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# **An evaluation of permitting avenues for deploying carbon mineralization projects with and without acid pre-treatment**

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## **Abstract**

Carbon mineralization is an emerging carbon capture and storage (CCS) technology that offers permanent sequestration through the conversion of CO<sub>2</sub> into stable carbonate minerals. Despite its potential as a long-term climate mitigation strategy, regulatory frameworks governing carbon mineralization remain underdeveloped compared to conventional CCS strategies. This paper examines the legislative and permitting landscape for in situ carbon mineralization projects in Canada, the United States, and select international jurisdictions (Iceland, Norway, the United Kingdom, and Australia). Existing CCS legislation, permitting requirements, and monitoring obligations are reviewed to assess their applicability to mineralization-based storage projects. Attention is given to the regulatory implications of acid pre-treatment, a proposed method to enhance basalt reactivity and accelerate mineralization rates. While acid pre-treatment could positively impact storage operations, it introduces additional permitting complexity related to well classification, chemical stimulation, waste management, and environmental protection requirements. Two implementation pathways (in British Columbia and Washington, DC) are evaluated to determine the extent to which current regulations could enable or restrict the deployment of carbon mineralization projects, with or without acid pre-treatment.

The analysis demonstrates that most regulatory frameworks were developed for conventional storage and do not explicitly address mineralization storage. Broad legislative

language may allow mineralization projects to be permitted under existing CCS regulations using a case-by-case approach. Regulatory uncertainty surrounding mineralization storage projects remains a significant barrier to deployment, particularly for projects incorporating an acid pre-treatment. However, existing CCS frameworks provide a foundation upon which mineralization-specific regulations can be developed. Establishing clear permitting pathways, monitoring requirements, and guidance for chemical stimulation could accelerate the deployment of carbon mineralization as a secure and scalable carbon management solution.

## Introduction

As of 2025, the average global surface temperature has risen 1.44 °C above pre-industrial (Rohde, 2026). This increase is predominantly driven by anthropogenic carbon dioxide (CO<sub>2</sub>) emissions. In response, the Intergovernmental Panel on Climate Change (IPCC) recommends limiting global warming to below 1.5 °C to avoid the most severe impacts of climate change. However, given current emission trajectories, achieving this target will require not only reducing ongoing emissions but also removing gigatons of CO<sub>2</sub> from the atmosphere (IPCC, 2022).

Many existing carbon storage technologies rely on storing CO<sub>2</sub> as a free phase (gas, liquid or supercritical CO<sub>2</sub>). This free phase CO<sub>2</sub> can be injected into geological formations for structural geologic storage, which allows for large-scale sequestration, but is susceptible to CO<sub>2</sub> leakage and necessitates extensive long-term monitoring. Current legislation in jurisdictions such as Alberta and British Columbia in Canada and the United States (US) requires 50 to 100 years of monitoring post injection (Government of British Columbia, 2025b; U.S. Environmental Protection Agency [EPA], 2022). An alternative and more secure method of storage is carbon mineralization, wherein CO<sub>2</sub> reacts with rock formations such as basalt to form stable carbonate minerals. This process offers permanent storage on a geological timescale, substantially reducing the risk of leakage and potentially shortening the required monitoring period (Snæbjörnsdóttir et al., 2020). British Columbia's jurisdiction suggests that mineralization projects may only require monitoring for 20 years, given the reduced long-term risk (Government of British Columbia, 2025b).

Over the past decade, successful pilot-scale projects in Iceland and Wallula, Washington have demonstrated that basalt carbonation is a promising CO<sub>2</sub> immobilization strategy. However, these projects have injected nominal amounts of CO<sub>2</sub>, with the largest injecting 12,000 metric tonnes of CO<sub>2</sub> per year (Oelkers et al., 2023). To meaningfully contribute to global climate goals,

basalt carbonation must be scaled to accommodate gigaton levels of CO<sub>2</sub> removal. Larger rates of injection will likely result in reduced mineralization rates due to slow reactions between the formation waters, basaltic minerals, and injected CO<sub>2</sub> (Tutolo et al., 2021). A proposed method to increase the efficiency of basalt carbonation at a gigaton scale is the use of acidity-enhanced basalt dissolution to accelerate the rate of CO<sub>2</sub> mineralization by promoting faster reactions between injected fluids and basaltic minerals (D’Ascanio et al., 2026; Zhang et al., 2024).

Deploying acidity-enhanced carbon mineralization at the field scale would offer valuable insight into the feasibility of large-scale mineralization storage as a climate mitigation tool. However, carbon mineralization is a relatively new emerging carbon capture and storage (CCS) technique, and current legislation predominantly addresses conventional structural storage. As a result, existing policies may not adequately account for the specific mechanisms and challenges of mineralization storage. This paper explores the permitting landscape for a pilot-scale field study employing acidity-enhanced basalt dissolution, with a focus on the western United States and Canada. It reviews current CCS legislation in this region and examines international policy frameworks relevant to mineralization storage. Finally, it evaluates how a basalt carbonation project could be implemented under current legal structures in British Columbia and Washington State and provides recommendations for policy adaptations to better support mineralization storage research while maintaining strong environmental safeguards.

### **CCS in Canada**

As CCS emerges as a promising strategy for long-term CO<sub>2</sub> immobilization, Canadian policy and legislation are struggling to keep pace with technological innovation, particularly in the area of carbon mineralization. While Canada has positioned itself as a global leader in carbon capture, utilization, and storage (CCUS) through various federal and provincial initiatives aimed

at reducing greenhouse gas (GHG) emissions, carbon mineralization lacks a clear regulatory framework (Global CCS Institute, 2024). Instead, mineralization projects would be governed by broader environmental, industrial, and resource management laws that vary across federal and provincial jurisdictions. This regulatory uncertainty poses significant challenges for project developers seeking clarity on permitting, liability, and long-term monitoring requirements.

### *Federal Regulations*

At the federal level, Canada regulates carbon sequestration primarily through environmental protection laws, industrial emissions policies, and financial incentives designed to accelerate CCUS deployment. The most relevant federal documents include the Canadian Environmental Protection Act, 1999 (CEPA 1999), the Impact Assessment Act, 2019 (IAA 2019), the Greenhouse Gas Pollution Pricing Act, 2018 (GGPPA 2018), and the draft Federal Offset Protocol for Direct Air Carbon Dioxide Capture and Geological Storage, 2025 (DACCS 2025).

