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Regulating Geologic Sequestration in the United States: Early Rules Take Divergent Approaches

MELISA F. POLLAK* AND
ELIZABETH J. WILSON

University of Minnesota Center for Science, Technology, and Public Policy, 301 19th Avenue South, Minneapolis, Minnesota 55455

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Regulations for geological sequestration (GS) of carbon dioxide (CO_2) have been adopted in the state of Washington and proposed by the state of Kansas and the U.S. Environmental Protection Agency (EPA) Underground Injection Control (UIC) Program. These three sets of rules take significantly different approaches to regulating GS of CO_2. This paper compares these rules, focusing on elements where their differences highlight the choices that must be made to create a regulatory framework for GS in the United States. Consensus is emerging in some areas, but there is still substantial disagreement regarding the allowable composition of the CO_2 stream, the size of the area of review, reservoir performance goals, and management of risks other than those to groundwater. Gaps include issues related to ownership of subsurface pore space, greenhouse gas accounting, and long-term stewardship. The divergent approaches of these rules raise two overarching questions: (1) Should policy makers create GS regulations by modifying and supplementing UIC rules or through new enabling legislation? (2) What should be the relative roles of state and federal governments in GS regulation? We outline trade-offs between the consistency and coordination that federal involvement could offer and the reality that states need to be heavily involved with implementation of GS regulations. We conclude that federal involvement above and beyond the proposed EPA Class VI rules is needed to create effective GS regulation in the United States.

Introduction

Geological sequestration (GS) of carbon dioxide (CO_2) is a technology with the promise to dramatically decrease greenhouse gas emissions to the atmosphere from the use of fossil fuels, especially coal. CO_2 can be captured from coal-fired power plants or other industrial sources, transported by pipeline to areas with suitable geologic conditions, and injected deep underground (*1, 2*). But in order for the technology to be deployed at a scale where it can meaningfully contribute to greenhouse gas reduction goals, it needs a framework of regulations to ensure that it is done safely, responsibly, and cost effectively (*3*). Any regulatory framework for carbon capture and sequestration (CCS) must cover the technology life cycle from site selection and characterization, through the operational injection of CO_2, to a postinjection monitoring period, and the final stewardship phase. The regulations must be able to address questions concerning property rights and access as well as manage environmental health and safety considerations. Additionally, any regulatory framework must clearly assign responsibility and attendant liability of the site and injected CO_2 over the project life cycle and must link CCS projects with a future climate regime.

While technical experts have discussed potential characteristics for a GS regulatory framework for years (*4, 5*), within the past year, policy makers have started to take action with regulations for GS introduced at the international, national, and state levels. The European Parliament approved a directive on the geological storage of CO_2 (*6*), and in Australia, laws to govern GS have been enacted in both the national parliament and the State of Victoria (*7, 8*). In the United States, the focus has been on the Environmental Protection Agency (EPA) Underground Injection Control (UIC) Program proposed regulations for GS of CO_2, but the states are also proposing regulatory frameworks. In fact, state CCS policy activism has received scant attention but in some respects has advanced further than the international or federal proposals. The state of Washington has adopted GS rules, and Kansas has proposed rules which are currently open for public comment. Also, five other states have agencies or task forces exploring regulatory frameworks for geologic sequestration. Table 1 summarizes state level geologic sequestration policies. Under the cooperative federalism model of the EPA UIC program, state injection regulations must be at least as protective as the federal UIC rules, although they may be more stringent. This paper compares the GS rules from the EPA, the state of Washington, and Kansas, focusing on elements where their differences highlight choices that must be made to create a regulatory framework for GS in the United States.

U.S. EPA Underground Injection Control Program Rules. In July 2008, the EPA UIC program published proposed amendments to 40 Code of Federal Regulations (CFR) parts 144 and 146 that would establish federal requirements under the Safe Drinking Water Act (SDWA) for underground injection of CO_2 for the purpose of GS [73 Federal Register (FR) 43491-43541, July 25, 2008]. These rules propose a new UIC injection well Class VI for GS wells. If adopted, they would serve as minimum federal requirements for states that elect to run their own UIC programs. The proposed Class VI rules are more protective and in general more demanding than the rules for any of the other UIC well classes. Currently, 33 states have primacy to implement the UIC program in their state, seven share authority with the EPA, and 10 have UIC programs run by the EPA. The EPA estimates that these proposed rules could be finalized by late 2010 or early 2011.

