 – introduced initially as part of the Carbon Offset Program – was signed into law on May 24, 2023, and contained a provision which directly authorizes the AOGCC to pursue Class VI primacy in Alaska.

In exercise of this newly granted authority, the AOGCC has already taken two important actions directed at obtaining state primacy. First, on August 22, 2023 the AOGCC opened a Request for Interest (RFI) seeking responses from expert companies or persons that could assist in the process of obtaining Class VI primacy from the EPA and the permitting, processing, and evaluating Class VI permit applications (Division of Oil & Gas, Department of Natural Resources, 2022). Second, the AOGCC has submitted a Letter of Intent back to EPA notifying them that we are interested in applying for the Class VI grant from the EPA when that grant opportunity becomes available later in 2023. (AOGCC, n.d.) The newly available funding provided to EPA under the Bipartisan Infrastructure Law (BIL) may help states gain the required agency capacity to effectively implement state primacy and more rapidly develop UIC in their territories[8].

Pore Space Ownership and Leasing

Pores are intergranular space or discrete void within a rock that can contain natural gas, water, hydrocarbons, or other fluids. Pore space refers to the open spaces or voids of a rock

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[8] EPA has announced that it is developing a new $50 million grant program through the Bipartisan Infrastructure Law that will support states, Tribes and territories in developing and implementing UIC Class VI programs. In launching this program, the Office of Water invited states, Tribes and territories to submit letters of intent (LOI) to indicate their interest in the new grant program. Responses to this request will help EPA understand where there is interest in applying for these funds and implementing a Class VI program. Upon receiving LOIs, EPA will determine state-by-state funding allocations and implementation recommendations. EPA intends to award the full $50 million in a one-time distribution through this process. See: https://www.epa.gov/uic/underground-injection-control-grants

taken collectively.[9] When carbon dioxide is stored underground, it fills pore space, which refers to the gaps or voids in the subsurface geologic formations. (Arnold & Porter, n.d.)

In many jurisdictions in the U.S., pore space rights are generally assigned to the surface owner. This is known as the American Rule. However, case law in a particular jurisdiction may be unclear or even contradictory, which can complicate negotiations between CCUS operators, landowners, and mineral rights holders. Several states have chosen to address this concern by clarifying the ownership of pore space rights by statute. (Arnold & Porter, n.d.)

Pore Space Ownership in Other States

While pore space ownership in other states is not a settled area of law, most states have adopted the so-called American Rule under which pore space belongs to the surface owners. The federal government is also leaning towards the American Rule but has not explicitly defined pore space ownership (Stantec Consulting Services, 2023). Alaska is unique as it does not apply the American rule. (see section above) North Dakota and Wyoming have enacted legislation on pore space ownership in line with the American Rule.

- North Dakota: In North Dakota, title to pore space in all strata underlying the surface of lands and waters is vested in the owner of the overlying surface estate.[10]
- Wyoming: In Wyoming the ownership of all pore space in all strata below the surface lands and waters of this state is declared to be vested in the several owners of the surface above the strata.[11]

Proposed Pore Space Ownership in Alaska

Although an in-depth legal analysis of case law in Alaska is beyond the scope of this document, it is worth noting that in Alaska, the statutory treatment and legal interpretations over ownership of pore space are distinct from the majority of other U.S. states (i.e. the American Rule does not apply). Instead, statutes in Alaska have generally reserved these rights to the State. For example, the 1958 Alaska Statehood Act, under which the State received all mineral rights underlying the land entitlement granted at statehood, required (under Section 6 (i)) that all mineral rights on land sold, granted, or otherwise disposed be reserved to the State. (Alaska Statehood Act). In addition, in City of Kenai v. Cook Inlet Natural Gas Storage, the Alaska Supreme Court found that subsurface pore space and storage rights belonged to the State — not the surface owner and affirmed that the American rule did not apply. (City of Kenai v. Cook Inlet Natural Gas Storage Alaska, Llc, 2016).

The clarity afforded both by statute and case law in Alaska is a positive factor in the development of CCUS in the state. This represents an opportunity to maximize the value of the State's significant amount of acreage and natural resources in partnership with prospective CCUS operators (DNR, 2022).