CEPA 1999 serves as Canada's overarching legislation for pollution prevention and environmental management. While it does not explicitly address carbon mineralization, it provides the foundation for regulating industrial processes that involve CO<sub>2</sub> emissions and storage. Carbon dioxide was added to The Toxic Substances List (Schedule 1) in November 2005 (Canadian Environmental Protection Act (CEPA), 1999). Hydrochloric acid (HCl), proposed for use in acid pre-treatment in mineralization, is not specifically listed but is broadly categorized as a toxic substance under CEPA 1999 (CEPA, 1999). Notably, CEPA 1999 includes a section protecting research, investigation, and evaluation of toxic substances for the purpose of assessing a manner in which to control a substance (CEPA, 1999). A pilot acid-treated basalt carbonation project would likely fall within this research mandate and could therefore be considered permissible under CEPA 1999. Additionally, some carbon mineralization projects involving industrial by-products

(e.g., cement and steel slag), may fall under hazardous waste disposal and recycling regulations rather than toxic substance controls. Whether HCl would be regulated as a waste product or as a process enhancer remains unclear and could depend on sourcing and application.

IAA 2019 mandates federal environmental assessments for projects that are likely to have significant impact on land, water, or air quality (Impact Assessment Act (IAA), 2019). While large-scale geological carbon storage projects may require full assessments, mineralization-based projects may be exempt if they are small-scale or classified as low-risk due to the permanence of sequestration and low leakage potential. For a pilot-scale field project, exemptions are possible under IAA 2019 if the project is unlikely to cause “adverse effects within federal jurisdiction or direct or incidental adverse effects” (IAA, 2019.). This could allow smaller mineralization storage projects to avoid the time and cost associated with a full federal review.

The GGPPA 2018 is the federal carbon pricing system that incentivizes emission reductions and provides financial mechanisms to support CCS including Carbon Credits and Offsets (Greenhouse Gas Pollution Pricing Act (GGPPA), 2018). Through the Output-Based Pricing System, eligible CCS projects may earn carbon credits and offsets. While the legislation does not specifically reference carbon mineralization, projects that use this technique to sequester CO<sub>2</sub> could potentially qualify for credits. Additional support may be available through investment tax credits introduced in Bill C-59, which offers a 50% refundable investment tax credit for eligible CCUS projects (C-59, 2023). However, it is unclear whether mineralization storage projects qualify under this credit.

Canada is also currently drafting the Federal Offset Protocol for DACCS 2025. A project under this protocol may only use CO<sub>2</sub> captured directly from the atmosphere and store it in onshore geological formations governed by an established CO<sub>2</sub> geological storage regulatory framework

(Direct Air Carbon Dioxide Capture and Geological Storage: Federal Offset Protocol, Public Consultation, Preliminary Draft, 2025). While the protocol does not explicitly name carbon mineralization, its language is broad enough that mineralization storage could fall within its scope.

### *Provincial Regulations*

In Canada, natural resource management and land-use regulations primarily fall under provincial control, leading to a fragmented policy landscape for carbon mineralization. The feasibility of an in-situ carbon mineralization project is dependent on suitable geology, such as the presence of mafic or ultramafic rocks, and local policy. Mafic or ultramafic rocks can predominantly be found in British Columbia, Ontario, Quebec, the Maritimes, and the Territories (Carbfix, 2025; Lawley et al., 2024). While these regions are geologically favourable for mineralization, most lack CCUS-specific legislation, with the exception of British Columbia.

Provinces with CCUS-specific regulations (namely Saskatchewan, Alberta, and British Columbia) have built their frameworks on pre-existing oil and gas legislation, focusing largely on structural CO<sub>2</sub> storage (The Oil and Gas Conservation Act, 1978). This limits the applicability to mineralization storage projects which may follow different technical pathways and risk assessments. The Territories, New Brunswick, Prince Edward Island, Newfoundland and Labrador, Nova Scotia, Quebec, and Ontario generally rely on the federal regulations around CCS and have limited provincial legislation. Ontario proposed the Geologic Carbon Storage Act in November 2024, which remains under review. If passed, this would allow CCS projects to be implemented on Crown land, i.e. public land that is owned and managed by the government on behalf of the public (Ministry of Natural Resources, 2024). Nova Scotia and Newfoundland have both expressed interest in developing frameworks but have not yet implemented new legislation. Quebec currently has limited CCS specific legislation, however, Carbfix and Deep Sky are

conducting a mineral evaluation project in Quebec which may prompt future regulatory development (Carbfix, 2024).

In Saskatchewan, CCS projects are primarily governed by the Oil and Gas Conservation Act, 1978, applying primarily to saline aquifers and depleted hydrocarbon reservoirs. The act prohibits injection into unmineable coal beds, shale formations, and salt caverns and excludes any project that would enhance oil recovery (The Oil and Gas Conservation Act, 1978). Manitoba enacted Bill 31: The Captured Carbon Storage Act on June 4, 2024, and amended multiple statutes to establish a regulatory scheme to enable safe storage of CO<sub>2</sub> in geological formations (Bill 31, 2024). While legislation in Saskatchewan and Manitoba does not explicitly address mineralization, it does not exclude it, leaving the possibility that mineralization storage projects could qualify under these frameworks.

Alberta is home to two major CCUS projects, the Shell Quest Project and the Alberta Carbon Trunk Line Project (ACTL). The Shell Quest Project started in 2015 and captures CO<sub>2</sub> from oil sands and stores it structurally 2 km below the earth's surface (Government of Alberta, 2025). Quest is expected to sequester 1.08 million tonnes of CO<sub>2</sub> per year. The ACTL Project has been operational since 2020. This 240 km pipeline transports CO<sub>2</sub> for enhanced oil recovery projects in central Alberta and has sequestered over 3.5 million tonnes of CO<sub>2</sub> during its operation (Government of Alberta, 2025). Due to the volume of ongoing and proposed CCS projects, Alberta developed a comprehensive and clear regulatory framework for CCUS (Government of Alberta, 2025). However, the province has not introduced legislation specific to mineralization storage, likely due to its unfavourable geology.

The permitting process begins with a tenure application through Alberta Energy and Minerals (AEM), which requires the submission of a development plan, technical justification, and

spatial data (Alberta Energy Regulator, 2023). Once tenure is secured from AEM, the proponent must apply for a well license from Alberta Energy Regulator (AER) in accordance with Directive 056: Energy Development Applications and Schedules (Alberta Energy Regulator, 2025). At this point in the process, the proponent may begin geological characterization of the injection site as well as acquire baseline data as described in the evaluation stage of Directive 065 Monitoring, Measurement, and Verification (MMV) Principles and Objectives for CO<sub>2</sub> Sequestration Projects (Alberta Energy Regulator, 2024). After evidence that the proponent has the right to inject captured CO<sub>2</sub> for sequestration into the proposed zone, the proponent may apply to the AER for a nonconfidential CO<sub>2</sub> sequestration scheme approval under Directive 065, which includes a detailed MMV and closure plan (Alberta Energy Regulator, 2024).

