Carbon Capture and Storage: Safety and Impact Considerations from Source to Sequestration

Executive Summary

Energy and Carbon Management Commission

COLORADO
Energy & Carbon Management Commission
Department of Natural Resources

Senate Bill 23-016 directed the Colorado Energy and Carbon Management Commission (ECMC) to undertake a study pertaining to safety considerations and potential impacts of carbon capture and sequestration (CCS) technology across each stage, from the CO_2 source, through transportation, to the injection well and sequestration reservoir. In adherence to this directive, this report presents a scientific grounding to illuminate core safety concerns and mitigation strategies, an overview of relevant state and federal regulations applicable to CO_2 pipelines and Class VI injection wells, and considerations to ensure CCS in Colorado is implemented in a manner consistent with state priorities and protective of public health, safety, welfare, the environment, and wildlife resources.

Colorado's statutory goals: At least 20% reduction in greenhouse gas (GHG) emissions from industrial and manufacturing sources by 2030, and to reach a 100% net reduction by 2050.

CCS strategies: CCS technology has been identified as a valuable tool in the GHG-reduction toolkit. Some industrial sources currently have no low- or zero-carbon alternative processes, such as in cement and steel production, making CCS the clearest path to remove CO_2 from those emissions streams. Direct air capture (DAC) is a developing technology that, should it fulfill expectations, would allow CO_2 to be directly captured from the atmosphere. For both CCS and DAC, sequestration is an end point for captured CO_2 that will place carbon back into the long-term geologic cycle.

Benefits beyond CO_2 reduction: Depending upon the type of technology utilized, other harmful emissions (SO_2, particulate matter, and NO_x) may be removed from the emission streams of facilities, which will improve local air quality and benefit nearby communities.

The process of CCS: Once CO_2 is captured, it is compressed into a liquid state that has special physical properties, called its "supercritical state." It can then be transported by either buried or above-ground pipelines to the site of injection, where it will be stored in a deep geologic formation permanently.