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[9] Glossary - U.S. Energy Information Administration (EIA)

[10] ND. Century Code. § 47-31

[11] WY. Stat. § 34-1-152

Unitization and Amalgamation of Ownership Interests

Unitization or amalgamation of interests "is a legal concept under which several lessees, lessors, and ownership interests, can be brought under a unit based on the assumed subsurface picture for simple and fair management and protection of respective interests. This unitization or amalgamation often occurs by private agreement among the owners and operators, but in instances where consensus cannot be achieved many states provide for compulsory unitization under certain conditions" (DNR, 2022).

Amalgamation of Interests in Other States

Amalgamation mechanisms are usually well developed in states where there has been a history of oil and gas extraction. Voluntary amalgamation is generally allowed, while compulsory amalgamation will include specific statutory or regulatory requirements to ensure a fair treatment of the parties involved. Common terms include pooling, amalgamation, integration, unitization, and eminent domain. (Arnold & Porter, n.d.)

Among the states that currently have primacy, compulsory amalgamation of interests is allowed under the following principles:

> North Dakota: In North Dakota, if a storage operator does not obtain the consent of all persons who own the storage reservoirs pore space, the commission may require that the pore space owned by nonconsenting owners be included in a storage facility and subject to geologic storage.[12] Before issuing a permit, the commission shall find: that the storage operator has made a good-faith effort to get the consent of all persons who own the storage reservoir's pore space; that the storage operator has obtained the consent of persons who own at least sixty percent of the storage reservoir's pore space; and that all nonconsenting pore space owners are or will be equitably compensated.
>
> Wyoming: In Wyoming, as a general rule, no order authorizing the commencement of unit operations shall become effective until the plan of unitization has been signed or in writing ratified or approved by those persons who own at least 80%. Under certain exception this percentage can be reduced to 75%.

Proposed Amalgamation of Interests in Alaska

In Alaska, the AOGCC has experience and authority with processes to settle unitization. A similar regulatory framework would provide a stable, predictable environment for CCUS projects, while protecting the correlative rights of property owners (DNR, 2022).

[12] ND. Century Code. §38-22-10

Alaska's regulatory experience and the legal clarity around property interests may favor the development of CCUS in the state.

The proposed legislation includes provisions related to both voluntary and compulsory unitization or amalgamation. Voluntary unitization is allowed under Section 14, which states that a plan of development is required for a carbon storage lease under which lessee may validly integrate their interests to provide for the unitized management, development, and operation of the tracts of land as a unit.

At its turn, compulsory unitization or amalgamation is allowed under Section 31 of the proposed legislation, which provides that if the storage operator does not obtain the consent of all persons with an ownership interest in the storage reservoir, the commission may order amalgamation of property interests prior public notice and hearing.[13] In addition, permit requirements would require that the commission find that: the storage operator has made a good faith effort to get consent; and that all nonconsenting land owners or holders of mineral rights are or will be equitably compensated.

Operational and Long-Term Liability

Operational and Long-Term Liability in Other States

Many states will assume title and responsibility over long-term stewardship activities after injection activities have ceased for a certain number of years and a certificate of completion is issued. To offset the costs associated with these long-term activities states also set up closure trust funds to offset the costs of CCUS activities. Some states link these funds to long-term state stewardship programs to offset costs incurred by the state after assuming the stewardship role. However, other states have funds to offset administrative or other costs without any connection to state stewardship. Trust funds may also be utilized to pool risk across multiple CCUS operators, similar to an insurance pool.(Arnold & Porter, n.d.). Another option that has been proposed for potential management and long-term stewardship of a geologic storage site is to create a publicly regulated geologic storage utility. (National Energy Technology Laboratory & Great Plains Institute, 2017)

Among the states that currently have primacy, we observe the existence of trust funds with the following characteristics:

- North Dakota: The storage operator has title to the carbon dioxide injected into and stored in a storage reservoir and holds title until the commission issues a certificate of project completion. A certificate of completion may be issued after ten years. Storage operators shall pay the commission a fee on each ton of carbon dioxide injected for storage. The fee must be deposited in the carbon dioxide storage facility trust fund and may be used only for defraying expenses the commission incurs in long-term monitoring and management of a closed storage facility.[14]

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[13] See Section 31. Art. 2 of SB 49

[14] ND. Century Code. § 38-22.

- Wyoming: The injector shall have title to any carbon dioxide the injector injects into and stores underground. A certificate of completion may be issued after twenty years. Wyoming has a geologic sequestration special revenue account which may be used for testing, monitoring, plugging, and claims.[15]

Proposed Operational and Long-Term Liability in Alaska

Generally, the storage site operator is best suited to bear any liability for damage caused by a storage site during the exploration, operation and closure periods (International Energy Agency, 2022). In line with this general principle, Section 31 of the proposed legislation in Alaska provides that the storage operator has title to the carbon dioxide stored and holds this title until the commission issues a certificate of completion. It also establishes operator liability for any damage the carbon dioxide may cause including damage caused by carbon dioxide that escapes the reservoir.