Washington State Legislation and Rules. Engrossed Substitute Senate Bill (ESSB) 6001, Mitigating the Impacts of Climate Change, was enacted in May 2007. This law set statewide greenhouse gas (GHG) emission reduction targets, established a GHG emission performance standard for electrical utilities, and directed the Washington Department of Ecology to adopt rules for GS. Two rules adopted in June 2008 govern geological sequestration. Washington Administrative Code (WAC) 173-407-110 implements the GHG emission performance standard for electrical power plants and includes a performance standard for GS. WAC 173-218-115 amends state UIC rules to cover injection of CO_2 for GS.

Kansas State Legislation and Rules. House Bill (HB) 2419, Carbon Dioxide Reduction Act, was enacted in March 2007. This law charged the Kansas Corporation Commission with developing rules for GS, created a fund to pay for regulatory,

* Corresponding author phone: 612-625-3046; fax: 612-625-3513; e-mail: fryxx035@umn.edu.

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TABLE 1. State Geologic Sequestration Policies

state	policy	year	description
Kansas	HB 2419	2007	requests agency establish rules for geologic sequestration; creates fund to pay for regulatory costs, remediation, and long-term stewardship
	KAR 82-3-1100-1120	under review	sets requirements for CO_2 storage facility operating permits
Massachusetts	SB 2768	2008	instructs agency to set sequestration definitions and standards
New Mexico	EO2006-69	2006	requires agency to study statutory and regulatory requirements for GS
Oklahoma	SB 1765	2008	declares CO_2 a commodity; declares existing rules apply to enhanced oil recovery (EOR); creates a task force to make recommendations on CCS
Utah	SB 202	2008	task force to recommend rules for GS by January 1, 2011; interim report by July 1, 2009
Washington	ESSB 6001	2007	directs agency to set rules for GS; specifies that GS can be used to meet GHG emission reduction goals
	WAC 173-218-115	2008	revises Washington UIC rules for GS
	WAC 173-407-110	2008	sets performance standard for GS
Wyoming	HB 0089	2008	declares pore spaces the property of surface owner
	HB 0090	2008	agency to propose rules for GS permitting, no set date; working group to recommend financial assurance and post closure care requirements by September 30, 2009

remedial, and long-term monitoring costs, and included property and income tax incentives for carbon capture and sequestration. Draft Kansas Administrative Regulations (KAR) 82-3-1100 through KAR 82-3-1120 propose requirements for CO_2 storage facility operating permits. The draft rules are open for public comment through March 26, 2009. The CO_2 storage facility rules include well construction requirements, and Kansas would require only a storage permit, not separate UIC injection permits for GS facilities (*9*).

Comparison

These three sets of rules represent significantly different approaches to regulating GS of CO_2, and all deviate from existing practice for regulating underground injection. They are built on three divergent models of statutory authority. The EPA UIC rules are authorized by the Safe Drinking Water Act, which protects underground sources of drinking water (USDWs). This constrains their ability to address some issues of concern for regulating GS such as leakage to the surface and the link between GS and greenhouse gas emission reductions. The Washington rules implement the state's UIC program for GS wells, but Washington State law requires their UIC program to protect all waters of the state, not just USDWs [Revised Code of Washington (RCW) 90.48.020]. Furthermore, they are coupled with a state climate change law [Senate Bill (SB) 6001] setting GHG emission reduction targets and are therefore able to include strong links to GHG reductions. Kansas passed new enabling legislation that treats GS as a unique activity and clarifies responsibility and funding for long-term stewardship.

The following sections highlight areas of emerging consensus, areas of disagreement, regulatory gaps, and unresolved questions, elaborating on the significance of differences between these regulatory approaches and the implications for GS regulatory design in the United States. Table 2 presents a more detailed comparison.

Implementing Agency. The difference in regulatory perspective begins with the agency that is delegated to oversee GS. In Washington State, an environmental regulator has authority, whereas in Kansas, authority rests with an oil and gas regulator. The divide on this institutional choice appears across the country. Of eight states where laws or rules have been proposed that delegate authority for GS regulation, half of them designate an environmental regulator (MI, MT, WA, and WY), while the other half designate an oil and gas regulator (CA, KS, ND, and OH). This is similar to the path that EPA UIC primacy has taken, where states with oil and gas industries typically delegate regulation of Class II wells (injecting fluids associated with oil and gas production) to state oil and gas regulators, while other UIC well classes are overseen by environmental regulators. It also reflects tension regarding the fundamental nature of GS, which encompasses both energy production and environmental protection.