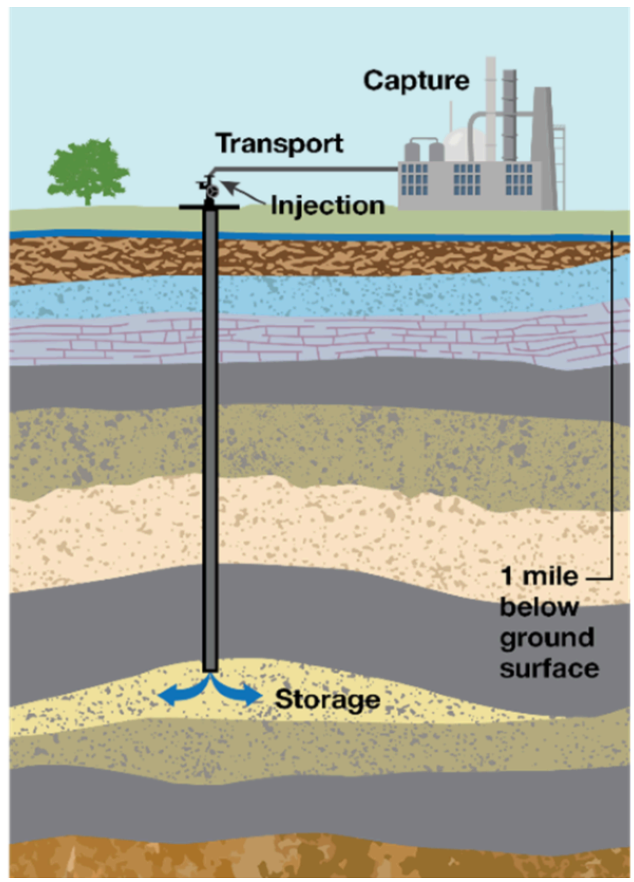


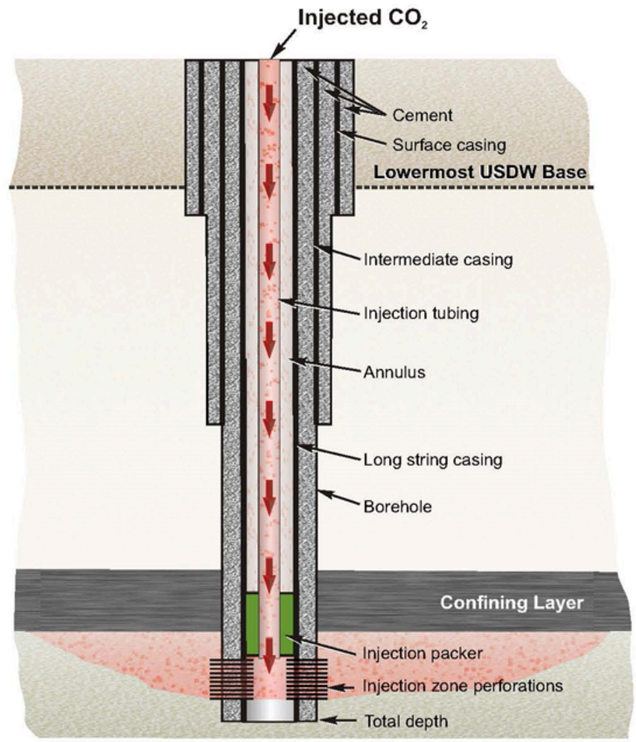
Image from: [EPA]

Pipelines: Compared to other types of hazardous materials transported via pipeline, CO_2 has a lower occurrence of incidents, and if a release should occur, CO_2 pipelines are less likely to cause injuries and have lower damage and recovery costs. Pipeline rupture simulations show that CO_2 pipeline volume and pressure have the most significant impact on the dispersion of CO_2 during a rupture incident.

Pipeline regulation: Construction and operation of CO_2 pipelines is regulated by the federal Pipeline and Hazardous Materials Safety Administration (PHMSA). The regulations are designed for the safe and secure transportation of hazardous fluids and require the development of an integrity management program that focuses on preventing leaks and ruptures and reducing the impact of pipeline systems on surrounding communities. Presently, the State does not have a significant role in the siting or regulation of CO_2 pipelines within its borders. Additional jurisdictional considerations for regulatory and siting authority will be addressed in a further study to be completed by the end of 2024.

Class VI injection wells: These wells exclusively inject CO_2 underground for permanent storage and thus require specific design and materials that are closely regulated. Wellbore integrity is key to ensuring the safe operation of these wells and preventing CO_2 from leaking into shallower formations or onto the surface. A robust collection of monitoring and testing methods exist to thoroughly assess the integrity of wellbores throughout the life of the well. Safety shut-off systems are a required measure to prevent surface leakage. Also, the continuous monitoring of the CO_2 stream prior to injection is a key practice to mitigate the risk of introducing impurities that may compromise the integrity of wellbores or the pipelines supplying them. These considerations are expected to be included in Colorado's Class VI regulations.

Regulation of Class VI injection wells: Class VI wells are currently regulated by the Environmental Protection Agency (EPA). SB23-016 directed ECMC to seek primacy to regulate these wells at the state level. In order for Colorado to obtain Class VI primacy, state regulations must be at least as stringent as that of the EPA. Further, the law also directs ECMC to establish regulations that will be more stringent than federal standards. ECMC has developed comprehensive regulations for the industries it regulates in a way that reduces risks to safety and impacts to sensitive receptors. This approach will serve as a basis for CCS regulations.



Note: figure is not to scale

Image from: EPA

Reservoirs: The locations where CO_2 is injected for permanent storage are variously referred to as "geologic systems," "formations," and "reservoirs." Class VI wells inject CO_2 into geologic formations that have been carefully characterized to ensure they possess suitable chemical and physical properties. While multiple types of storage formations exist in Colorado, the most likely to be utilized are deep saline reservoirs, which are typically deeper than underground sources of drinking water (USDWs), and are widespread and abundant in the deep subsurface. While the likelihood of CO_2 leakage is low, potential pathways include wellbores with compromised integrity, insufficiently mitigated legacy wellbores, and fault zones or fractures not discovered during characterization. Injecting supercritical CO_2 into reservoirs at pressure creates an expanding front called a "plume." CO_2 achieves stability in the reservoir through diverse trapping mechanisms, including mineralization, structural, residual, and solubility processes.

Regulation of reservoirs: The EPA requires extensive reservoir characterization, ongoing monitoring, and modeling of the subsurface extent of the injected CO_2 to ensure the protection of underground sources of drinking water (USDWs) and permanent containment of the CO_2. Existing regulations require careful monitoring of the injection wellbore, remediation of any wellbore in the area that could act as a conduit for flow out of formation and additional monitoring in and above the injection zone to help prevent any leak from occurring and in order to recognize any potential issue before it escalates.