As proposed, a certificate of completion may be issued after ten years from the moment carbon dioxide injections end. Once a certificate of completion is issued, title to the storage facility and to the stored carbon dioxide transfers, without payment of any compensation, to the state under management of the Alaska DNR. Provided that certain conditions necessary for the issuance of the certificate of completion are met, the operator is released of title and liability and such title and liability passes to the state.

In order to fund and ensure the long-term stewardship over the storage site, Section 2 of the proposed legislation in Alaska creates a new Carbon Storage Closure Trust Fund. This fund is intended to be used for long-term monitoring and maintenance related to injected underground carbon after a carbon storage facility has ceased operation and the operator has dismantled infrastructure and remediated the facility site except for the underground carbon. This fund will be funded through payments from operators based on the volume of injected carbon. The payment amounts will be set by the AOGCC at the time that a permit is issued for the facility (Alaska Department of Natural Resources, 2023b).

Additional Considerations Relevant to Regulating CCUS in Alaska

Carbon Capture, Utilization and Storage is an emerging technology with a complex regulatory framework for implementation. While enabling legislation such as the one proposed in Alaska can provide a sound foundation for successful implementation, legislation alone can never be all encompassing and be fully prescriptive of all situations and risks that may emerge in a developing field. This section describes some potential risks and issues that are related to CCUS and that should be considered during the passing of legislation, in the subsequent development of rules and regulations, and beyond.

[15] WY. Stat. § 35-11-318 through 320

Public Perception Risks

Although CCUS and its potential has been researched for several decades,[16] it remains a highly specialized and niche sector, and one that is not easy to understand. As such, states developing wide-spread policies to promote CCUS projects will need to address the general lack of awareness of CCUS technologies as well as public perception about its risks and benefits. Public concerns may include health and safety, historical skepticism regarding extractive industries (e.g. oil and gas companies), and greenwashing. A study published in 2021 on this topic found that U.S. residents in general have very low awareness of CCUS technologies. The same study found that bans on the construction of unabated fossil fuel plants are more supported than just subsidies for carbon capture and storage (CCS); required distance of CCS infrastructure from residential areas is a key attribute influencing policy support; and policy support considerably differs among individuals with different partisan orientation and individual views on climate change. (Pianta et al., 2021)

Communication and educational campaigns will be important in the rollout of new legislation. The dissemination of information already taking place around educational resources, taskforces, working groups, and industry associations is likely to provide state governments, developers, and communities the required tools to better understand and promote the industry. However, active public engagement should also be considered, and where local concerns are valid, communities should be offered the opportunity to shape policy.

Developing a Comprehensive Approach to CCUS in the State

Under the EPA's UIC program, to receive primacy a state, territory or tribe must demonstrate to the EPA that its UIC Program is at least as stringent as the federal standards. However, the state, territory or Tribal UIC requirements may be more stringent than the federal requirements. In that sense, states can add requirements and protections that safeguard particular interests or prevent certain local risks.

Under EPA's perspective, states are also well positioned to also develop a more comprehensive approach to managing geological sequestration projects and the integration of carbon capture and storage issues that may be outside the scope of the Safe Drinking Water Act. (EPA, 2014)

Initial Capacity Building, Staffing, and Expertise

Agency capacity building, staffing, and expertise and associated costs will be important factors in the successful deployment and implementation of CCUS at the state level. According to the proposed legislation's supporting documents, FY2024-FY2025 will mainly be focused on obtaining primacy and promulgating regulations. Expenditures for these years may be offset by potential grant receipts through the EPA Class VI Grant Program but the volume of permit applications and program activity beginning in FY2026 is not known at this time. The AOGCC also anticipates that program management and administration may to be

[16] The Department of Energy (DOE) has funded research and development (R&D) in carbon capture and storage (CCS) since at least 1997 within its Fossil Energy and Carbon Management Research, Development, Demonstration, and Deployment program (FECM) portfolio (Jones & Lawson, 2022)

accomplished through either contractual support, AOGCC staff, or a combination of the two (Department of Commerce, Community and Economic Development, 2023). The Alaska DNR also anticipates that program implementation and oversight be accomplished through existing staff and at least two additional staff positions (Alaska Department of Natural Resources, 2023b).