While Alberta's regulatory framework is comprehensive, it is tailored to structural CO<sub>2</sub> storage. For example, MMV requirements presume stratigraphic, structural, and hydrodynamic trapping mechanisms and injection fluid estimates are based on physical pore space rather than reactive geochemistry (Alberta Energy Regulator, 2024). These assumptions do not align with the mechanisms of basalt mineralization, which presents a barrier to using the current framework without substantial adaptation.

British Columbia stands out as the only province with both the necessary geology and legislation suited to mineralization-based CCS. In 2015, the province modified its oil and gas regulatory framework to accommodate CCS projects (Government of British Columbia, 2015). Although no stand-alone CCS legislation has been enacted, the province has taken significant steps to adapt existing laws. In 2022, amendments were made to The Petroleum and Natural Gas Act, 1996 (PNGA 1996) that established the government's ownership of subsurface pore space (subject to certain exceptions) and introduced licences specific to CCS activities (Petroleum and Natural

Gas Act (PNGA), 1996.). CCS wells fall under Section 75 Special Project under the Energy Resource Activities Act, 2008 (ERAA 2008) and wells must be constructed and operated in accordance with CSA Standard Z741 (Energy Resource Activities Act, 2008). A draft CCS offset protocol was released in September 2023 and was last open for public feedback in early 2025 (Government of British Columbia, 2025a). The draft mentions the injection of CO<sub>2</sub> into mafic rock and proposes a 20-year monitoring period, substantially shorter than the 100-year monitoring period applied to conventional storage projects (Government of British Columbia, 2025b).

The Ministry of Energy, Mines and Low Carbon Innovation administers petroleum and natural gas (PNG) rights in form of tenure (PNGA, 1996). BC offers two types of tenure: a PNG lease, which permits CO<sub>2</sub> storage from oil and gas sources (section 71), and a storage reservoir licence, which covers CO<sub>2</sub> obtained from other sources (section 130). Under section 126 of the PNGA 1996, a storage reservoir exploration licence is required from the ministry if additional geology or engineering properties of a potential storage site is required to support a storage reservoir licence. Applications must follow the Petroleum and Natural Gas Storage Reservoir Regulation and can be made for Crown or private lands, with certain exclusions such as First Nations reserves, federal lands, ecological reserves, and designated parks (PNGA, 1996).

Despite progress in CCUS policy, carbon mineralization remains under-regulated in Canada and faces several legislative and practical hurdles. The most pressing challenge is the regulatory uncertainty. Without a clear permitting process, mineralization storage projects must rely on frameworks built for structural storage and would require case-by-case approvals. Long-term monitoring requirements for carbon mineralization remain unclear and would need to be developed by proponents and assessed on an individual basis until such guidelines could be developed. The addition of an acid pre-treatment further complicates regulatory pathways.

However, since permit approval for a mineralization storage project requires case-by-case investigation, the addition of an acid pre-treatment could be included and permitted in this process. Unlike conventional CCS, which can be used for oil recovery and attracts substantial investment, mineralization storage lacks dedicated financial incentives. However, carbon mineralization may qualify for existing CCS programs, but this remains untested and would require careful navigation. While Canada has made strides in CCUS policy, carbon mineralization remains under-regulated and in need of clearer legislative pathways. Addressing these gaps through dedicated policies, incentives, and streamlined approvals could accelerate the deployment of mineralization as a permanent and scalable climate solution.

### **CCS in the United States**

Similar to Canada, CCS projects in the United States are governed by both federal and state authorities. However, the U.S. federal government plays a significantly larger role in regulating CCS projects than the Canadian federal government. This approach results in a more standardized process and allows for all states to engage in CCS projects with minimal need for independent state legislation. Unfortunately, this puts more of a burden onto the federal government in terms of application approvals and results in a slower permitting process. Regulatory frameworks in the U.S. primarily address conventional storage, leaving mineralization storage in a relatively ambiguous legal space. Nonetheless, the use of broad regulatory language has allowed for the inclusion of mineralization storage under existing legislation.

#### *Federal Regulations*

In the U.S., the federal government controls most of the permitting process around CCS projects. The most relevant federal documents include the Underground Injection Control (UIC) Program, the Greenhouse Gas Reporting Program (GHGRP), the National Environmental Policy

Act (NEPA), and the 45Q Tax Credit for Carbon Capture Projects. The Environmental Protection Agency (EPA) plays a central role in CCS project permitting. Under the authority of the Safe Drinking Water Act, the EPA developed requirements for the UIC Program, which regulates the injection of fluids into the subsurface to protect underground sources of drinking water (U.S. EPA, 2025b). The UIC program is responsible for maintaining a well inventory, reviewing permit applications and issuing permits for injection wells, performing inspections, and ensuring compliance with permit requirements. The program defines six well classes. Class VI wells are designated specifically for geologic sequestration of CO<sub>2</sub> and are therefore the relevant designation for in situ carbon mineralization projects in the U.S. (U.S. EPA, 2025c).

To obtain a Class VI well permit, proponents must first conduct site characterization, which includes assessments of geology, seismicity, fault and fracture presence, and the predicted movement of both the injected CO<sub>2</sub> plume and the associated pressure front (U.S. EPA, 2025b). The regulations also establish detailed requirements for well construction, ongoing testing and monitoring, operational procedures, financial assurances, emergency and remedial response planning, and closure protocols. Operators are required to report all testing and monitoring results to the EPA or to the relevant state authority. As of 2026, only a few states (Arizona, Louisiana, North Dakota, Texas, West Virginia, and Wyoming) have been granted primacy, or primary enforcement authority, for Class VI wells. In all other states, the EPA regional offices are responsible for directly overseeing Class VI well permitting and compliance (U.S. EPA, 2025d).

The permitting process begins with a notification of intent to apply for a Class VI permit and community engagement is encouraged at this stage. Once a formal application is submitted, it undergoes a detailed technical review by the permitting authority. If the application meets regulatory standards, a draft permit is issued and opened to public comment for a minimum of 30

days (U.S. EPA, 2025b). After evaluating public feedback, the authority issues a final decision. If a permit is granted, the well can then be constructed, tested pre-operationally, and (pending further evaluation) authorized for injection. During operation, the proponent must monitor the site and ensure compliance with all applicable requirements. According to 40CFR 146.93, closure involves plugging the well and continued monitoring for 50 years (or an alternative agreed upon timeframe) following the cessation of injection, at which point it can be formally closed (U.S. EPA, 2018).