After CO_2 injection ends: Class VI projects require an extended post-injection site care (PISC) phase, typically for decades after injection has ceased. During this time, the plume is continuously monitored and modeled with updated data until the CO_2 fully integrates with the formation, achieving a state of equilibrium. At that time the plume is considered to be stabilized, effectively eliminating the likelihood of any subsequent leak and removing any risk to USDWs. The timing of plume stabilization is site- and project-specific. Site closure can be approved by the regulator once the plume has fully stabilized and all financial and regulatory obligations of the operator will conclude. The EPA defaults to 50 years for PISC, while states have taken varying approaches such as 10-20 year minimum monitoring periods.

In the long-term: Once site closure has occurred, considerations regarding long-term site stewardship and liability take precedence. States with regulatory jurisdiction over Class VI wells have enacted legislation to address post-closure site stewardship, whereas the federal government does not currently have any strategies in place. At this time, Colorado has not addressed long term site stewardship and liability.

Potential natural hazards: The ECMC has previously enacted Rules intended to prevent induced seismicity. These regulations could be updated or adjusted to apply to Class VI operations. Evidence indicates that supercritical CO_2 has different properties from injected wastewater, and may therefore pose a lower risk of induced seismic activity. Strategies to mitigate potential induced seismicity include proactively lowering injection pressures and volumes or implementing a "traffic light" system to alter operations in the event of any seismicity in the area. Further, each Class VI permit requires a seismic evaluation to ensure the risk is understood prior to authorizing injection. Other Colorado hazards, such as land movement, extreme weather, and swelling or collapsible soils, do not pose a unique threat to CCS installations or pipelines.

Protecting disproportionately impacted (DI) communities: SB23-016 requires the ECMC to conduct a rigorous cumulative impacts analysis for any Class VI project being considered within a DI community. Furthermore, if it is determined that a proposed project will have a net negative cumulative impact on the community, the ECMC is required to deny the application. ECMC will advance environmental justice goals during rulemaking around CCS, such as ensuring robust community involvement and engagement throughout the entire project lifespan, and making educational materials, project plans, regulatory processes, and records more accessible and transparent. ECMC understands that its rules need to ensure that community engagement is a cornerstone in guaranteeing a prospective CCS project fits the needs and values of the community.

In the future: To attain Class VI primacy, the State must conduct a Class VI Rulemaking to establish regulations at least as stringent as those of the EPA, while adhering to SB23-016 and Colorado environmental justice goals. A full legal framework for ownership and unitization of pore space is also necessary. Other matters in need of consideration include long-term site stewardship (and its potential funding), inspection and potential regulation of CO_2 pipelines, State communication and education goals with communities and operators, the applicability of existing regulations and tools, and resources to keep Staff informed and regulations up-to-date.

TOPIC	SUMMARY AND CONSIDERATIONS
Carbon Capture and Sequestration (CCS) Fundamentals	● Carbon capture and sequestration (CCS) is the capture of CO2 from an emission stream or even directly from the air (Direct Air Capture or DAC), transporting it to a site with a suitable underground reservoir formation, and then injecting it for permanent storage. ● While the IPCC is clear that necessary CO2 reductions cannot be achieved with any single technology, CCS is key to reducing carbon emissions from industries that have no carbonfree alternatives, such as cement and steel production. ● The EPA currently regulates permitting of Class VI wells (those used for CCS), and ECMC has been directed to seek regulatory primacy; in order for Colorado to gain primacy, our regulations will have to be at least as strict as those of the EPA. ● The 45Q tax credit provides direct support to CCS and DAC operators, amounting up to $180 per metric ton of carbon stored, and extends up to 12 years.
Carbon Capture Technologies and Impacts	● Carbon capture is the process of separating and removing CO2 from a larger body of gas, such as the atmosphere, the emissions of power plants, or industrial process emissions. ● Certain carbon capture technologies may require additional clean-up of emissions, removing other co-pollutants and bringing additional health, social, and environmental benefits, known as co-benefits. ● Industries with the greatest projected health benefits from the removal of co-pollutants, and communities near facilities utilizing carbon capture technology are expected to experience the greatest health impacts.
Pipeline Safety	● • Ensuring effective public engagement, providing educational resources, and establishing comprehensive guidance are essential to help address concerns related to CO2 pipelines. ● Compliance with U.S. Pipeline Hazardous Material and Safety Administration (PHMSA) regulations is essential for preventing accidents, protecting the environment, and safeguarding public health. ● CO2 pipelines display a generally positive safety record compared to those carrying other hazardous fluids, and releases are much less impactful than releases from all other hazardous liquid pipelines. ● Pipeline sensitivity analyses provide information to understand the dynamics of CO2 pipeline ruptures and identify critical factors that influence the release and dispersion of CO2 , including volume and pressure. ● Inspection or potential regulation of CO2 pipelines is a topic for further consideration, and will be addressed in a study from ECMC and the Colorado Public Utilities Commission due at the end of 2024.
Siting and Surface Considerations	● The ECMC has developed comprehensive and highly protective regulations and processes for oil and gas operations; this approach is proposed to be extended to Class VI wells. ● Operators seeking to permit a CCS project must take various siting and impact considerations into account. ● Deep and shallow monitoring operations are required to ensure that the CO2 plume remains contained in the authorized formation(s) and to certify that no environmental degradation has occurred.