Additional Regulatory Requirements

It is important to note that CCUS projects may need to comply with the requirements of other complex environmental laws and frameworks. For example, some CCUS projects depending on site location and other circumstances may trigger review under the National Environmental Policy Act (NEPA), new source review under the Clean Air Act (CAA), permitting under the Clean Water Act's (CWA) National Pollutant Discharge Elimination System (NPDES), compliance with the Endangered Species Act (ESA), the National Historic Preservation Act (NHPA), among others. Developers will need to be aware and conduct due diligence of all applicable laws and regulations prior to the implementation of any CCUS project.

Developers will also need to consider that applicable rules and regulations may be subject to frequent revision and changes given broader mandates to federal to facilitate and help accelerate the adoption of these new technologies. Therefore, staying up to date with potential changes and engaging with federal agencies will be key to a successful and more cost-efficient development of the industry in Alaska.

As part of the USE IT Act, included in H.R. 133 (116th Congress), Congress directed the chair of the Council on Environmental Quality (CEQ) to prepare a report on CCUS, with a particular focus on identifying and inventorying existing permitting requirements, including best practices to advance the efficient, orderly, and responsible development of CCUS projects at increased scale. This, and other subsequent federal agency guidance[17] will be helpful in identifying additional regulatory requirements and considerations that would be applicable to individual CCUS projects implemented in Alaska. (CEQ, 2021)

Permanence and Leakage

According to a report from the Congressional Research Service, "the suitability of any particular CCUS site, depends on many factors, including proximity to CO_2 sources and other reservoir-specific qualities such as porosity, permeability, and potential for leakage." (Jones & Lawson, 2022) "For CCUS to succeed in mitigating atmospheric emissions of CO_2, it is assumed that each reservoir type would permanently store the vast majority of injected CO_2, keeping the gas isolated from the atmosphere in perpetuity. That assumption is untested, although part of the DOE CCS R&D program has been devoted to experimenting and modeling the behavior of large quantities of injected CO_2" (Jones & Lawson, 2022).

[17] CEQ recently issued an interim guidance document on carbon capture, utilization, and sequestration to assist Federal agencies with the regulation and permitting of CCUS activities in the United States. (CEQ, 2022)

While nothing can be done to ensure that permanence and leakage can be achieved in perpetuity, appropriate measures, actions, and funding during operation and post closure of the site are extremely important.

CO_2 transportation infrastructure and appropriate risk management is also likely to create public safety concerns and will require special consideration. Best practices for adequate transportation of CO_2 over long distances may not be possible without significant investment in new infrastructure and requires close oversight to ensure safety. (Energy, Equipment & Infrastructure Alliance, No Date) Mismanagement, accidents, or other incidents such as a pipeline accident occurred in Mississippi in 2020,[18] may tarnish the CCUS industry's reputation and may create apprehension against wide scale build out of pipelines.

Financial Feasibility and Risk

The financial profile of CCUS projects is complex and success in every project is not guaranteed. To date, investment in CCUS projects have typically been financially feasible through public grant funding and revenues from enhanced oil recovery (EOR) (Zapantis et al., 2019). Recent legislation in the U.S. under the Bipartisan Infrastructure Law (BIL) included additional public funding to expand CCUS as part of various federal programs. At the same time, the Inflation Reduction Act (IRA) enhanced federal tax credit incentives[19] to provide for an additional source of financing. However, these incentives are unlikely by themselves to make all CCUS activities profitable. Project profiles may need to be assessed individually and supplemented by other revenues sources if necessary.

For Alaska, the exact revenue potential from CCUS remains highly uncertain at this stage. The Department of Revenue has highlighted that while the 45Q credit will reduce the state's corporate income tax collection because the state tax code adopts by reference the federal code, there are numerous fees, penalties, and other charges that will generate the revenue necessary to administer this new program. (Alaska Department of Natural Resources, 2023b) In addition, the state is expecting that it will be able to monetize carbon injection from other jurisdictions for a fee once the program is underway. (Alaska Department of Natural Resources, 2023b) However, there is not currently sufficient detail on how funding from other jurisdictions will be successfully achieved.