As of May 2026, the EPA was reviewing 51 CCS projects with 199 wells across 10 states (U.S. Environmental Protection Agency, 2026). At least 91 additional wells were under review in states with Class VI primacy. However, progress has been slow. By May 2026, the EPA had issued only 18 active Class VI permits in total (Sowecke, 2026; US EPA, 2026) (n.b. this value was determined by summing the six permits issued since early 2025, the 11 permits issued by the end of 2024, and one unidentified permit that EPA web information indicates was issued, potentially in the gap between the two periods), with EPA information currently indicating that just three of those sites are past the pre-injection phase (U.S. Environmental Protection Agency, 2025f). Beyond the Class VI permit, CCS projects may also require additional approvals under various programs. These include the Hazardous Waste Management Program under the Resource Conservation and Recovery Act, the National Pollutant Discharge Elimination System, the Prevention of Significant Deterioration program, the Clean Air Act (CAA) Nonattainment Program, the National Emission Standards for Hazardous Air Pollutants Preconstruction Approval under the CAA, and the Ocean Dumping Permits under Marine Protection, Research and Sanctuaries Act, Section 404 Dredge and Fill Permits, among other environmental permits (U.S. EPA, 2022). Different states may have additional permit requirements for CCS related activities.

The EPA's GHGRP, specifically Subpart RR, mandates that any facility injecting CO<sub>2</sub> underground for geologic sequestration must develop and implement an EPA-approved monitoring, reporting and verification (MRV) plan. Under this program, operators must report the quantity of CO<sub>2</sub> received, injected, produced, leaked, and successfully sequestered (Pullins, 2021). These reports must be submitted annually and form the basis of federal oversight of long-term storage operations.

NEPA dictates how environmental review and permitting works at the federal level. If a project has need of a significant federal permit, involves federal land or funding, or relies on federally managed infrastructure, it may be subject to NEPA (Pullins, 2021). The Department of Energy (DOE) frequently leads this process, particularly in cases where DOE is the primary funder. Since 2007, the DOE has funded 12 mineralization storage projects, none of which have reached phase III (site characterization and permitting) and have therefore not yet undergone NEPA determination and issuance (DiRaddo et al., 2025; U.S. Department of Energy, 2025a). If federal involvement is minimal or indirect, NEPA requirements may not apply (U.S. Department of Energy, 2025b). However, when they do, the review process can be lengthy, involving stakeholder consultations and public comment periods. Projects subject to NEPA must undergo an Environmental Assessment (EA), and based on the EA, the federal agency may prepare a more rigorous assessment called an Environmental Impact Statement and open it to public review. To streamline certain low-risk research efforts, the DOE created 20 categorical exclusions to NEPA review. These exclusions apply to small scale (less than 500,000 tons of injected CO<sub>2</sub>), remote experimental wells with low risks of seismicity, subsidence or contamination of freshwater aquifers (U.S. Department of Energy, 2025b).

Financial incentives for CCS projects are provided through Section 45Q Tax Credit for Carbon Capture Projects, which offers performance-based tax benefits for projects that securely store captured CO<sub>2</sub> (Carbon Capture Coalition, 2023). This includes both geological storage and the use of CO<sub>2</sub> or CO as feedstock to produce low embodied carbon products. The tax credit's broad eligibility criteria mean that mineralization storage projects can qualify, provided they can demonstrate successful and permanent storage through MRV.

In summary, while the U.S. federal government has developed a comprehensive and standardized framework for structural CO<sub>2</sub> storage, carbon mineralization remains under-defined and subject to interpretation within existing legislation. Nevertheless, the regulatory flexibility and supportive tax incentives have enabled some progress in mineralization storage. A more clear and explicit framework would help further accelerate deployment and provide more certainty for project developers working with mineralization storage solutions.

### *State Regulations*

The most promising U.S. states for basalt carbonation projects include Washington, Oregon, Idaho Nevada, Alaska, and California. These regions are characterized by abundant mafic and ultramafic geological formations that are well-suited to carbon mineralization storage (Carbfix, 2025; DiRaddo et al., 2025). In the U.S., primacy under the federal UIC program can only be delegated to a state, territory, or Tribal Nation if their regulatory framework meets or exceeds federal requirements. As of early 2026, none of the selected states currently has primacy status for class VI wells.

Washington, Oregon, Idaho, and Alaska fall under EPA Region 10, while Nevada and California are in Region 9 (U.S. Environmental Protection Agency, 2025e). For states without

primacy, the permitting and oversight of Class VI wells are managed directly by the EPA and carbon mineralization projects in these states would primarily be subject to federal regulation. However, state-level involvement may become significant depending on how CO<sub>2</sub> is sourced and transported. For example, the permitting of CO<sub>2</sub> pipelines is regulated on a state-by-state basis, and any project involving pipeline construction would need to comply with the regulatory requirements of all affected states (Parfomak, 2023). If the pipeline intersects with any waterways, the federal government would have the primary sitting jurisdiction for that section of pipeline.

Several of the selected states have expressed growing interest in CCS technologies and have taken legislative steps to support CCS deployment. In 2024, Alaska enacted the Carbon Capture, Utilization, and Storage (CCUS) Act (HB 50, 2024), which encourages the transfer of pore space ownership to facilitate CO<sub>2</sub> storage operations and imposes new fees on operators to support the Carbon Storage Closure Trust Fund for long-term monitoring. In 2022, California passed two significant bills aimed at regulating and supporting CCUS projects, Senate Bills 905 and 1314. Senate Bill 905 directs the California Air Resources Board (CARB) to develop enhanced monitoring procedures and establish a unified permitting system for CCS projects by January 1, 2025 (SB 905, 2022). As of early 2025, CARB has not yet implemented these statutory requirements of SB 905 (Ress et al., 2025). Senate Bill 1314 prohibits the use of Class II wells for CO<sub>2</sub> injection associated with enhanced oil recovery (SB 1314, 2022). Additionally, California supports CCUS deployment through regulatory programs such as the California's Low Carbon Fuel Standard (LCFS) program. The LCFS program offers financial incentives through credits for projects that demonstrably reduce carbon emissions. However, to qualify, a CCS project must involve the onshore injection of CO<sub>2</sub> into saline or depleted oil and gas reservoirs, which may limit eligibility for mineralization projects (California Air Resources Board (CARB), 2020).

Washington State has implemented its own supportive measures through the 2021 Climate Commitment Act (CCA), which established a cap-and-invest program targeting statewide greenhouse gas reductions (Washington Climate Commitment Act (CCA), 2021). The program allows for the generation of credits from CCS projects, and the statutory language is inclusive of mineralization-based approaches. Washington also housed the Wallula Basalt Project in 2013 to 2015, which involved CO<sub>2</sub> injection into basalt formations (Karimjee, 2013). At the time, the project was permitted under the UIC Class V program, over which the state holds primacy. Because the project was classified as research, the permitting process was streamlined, and the project was given an exception from the monitoring plan requirements. The EPA has since developed the Class VI well designation, which would now be applicable to similar projects. As of 2025, any new mineralization storage projects would likely require a Class VI permit.