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Class VI Regulatory Requirements	• All Class VI projects require a permit from the Environmental Protection Agency (EPA) or a state with primacy. Extensive data collection, evaluation, reservoir modeling, as well as a multitude of plans are required before a permit can be issued. • Continuous monitoring of operations is required to track CO_2 plume movement, pressure changes, and potential impacts to underground sources of drinking water (USDWs). • Post-Injection Site Care and Site Closure Plans ensure proper abandonment of wells and monitoring until the injected CO_2 has stabilized.
Injecting CO2	• Wells must be constructed to be compatible with injection and reservoir fluids and capable of withstanding anticipated pressures, temperatures, and stresses throughout the project lifecycle. Various barriers, including casing, packers, and cement, are incorporated into well construction to mitigate the risk of leaks. • Pressure tests, surveys, and logs are useful tools for evaluating the integrity of the wellbore, cement, and surrounding formation. • In addition to implementing comprehensive wellbore monitoring techniques, all Class VI wells are equipped with safety shut-off systems that are designed to shut automatically, ceasing injection of CO_2 if pre-set limits on variables such as pressure, flow rate, or temperature are exceeded.
Sequestration Reservoirs and Plume Stabilization	• Of Colorado's potential storage reservoirs, deep saline formations are the most common and have the greatest potential storage capacity; additionally, they are generally deeper than USDWs. • Properly characterized reservoirs will experience no leakage due to four major trapping mechanisms that operate on different time horizons from the hour- to century-scale. • CO_2 injection in a formation creates a three-dimensional "plume" that moves and expands during injection. When that plume ceases movement after injection has ended, it is considered stable. • No set timeline exists for plume stabilization, though evidence suggests a scale of a few decades. Continuous monitoring and modeling allows operators to track plume stabilization.
Natural Hazards	• It is possible for CO_2 injection to induce seismicity. However, Colorado has regulations to mitigate injection-induced seismicity in Class II wells that could be implemented for Class VI wells, and EPA rules allow greater seismic monitoring and mitigation to be required. • Other natural hazards in Colorado, such as extreme weather conditions, landslides, and collapsible or swelling soils must be taken into account when CO_2 facilities are constructed but represent no special risk so long as applicable regulations, standards, and guidelines are complied with.

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Considerations and Recommendations for Community Safety	● Colorado's regulations must be at least as stringent as EPA regulations for the state to gain primacy, and CCS projects in the state must also comply with the Clean Air Act and Air Quality Control Commission. ● Colorado prioritizes Environmental Justice, and that practice will continue in the administration of CCS projects. ● Proposed Class VI wells must be evaluated for cumulative impacts, and permits denied if there are net negative impacts on disproportionately impacted communities. ● Community Benefit Plans are required for project developers to access many Federal grant opportunities.
Moving Forward	● In pursuit of regulatory primacy, the State must conduct a Class VI Rulemaking and establish regulations at least as stringent as current federal regulations that align with SB23-016. ● A full legal framework for the ownership and utilization of pore space will be necessary, as well as a mechanism for aggregating property rights. The status of long-term site stewardship, liability, and the use of injection fees to fund state-led monitoring and maintenance activities after site closure warrant consideration. ● Continued communication and development of educational materials by the State and operators for impacted communities and the public is recommended, discussing the purpose, processes, and potential benefits and risks associated with a CCS project.