It is important for regulators and developers to understand the full and complex range of factors that may jeopardize project completion and create financial risk. A Government Accountability Office (GAO) report on demonstration projects undertaken by the

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[18] In 2021, a CO_2 pipeline rupture occurred less than half a mile from the little village of Satartia, Mississippi forcing large evacuations. (Zegart, 2021)

[19] Federal tax credits for carbon sequestration were first authorized in 2008 with the enactment of the Energy Improvement and Extension Act (Division B of P.L. 110-343). This act added Section 45Q to the Internal Revenue Code (I.R.C), which established tax credits for CO_2 disposed of in "secure geologic storage" or through EOR with secure geologic storage. The Bipartisan Budget Act of 2018 (P.L. 115-123) amended Section 45Q to increase the tax credit for capture and sequestration of "carbon oxide," for its use as a tertiary injectant in EOR operations, or for other qualified uses. In 2022, the Inflation Reduction Act of 2022 (IRA; P.L. 117-169) made numerous changes to Section 45Q.

Department of Energy (DOE), found that despite spending about $1.1 billion, with the aim of accelerating the development and commercial deployment of CCS, the demonstrations ended with only three of eleven projects being built. This report also highlighted the importance of learning from these demonstration experiences. (Rusco, 2021)

Indigenous Rights, Consultation Considerations

In general, environmental justice considerations are important in the development and management of natural resources because projects have the potential to affect the health, well-being, and rights of the communities that live near the project sites and transportation pipelines. Ensuring the engagement of all community voices, stakeholders, and Tribal Nations is of critical importance for the successful development of carbon management practices and use of state lands.

CCUS implementation will require further action to address both long-standing and emerging environmental justice concerns.

Implementation of CCUS projects in Alaska will also need to observe any limitations imposed the Alaska Native Claims Settlement Act of 1971 (ANCSA) and other Indigenous rights. For example, in relation to pore space ownership, the full fee estate held by regional Alaska Native Corporations includes the pore space. (DNR, 2022)

At the federal level, the current federal administration has given significant priority to both climate change and environmental justice issues. This has resulted in a series of policies that are relevant for federal agencies and will impact federal funding. Relevant environmental justice policies applicable to the CCUS industry are described below:

CEQ guidance for CCUS. Under its recently proposed guidance, the Council on Environmental Quality (CEQ) recommends that agencies undertake measures to facilitate a transparent process and meaningful public engagement. In addition to developing robust Tribal consultation and stakeholder engagement plans and conducting regular engagement, agencies should prioritize the development and application of environmental justice best practices for CCUS efforts. According to CEQ, actions that should be taken include:

- Evaluating the impacts of proposed CCUS actions on potential host communities early in the planning process;
- Providing information about the impacts, costs and benefits of CCUS in advance of Tribal consultation and stakeholder engagement;
- Consulting Tribal Nations on potential CCUS projects in a manner that strengthens Nation-to-Nation relationships;
- Avoiding the imposition of additional burdens on overburdened and underserved communities, including by evaluating direct, indirect, and cumulative effects and identifying and implementing appropriate mitigation and avoidance measures; and

- Ensuring transparent decisions and accountability to Tribes and communities with respect to any applicable mitigation measures designed to reduce environmental impacts. (CEQ, 2022)

Executive Order 14008. On January 27, 2021, the Biden administration issued this Executive Order which seeks to prioritize climate change and environmental justice. This order creates the Environmental Justice Interagency Council, announced the Justice40 initiative, and seeks to compel agencies to make achieving environmental justice part of their missions by developing programs, policies, and activities to address the disproportionately high and adverse human health, environmental, climate-related and other cumulative impacts on disadvantaged communities, as well as the accompanying economic challenges of such impacts. (The White House, 2021)

EPA Policies on Environmental Justice for CCUS. On Dec. 9, 2022, EPA Administrator Michael Regan sent a letter to state governors calling for partnership to advance the twin goals combating climate change and supporting environmental justice goals. This letter provides that states should include environmental justice as a core element in implementing their Class VI programs. (Regan, 2022) Similarly, under EPA's newly funded $50 million Class VI UIC grant program, applicants must demonstrate how environmental justice and equity considerations will be incorporated into their Class VI UIC primacy programs. Primacy program commitments may include identifying communities with potential environmental justice concerns, enhancing public involvement, appropriately scoped environmental justice assessments, enhancing transparency throughout the permitting process and minimizing adverse effects associated with permitting actions. (US EPA, 2023) On Aug. 17, 2023 a letter from Assistant Administrator Radhika Fox to all EPA regional water division directors outlined environmental justice considerations for Class VI permitting. (Fox, 2023)

Tribal Consultation. It is not only important that Tribal consultation is conducted when appropriate, but that it occurs in a way that is timely and meaningful. Federal guidelines such as those included in the Memorandum on Uniform Standards for Tribal Consultation, provide useful information to federal agencies and may be used for others in defining the appropriate methods of engagement. (The White House, 2022) States should seek Tribal input on how to conduct Tribal consultation for carbon management projects including the relevant Tribal authorities which should be approached and appropriate timelines. Similarly, states should promote relationships with Tribes that consider their status as sovereign Nations as well as their unique history, circumstances, and characteristics.