Although the U.S. has a robust federal framework for structural CO<sub>2</sub> storage, there remains a regulatory gap specifically concerning mineralization. While the language in existing legislation is broad enough to encompass mineralization, no mineralization-specific project has yet been permitted under the Class VI program (U.S. Environmental Protection Agency, 2025f). Notably, Class VI wells require extensive long-term monitoring, typically 50 years, which may be excessive for mineralization projects, given the relatively rapid and permanent nature of basalt mineralization (US EPA, 2022). To date, only three of the eighteen (see n.b. above) EPA permitted Class VI wells have progressed beyond the pre-injection phase, two for the Decatur Campus project and one for the Russell CO<sub>2</sub> Storage Complex (U.S. Environmental Protection Agency, 2025f). For the Decatur Campus project, one well is currently in the injection phase and the other is in the post injection monitoring stage. The permitting process for these wells took between three to six years, significantly longer than the estimated 24-month timeline (Gollakota & McDonald, 2014). In

contrast, states with primacy have demonstrated much faster turnaround times. For instance, North Dakota issued its first Class VI well permit for Red Trail Energy LLC in approximately 9 months after receiving a complete application (Department of Mineral Resources, 2025).

Accelerating the delegation of primacy to more states could significantly reduce permitting delays and encourage broader CCS deployment, including mineralization projects. As it stands, the U.S. regulatory framework for carbon mineralization is still evolving. While existing statutes offer viable pathways for project approval, they were primarily designed for conventional CCS projects. The addition of an acid pre-treatment is unprecedented and could pose additional delays in the permitting process. As momentum builds around mineralization storage as a permanent carbon removal solution, there is growing need for tailored permitting guidance, refined liability frameworks, and supportive financial incentives to unlock the full potential of this technology.

### **International legislation**

CCS is increasingly recognized as a vital technology for mitigating climate change globally. In 2024, the Global CCS Institute reported a total of 50 commercial projects in operation and over 680 projects in development worldwide (Global CCS Institute, 2024). Various countries have established legal and regulatory frameworks to support deployment, reflecting diverse approaches based on regional priorities and resources.

The Global CCS Institute's CCS Readiness Index evaluates countries based on policy, laws and regulations, and storage resource development. As of 2024, five countries scored above 60 out of 100: the U.S. (72), Canada (71), Norway (67), the UK (66), and Australia (62) (Global CCS Institute, 2025). Another notable player is Iceland, which, although it scored only 21 on the CCS Readiness Index, hosts CarbFix, the world's leading mineralization storage project. This section

examines the regulatory landscape in Iceland, Norway, the UK, and Australia, with a focus on how each addresses or accommodates carbon mineralization.

### *Iceland*

Despite its modest readiness score, Iceland is a global pioneer in CCS through its innovative CarbFix project, which focuses on in situ basalt mineralization. In 2016, Iceland implemented the EU CCS Directive (European Union, 2009) through an amendment to its Climate Law. This amendment prohibited the storage of CO<sub>2</sub> in geological formations, exclusive economic zones and in the continental shelf with the exception of research projects that inject sufficiently low amounts of CO<sub>2</sub> (Act Amending the Climate Change Act, 2015).

CarbFix began in 2012 as a research project with injection volumes of less than 100 kilotonnes of CO<sub>2</sub> and therefore did not require any permitting (Act on Hygiene and Pollution Prevention, 1998; Directive 2009/31.) In 2019, the government of Iceland and six major industrial operators signed a declaration of intent to investigate industrial-scale CCS opportunities based on the methodology of the CarbFix research project (Government of Iceland et al., 2019).

In 2021, Iceland transposed the EU CCS Directive into Icelandic law. The relevant provisions are found in the Act on Hygiene and Pollution Prevention, the Act on Environmental Impact Assessment, and the Act on Climate (Carbon Dioxide Injection) (Bill 391, 2021). The legislation authorizes the Environmental Agency to issue injection permits dependant on a satisfactory application. Though the CCS directive was originally developed for conventional supercritical storage of CO<sub>2</sub> in geological formations, Iceland's geology is dominated by basaltic formations ideal for basalt mineralization but not conducive for conventional CO<sub>2</sub> storage. As such, the legislation has been adapted to Iceland's unique position and distinguishes between conventional and mineralization storage. Although the original Directive requires a 30-year post-

closure monitoring period for structural storage, Iceland's version acknowledges that mineralization storage may warrant a shorter period, though no alternative duration is specified (Bill 391, 2021; Directive 2009/31).

As of 2025, no industrial scale CCS projects have been granted permits in Iceland. However, in 2024, the European Free Trade Association (EFTA) issued an opinion on the first Icelandic draft storage permit for the storage of CO<sub>2</sub>; this draft permit would authorize CarbFix to store a total of 3,180,000 t CO<sub>2</sub> (106,000 t CO<sub>2</sub>/year for 30 years) (EFTA Surveillance Authority, 2024). The decision on this permit was not yet public as of April 2025. Overall, Iceland's CCS legislation is still evolving but is among the most explicit in addressing mineralization. Iceland is in a position to be a leader in mineralization storage due to its adoption of CCS legislation and its favourable geology for mineralization storage.

#### *Norway*

Norway's CCS regulatory framework is considered one of the world's most advanced. Two ministries were responsible for the implementation of the EU CCS Directive in 2013: The Ministry of Petroleum and Energy (resource management) and The Ministry of Climate and Environment (environmental issues) (Regulation 653/1997; Regulation 931/2004; Regulation 1517/2014). The CCS Directive has been implemented in the new Storage Regulation Act and amendments to the Petroleum Regulation and Pollution Regulation. The Storage Regulation Act is based upon the existing petroleum regulation and lays the groundwork for CO<sub>2</sub> storage in underwater reservoirs on the continental shelf and establishes a permitting system for exploration and exploitation (Regulation 1517/2014). The amendment to the Petroleum Regulation (Chapter 4A) adds resource management requirements that align with the Storage Regulation Act (Regulation 653/1997). The Storage Regulation applies to all CCS projects whereas the Petroleum Regulation only applies to

CCS that is linked with petroleum activity. The amendment to the Pollution Regulation addressed the environmental aspects of the CCS Directive. The Pollution Regulation states that all CCS operations must obtain a permit for drilling activity, injection, and storage from the Ministry of Climate and Environment (Regulation 931/2004). Proponents also need to obtain an exploitation and exploration permit from the Ministry of Petroleum and Energy. Projects must demonstrate detailed site characterization and abide by rigorous well construction and injection protocols. Environmental impact assessments are mandatory, and projects must include comprehensive monitoring plans. The regulation does not explicitly state the required duration of monitoring, which is instead decided on a case-by-case basis.

Currently, only offshore storage is permitted due to Norway's geological profile, but onshore basalt mineralization could be possible in the future (Carbfix, 2025). Norway has proven their ability to implement industrial scale CCS projects with their Longship Project and Northern Lights Project (Northern Lights, 2025). Norway also has shown interest in basalt mineralization through governmental support of mineralization storage research at the University of Oslo (Nooraiepour, 2024). However, basalt mineralization is not well established in Norway and the implementation of a mineralization storage project in Norway would likely follow the current CCS legislation with a case-by-case focus.

### *United Kingdom*

The government of the United Kingdom is implementing CCS via a unique approach called cluster sequencing, targeting the seven major industrial regions that account for 50% of industrial emissions (Department for Energy Security and Net Zero, 2025). The Cluster Sequencing Programme supports large-scale CCS development using shared infrastructure to reduce costs. The UK has established a comprehensive legal and regulatory framework to support CCUS initiatives.

The UK's dedicated CCS regulatory framework is composed of the Energy Act 2008, the Energy Act 2023, and the Carbon Dioxide (Licensing etc.) Regulations 2010. The Energy Act 2008 established a foundational legal framework for CO<sub>2</sub> storage and developed a licensing system for the offshore storage of CO<sub>2</sub> in the UK (Energy Act, 2008). The Energy Act 2023 built upon and amended the Energy Act 2008 in relation to CCS, setting a clear economic licensing framework for CCS and providing financial support to industrial carbon capture. It outlines the regulatory responsibilities of bodies such as the Office of Gas and Electricity Markets (Ofgem) and the North Sea Transition Authority (NSTA), ensuring a coordinated approach to CCUS infrastructure development (Energy Act, 2023).

Ofgem oversees the licensing and regulation of CO<sub>2</sub> transport and storage networks, ensuring compliance with the provisions set out in the Energy Act. The NSTA is responsible for regulating offshore CO<sub>2</sub> storage activities, including the issuance of storage permits, oversight of the licencing regime, and maintenance of a public register of storage sites. Chapter 4 of the Energy Act 2023 provides specific provisions in CO<sub>2</sub> storage licenses (Energy Act, 2023). Onshore CO<sub>2</sub> storage and CO<sub>2</sub> storage in adjacent internal waters is regulated by the Carbon Dioxide (Licensing etc.) Regulations (The Storage of Carbon Dioxide (Licensing Etc.) Regulations 2010, 2010). A CCS licence must be obtained from the Oil and Gas Authority to explore the licenced area to support an application for a storage permit. In addition to the licence, the proponent must also obtain a grant of the appropriate rights from The Crown Estate (North Sea Transition Authority, 2025). Once the exploration required by the licence has been completed, a proponent may apply for a storage permit for the licenced area. The storage permit application requires a close interaction with the NSTA and the submission of a monitoring plan, a corrective measures plan, a

provisional post-closure plan, and a proposal for financial security (North Sea Transition Authority, 2023).

While the UK has expressed interest in carbon mineralization with projects such as DACMIN and CO2LOC run by Cambridge Carbon Capture Ltd., these projects are small-scale ex-situ mineralization efforts (Evans, 2022). The DACMIN project aims to capture 100 tonnes per year of CO<sub>2</sub> via direct air capture using CO2LOC technology which uses magnesium silicates, water, and air to produce magnesium carbonate. Current legislation is vague, but flexible enough to accommodate mineralization under existing frameworks. The case-by-case basis with which permits and the relevant site plans are developed with NSTA allows more room for a mineralization storage project to be legislated under the existing regulatory framework. However, no industrial scale CO<sub>2</sub> mineralization project has been permitted as of 2025 in the UK.

### *Australia*

Australia has developed strong federal and state legislation and regulatory frameworks to support CCS initiatives. Federally, there are five major Acts that regulate CCS: the Offshore Petroleum and Greenhouse Gas Storage Act 2006 (OPGGS), the Greenhouse Gas Storage Act 2009 (GGS), the Environment Protection (Sea Dumping) Act 1981, the Environment Protection and Biodiversity Conservation Act 1999 (EPBC), and the National Greenhouse and Energy Reporting Act 2007 (NGER).

The OPGGS Act provides the primary legal framework for the exploration and storage of GHG in Commonwealth waters (Offshore Petroleum and Greenhouse Gas Storage (OPGGS) Act, 2006). It establishes a system for granting titles related to greenhouse gas storage, including assessment permits, injection licenses, and holding leases. The National Offshore Petroleum Titles Administrator manages the granting of the titles and the National Offshore Petroleum Safety and

the Environmental Management Authority is the national regulator for structural safety and environmental regulations. Onshore CCS activities are regulated by the GGS Act (Greenhouse Gas Storage (GGS) Act, 2009). The Sea Dumping Act was amended in 2023 to require permits for exporting CO<sub>2</sub> for sequestration (Environment Protection (Sea Dumping) Act, 1981). The EPBC Act governs environmental assessments for projects that may impact the national environment; this includes CCS activities. CCS Projects must submit an EPBC Referral to determine if further review is needed (Environment Protection and Biodiversity Conservation Act, 1999). The NGER Act includes the Safeguard Mechanism, which caps emissions from industrial facilities. As of 2023, the government expanded this mechanism to allow CCS but excluded such projects from eligibility for Australian Carbon Credit Units (ACCUs) (National Greenhouse and Energy Reporting Act, 2007).

State legislation also plays a key role. The Western Australian Government passed the Petroleum Legislation Amendment Bill, which integrates transport and storage of greenhouse gases into the current legislation (Petroleum Legislation Amendment Bill, 2023). The Bill is aimed at providing industry with the option of using CCS technology to reduce emissions and includes permitting requirements for onshore and offshore storage operations, site closure requirements, and allowance of GHG transport via pipelines to depleted petroleum reservoirs in the state. In 2010, Victoria passed the Offshore Petroleum Greenhouse Gas Storage Act, which regulates CCS activities offshore in Victoria (Offshore Petroleum and Greenhouse Gas Storage Act, 2010).

Australia has a well-developed CCS regulatory landscape. However, its regulations are targeted towards offshore structural storage and are not well suited to mineralization storage. Mineralization storage projects would need to be assessed on a case-by-case basis to address the specific circumstances of these projects.

### ***Global Developments***

The International Energy Agency reports a significant increase in CCS projects worldwide, with over 700 projects in various stages of development. In the year 2023, announced capture capacity and storage capacity for 2030 rose by 35% and 70%, respectively, indicating growing commitment to CCS as a climate mitigation tool (International Energy Agency, 2025). While CCS is gaining momentum globally, challenges remain, including high costs, logistical complexities, and barriers to public acceptance. Critics argue that reliance on CCS may prolong dependence on fossil fuels, underscoring the need for comprehensive strategies that include renewable energy adoption and energy efficiency improvements (Phillis, 2023).

International CCS legislation is evolving, with countries tailoring their legal and regulatory frameworks to support the deployment of this technology in alignment with their climate goals and regional needs. However, the evolving CCS legislation is directed predominantly at conventional storage and rarely takes carbon mineralization into account. This gap in regulation may persist until more carbon mineralization projects are successfully deployed. The first large scale conventional CCS project, Norway's Sleipner project, began operations in 1996 (Dickson, 2024), but it was not until 2009, 13 years later, that the first globally recognized CCS specific legislation was adopted (Directive 2009/31).