Conclusion

CCUS is an emerging area with growing interest – particularly in Alaska and other oil and gas-producing states that have experience with enhanced oil recovery (EOR). While there are examples of these projects currently being carried out, there are also a variety of risks, issues, and considerations that must be balanced in these projects.

CCUS projects include three parts: capturing CO_2, transporting it (if needed) to a storage location, and injecting it below ground for permanent storage. However, storing carbon underground requires unique attention to storage site and reservoir suitability. Even when these needs are met, projects must be attentive to post-injection monitoring in order to assess and control for induced seismicity, underground leakage impacting water quality, and surface leakage that could lead to toxicity. On a larger scale, scaling CCUS also presents a variety of environmental considerations.

Technical considerations surrounding CCUS projects are enmeshed within the broader context of regulating and governing CCUS activities. In other states, we see regulatory frameworks paying particular attention to where regulation authority lies, Class VI well primacy, the ownership and leasing of pore space, how ownership interests are handled, and liability – both operationally, as well as for the long-term. Proposals for governance of CCUS in Alaska largely considers the same factors. However, beyond simply regulating CCUS, a variety of other place-specific considerations for Alaska must be factored into these project proposals as well as how the State of Alaska interacts with them. Top of mind within these considerations are: public perception risks, comprehensiveness of the approach taken, the need for key staffing and expertise, permanence and leakage, financial feasibility and risk, and attention to Indigenous rights, consultation, and community engagement.

In conclusion, there is no one-size-fits-all approach to CCUS, nor have all the questions been answered. However, in this emerging field, other states, projects, and case studies provide examples that can help weigh the risks and considerations at hand for CCUS in Alaska.

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Glossary

Additionality
A term to refer to a key issue for carbon-offset projects, which is whether they can be sure that the emissions reductions achieved are truly "additional" to what would have happened without the project. If not, the carbon offsets sold could be considered worthless.

Carbon capture, utilization and storage
CCUS involves the capture of CO_2, generally from large point sources like power generation or industrial facilities that use either fossil fuels or biomass as fuel. If not being used on-site, the captured CO_2 is compressed and transported by pipeline, ship, rail or truck to be used in a range of applications, or injected into deep geological formations such as depleted oil and gas reservoirs or saline aquifers. Carbon capture and storage (CCS) is sometimes used interchangeably with CCUS.

Carbon credits
Tokens representing one ton of CO_2 equivalent that can be traded between an entity that continues to emit and an entity that reduces its own emissions or removes CO_2 from the atmosphere. Used interchangeably with "carbon offsets."

Carbon markets
Trading systems in which carbon credits can be bought and sold.

Carbon-offset project
A method for reducing emissions or removing CO_2 from the atmosphere that is at least partly financed through carbon offsets.

Class VI injection well
Injects CO_2 below the surface into rock formations typically thousands of feet deep and separated from drinking water.

Enhanced Oil Recovery (EOR)
While not a climate solution, enhanced oil recovery is currently the major use of captured CO_2 described by carbon capture, utilization and storage (CCUS). The process involves injecting CO_2 into oil reservoirs to recover more oil.

Environmental, social and corporate governance
A range of considerations, including environmental issues, social issues and corporate governance that are considered in business goals and operations.

Offset protocols
Formal methodologies for quantifying emissions reduction from a proposed offset project.

Permanence
A term used in reference to how different carbon-offset projects can reduce emissions over various timescales. For example, carbon stored in a forest may remain there for tens to hundreds of years, whereas CO_2 injected into rock can remain there for thousands of years. Not adequately considering permanence can lead to projects overestimating their ability to reduce emissions.

Pore space
An underground geological formation suitable for carbon storage.

Unitization
The cooperative operation of an oil or resource pool as if it were owned and operated by a single entity, with benefits accruing to individual owners.