Currently, the first large-scale mineralization storage project is undergoing permitting in Iceland, but if historical patterns repeat, it may take a decade or more before dedicated international legislation for mineralization storage emerges. However, existing CCS regulatory frameworks may help shorten this timeline, as many mineralization projects can be partially governed under current rules. The permitting process for a large-scale mineralization project is uncertain at a global scale and the addition of an acid pre-treatment further complicates this process. However, since

the legislation is currently adapting, it is possible that the permitting of an acid pre-treatment could be developed alongside mineralization CCS legislation.

### **Permitting Process Road Map**

Two of the most promising jurisdictions for carbon mineralization projects in North America are British Columbia and Washington State. Both regions have relatively well-developed CCS legislation, and Washington has previously permitted a basalt carbonation research project. While permitting pathways for conventional CCS are more established, neither jurisdiction has specific legislation or permitting processes tailored to mineralization storage. This section outlines the current permitting framework and discusses potential hurdles for implementing a mineralization project under the existing regulatory systems.

#### *British Columbia*

British Columbia's CCS regulatory framework is still evolving. A draft CCS offset protocol was released in September 2023, with the most recent public comment period open from February 2 to March 4, 2025. The draft mentions CO<sub>2</sub> injection into mafic rock and recommends a 20-year post-injection monitoring period, significantly shorter than the 100-year period for saline aquifer injection (Government of British Columbia, 2025b). This indicates potential regulatory openness to mineralization storage and an opportunity to engage with regulators as the protocol develops.

In 2022, amendments were made to the PNGA to establish provincial ownership of pore space (with certain exceptions) and to create a specific licence for CCS projects (PNGA, 1996.). The permitting framework includes tenure acquisition for the storage site, approval of the CCS project, and separate permits for wells, facilities, and pipelines. CCS projects are designated as a

Special Project under Section 75 Special Project of the ERAA and must follow CSA Standard Z741 for construction and operation of wells.

CO<sub>2</sub> storage tenure is managed by the Ministry of Energy, Mines and Low Carbon Innovation and falls under two types: Petroleum and Natural Gas (PNG) Leases (part 6 or Section 71, PNGA), and Storage Reservoir Licences (Section 130, PNGA) (PNGA, 1996). PNG leases only cover CO<sub>2</sub> that is associated with oil and gas activities while Storage Reservoir Licences cover CO<sub>2</sub> sourced from non-oil and gas sources. If additional subsurface data are required to support a storage reservoir licence application, proponents must obtain a Storage Reservoir Exploration Licence (Section 126, PNGA). The licence enables applications to the British Columbia Energy Regulator for activity permits such as well permits. Detailed application requirements for both licenses are provided in the Petroleum and Natural Gas Storage Reservoir Regulation (PNGSRR) and the 2024 BC Government Application Guide (Ministry of Energy, 2024; Petroleum and Natural Gas Storage Reservoir Regulation, 2023).

The use of a storage reservoir is a non-exclusive right and may be shared by more than one user (Energy Resource Activities Act, 2008). If a storage reservoir licence only covers a portion of a larger reservoir, a permit may be issued to another proponent for the additional capacity of the same reservoir. Exploration licences and storage reservoir licences may be issued anywhere in Crown and free land, except for Federal and First Nation reserve lands, ecological reserves and certain parks, most of the Lower Mainland, and specific First Nation lands. The licence must cover the entire expected extent of the reservoir plume and the project must be designated as a Special Project under Section 75 of the ERAA.

To obtain Special Project status, an application must be submitted to the Supervisor of the Reservoir Engineering Department of the British Columbia Energy Regulator. The application for

Special Project status has nine sections: general information, well chronology, casing, cementing and hydraulic isolation, geology, reservoir, facilities and measurement, groundwater, emergency response, and letters (B.C. Energy Regulator, 2024). The application requires either mini-frac or diagnostic fracture injection test simulation of the proposed well to determine or interpret instantaneous shut-in pressure and fracture closure pressure, or a step-rate injectivity test to determine fracture parting pressure. These tests may still be required for a mineralization project, and it is likely that further geochemical modelling will be required to determine carbon mineralization rates.

An Exploration Licence application must include location and geological descriptions, source and volume of substances to be stored, geological suitability with supporting data (cross-sections, seismic maps), justification for location and exploration plans, identification of impacted wells or stakeholders, and registered professionals' contact information (PNGSRR, 2023). A summary of engagement with First Nations, potentially impacted communities, residents, and right holders is optional but encouraged.

The Storage Reservoir Licence application follows similar steps with additional requirements including reporting the reservoir size and nature, the confinement mechanism, and the predicted groundwater impacts for shallow storage. A summary of engagement is also recommended for this application but not required. There is a \$200 fee for this 15-year licence with an annual rent of \$7.50/hectare (Ministry of Energy, 2024).

The application processes for both the exploration licence and the storage reservoir licence can be applied to mineralization storage projects. Although mineralization differs from conventional CO<sub>2</sub> storage, the flexible, case-specific nature of the application processes and broadly applicable terminology make the use of these licences for mineralization storage projects

feasible. British Columbia does not provide permitting exemptions for CCS research projects and all projects, regardless of their scale, require the same permits (J. Condor, personal communication April 7, 2025).

The addition of the acid pre-treatment further confuses the permitting process. In British Columbia, CCS wells are treated similarly to acid gas disposal wells, which typically inject H<sub>2</sub>S and CO<sub>2</sub> mixtures (B.C. Energy Regulator, 2020). While it is unclear how the addition of HCl would impact an application process, applications are assessed on a case-by-case basis. A proponent could justify the need for an HCl pretreatment and outline the additional safety precautions that will be taken in an application and this may be sufficient.

It may be possible to permit a mineralization project with acid pre-treatment under the existing legislation if project developers collaborate with the permitting authorities. In total, there are three CCS specific licences required to permit a mineralization storage project in BC (Special Project designation, Exploration Licence, Storage Reservoir Licence). Additional licenses are required to run a CCS operation (e.g. well licences) and must be acquired through appropriate channels.

### *Washington*

In the U.S., a CCS project requires a Class VI well permit from the EPA. Washington state is in EPA Region 10 and does not have primacy, therefore the application process follows that set out by the EPA (Jones, 2024). This roadmap applies to all states where the EPA has Class VI well permitting authority. The Class VI permitting process is divided into five main phases: pre-permitting, pre-construction, pre-operation, injection, and post-injection. During the pre-permitting phase, the proponent must first notify the permitting authority (EPA in Washington's case) of the intent to apply for a Class VI permit (U.S. EPA, 2025b). Early engagement with the

EPA is encouraged, as is community outreach prior to submitting the application. The permit application is guided by a completeness checklist designed to assist operators through the process. While this checklist is not legally binding, it expands upon the legally required elements outlined in 40 CFR 146.82 to help ensure a thorough application (U.S.EPA, 2022). The application consists of thirteen sections that cover various technical and regulatory requirements. These include general project information, site characterization, well construction and operation details, monitoring and testing plans, and financial assurances.

The general information section includes a list of required and acquired permits, operator contact information, and maps identifying the project location and Area of Review (AoR) (U.S. EPA, 2022). The site characterization section requires data on geologic structure, hydrogeologic properties, faults, injection and confining zones, seismic history, baseline geochemistry, and modelling to demonstrate site suitability. Planned well operations must detail injection rates and pressures, the CO<sub>2</sub> source, and CO<sub>2</sub> injection stream characteristics. The AoR and corrective action plan must include the delineation method, re-evaluation schedule, and a list of wells within the AoR. The monitoring plan outlines how the CO<sub>2</sub> stream will be tested and how operational parameters will be continuously monitored. It must also include corrosion monitoring, pressure testing, plume tracking, and surface monitoring strategies, along with a quality assurance plan (U.S. EPA, 2022). Other sections of the application include the injection well plugging plan, the post-injection site care and closure plan, the emergency response plan, the well construction plan, the pre-operational testing plan, financial responsibility documentation, a stimulation plan, and an injection depth waiver request (if applicable).

Once the application is submitted, the project enters the pre-operation phase. During this phase, the EPA conducts a completeness review followed by a detailed technical review of the

application (EPA, 2025b). If deemed acceptable, the EPA will issue a draft Class VI permit for public review for a minimum of 30 days. The EPA aims to review and issue permits within 24 months. If the permit is issued, the project enters the pre-construction phase during which the proponent must perform pre-operational testing and submit any additional information required. If there are any changes to permitting conditions, the permit must be modified and released for another public review.

Once the EPA authorizes injection, the project enters the injection phase. At this stage, operators can begin CO<sub>2</sub> injection and are responsible for testing and monitoring, re-evaluating the AoR, and submitting the results to the EPA (U.S. EPA, 2025b). These results are reviewed and made publicly available. The post-injection phase begins once injection activities cease. The operator must plug the well, monitor the CO<sub>2</sub> plume and pressure front, demonstrate no risk to the underground source of drinking water (USDWs), and return the site to pre-operation conditions. Once these steps are completed to the satisfaction of the EPA, the site may be closed.

For mineralization storage projects, some aspects of the permitting processes, such as site assessment and monitoring, may differ from conventional CCS projects. The type of modelling required to assess a site's suitability will differ between mineralization and conventional storage. The monitoring plans will also need to differ to account for the different storage mechanisms. The Class VI application allows for some flexibility in how regulatory requirements are met, making it possible to tailor assessments and monitoring approaches to the specific project. While monitoring and reporting are expected for 50 years post injection, the application allows for an alternative post-injection site care timeframe (U.S. EPA, 2022). This would allow for a mineralization storage project to propose an alternative post-monitoring timeframe based on computational modelling of the AoR.

The inclusion of an acid pre-treatment step may change the way the project would be permitted. The Required Class VI permit information found in 40 CFR 146.82(a)(9) mentions the applicant must submit a proposed stimulation program with information on the stimulation fluids and proof that stimulation does not interfere with containment (U.S. EPA, 2022). It is possible this acid pre-treatment could be included in this section of the application and the well would still fall under a Class VI permit. Another possible route would be to use a combination of Class VI and Class III wells and permits. Class III permits are intended for injection wells for solution mining (U.S. EPA, 2025a). They are most often used for uranium mining and are permitted for the injection of a solution called lixiviant. The solution is injected and remains in contact with the rocks for an extended period of time to dissolve the uranium ore. This is a similar mechanism to how an acid pre-treatment step functions. Furthermore, lixiviant can be an acidic solution. Therefore, it is possible that collaboration with permitting authorities could result in a well used for acid pre-treatment being permitted as a Class III well.

Overall, the only CCS specific permit required in Washington is the Class VI permit. However, acid pre-treatment may necessitate a Class III permit as well. Additional permits and construction approvals may be required depending on the project scope and state-specific regulations. The most confronting concern about this permitting process is the timeframe. Although the EPA aims to complete the review and permit issuance within 24 months, they have yet to meet this standard. Consequently, a project that is as complex and novel as the proposed mineralization storage project would likely take significant time to permit through the EPA.

### **Conclusion**

While global CCS policy and regulation is developing rapidly, current schemes focus on conventional storage projects. Nonetheless, the development of existing CCS legislation is

beneficial to mineralization storage projects as they may fall under the pre-existing legislation. As mineralization storage becomes more commonplace, implementation of mineralization CCS projects may be hastened by amending the existing CCS frameworks, similar to how CCS frameworks were themselves originally made as amendments to pre-existing oil and gas regulations. Another potential option is to proceed with mineralization CCS projects under the current legislative framework and collaborate with permitting authorities when gaps or incongruities occur. While there is some inherent risk to proceeding without more explicit regulatory guidance, the potential gains of data from large scale mineralization CCS projects cannot be underestimated. The large scale success of mineralization storage is, paradoxically, one of the prerequisites for fomenting any significant political power for drafting or amending legislation.

Unfortunately, the current legislative framework is not particularly conducive to permitting a mineralization storage project expediently. Even conventional CCS projects move through permitting very slowly, mostly due to the novelty of the current permitting processes and how each application is assessed on a case-by-case basis. While this allows for better environmental protections and community engagement, it also reduces the feasibility of CCS as an efficient carbon removal technique in the short term. There is the potential that speed may increase as permitting authorities and proponents gain experience and familiarity with these new processes. However, this increase in speed would not apply to any theoretical mineralization storage projects, as they would remain a novel application that would by necessity be assessed individually.

Globally, only one large scale mineralization project is currently being permitted. It will likely take many more project deployments before mineralization specific legislation is developed.

Since there is a legislative gap and a lack of clarity around the application process, any potential mineralization project must collaborate with permitting authorities intensively. This presents a highly individual and labour-intensive method dependent on strong institutional, private, and governmental cohesion and commitment. Mineralization storage project permitting and operation under current legislation in both Canada and the United States is therefore likely to be a slow-moving prospect. The addition of a novel acid pre-treatment further complicates the permitting process. Consequently, there are clear legislative hurdles for researching mineralization storage at field scale. As research is inhibited due to the labour and time requirements under current legislation, the necessary scaling of mineralization storage required to reduce climate change impacts becomes a gargantuan task. One potential solution to this would be providing research exemptions to the legislation, as was done for the pilot CarbFix projects and the Wallula Basalt project. It is also possible that the future permitting of the largescale CarbFix project will establish precedent, making the permitting process for mineralization storage more clear and expedient.

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