Composition of the CO_2 Stream. Washington State's rule prohibits the use of GS for disposal of non-CO_2 contaminants. This would require much more treatment of the CO_2 stream than the UIC rule, which allows incidental associated substances as long as the stream does not meet the definition of a hazardous waste. Kansas takes a third approach, allowing any CO_2 stream that does not compromise the performance of the reservoir or confining layers. The variation between these rules would create differences in operating conditions, costs, and risk assessment requirements.

Performance Objectives. Performance objectives are important because they form the basis for selecting high quality sites and provide flexibility for adaptable, site-specific implementation. Comparing the performance objectives of these three proposals, we find the most obvious point is the limitations imposed on the EPA UIC rules by the statutory authority of the SDWA. Only criteria for impacts on human health and the environment due to contamination of drinking water are included. Washington, with rules that implement the state UIC program under broader statutory authority, adds criteria regarding impacts to other underground resources. Kansas, on the other hand, with rules authorized under stand-alone GS legislation, has written performance objectives that include any impacts to human health, the environment, or the property of people of the state.

Washington State has written a stringent reservoir performance standard: GS must retain substantially 99% of the

TABLE 2. Comparison of U.S. Regulations for Geological Sequestration[a]

	EPA UIC Class VI[b]	Washington State[c]	Kansas[d]
permitted activity	injection	injection, pilot studies	storage
implementing agency	U.S. EPA Office of Water, state UIC programs with primacy	Department of Ecology	Kansas Corporation Commission
classification of CO_2	no determination[e]	wells must obtain a state waste discharge permit[f]	not addressed
composition of CO_2	CO_2 stream with incidental associated substances as long as it does not meet the definition of a hazardous waste under 40 CFR part 261[g]	must use all known, available, and reasonable methods to remove contaminants from the injected CO_2; GS shall not be used for disposal of non-CO_2 contaminants[h]	CO_2 shall be of sufficient purity and quality to not compromise the safety and efficiency of the reservoir to effectively contain CO_2[i]
enhanced oil recovery (EOR)	rules do not apply to existing wells; director has discretion to grandfather existing wells if they do not endanger USDWs and they meet all requirements except construction[j]	no large scale commercial oil production in WA; rules do not apply to EOR wells	rules do not apply to EOR wells; operator that wants to transition from EOR to storage must apply for a storage permit[k]
performance objectives			
health impacts: drinking water	yes[l]	yes[l]	yes[m]
health impacts: other	no	no	yes[m]
environmental impacts: drinking water	yes[l]	yes[l]	yes[m]
environmental impacts: other	no	no	yes[m]
impacts to other resources	no	yes[s]	yes[m]
reservoir performance	suitable geologic system has an injection zone that can receive the total planned volume of CO_2 and confining zone(s) with areal extent and integrity to contain it[n]	sequestration must retain substantially 99% of the CO_2 for at least 1000 yrs[o]	"loss of containment" means CO_2 has migrated out of the CO_2 reservoir or facility[p]
GHG emissions	no statutory authority[q]	sequestration must provide safe, reliable, and permanent protection against CO_2 entering the atmosphere[r]	storage must prevent escape of CO_2 into the atmosphere[m]
area of review (AoR)	subsurface three-dimensional extent of the CO_2 plume, associated pressure front, and displaced brine[t]	area containing 95% of injected CO_2 100 years after injection stops or plume boundary when expansion is less than 1% per year[u]	ambiguous, but probably based on maximum extent of the CO_2 plume[k]; permit requires modeling to determine long-term distribution of CO_2 and long-term displacement of brine[v]
risk assessment			
hazard identification	all require identification of wells that penetrate the confining zone and reservoir in the AoR as well as geologic data on faults, fractures, stratigraphy, and seismic history		
human health and ecological impact assessment	show that injection will not endanger USDWs based on modeling of CO_2 plume and formation fluid movements[w]	perform a risk assessment that quantifies hazards, probabilities, features, events, and processes that might result in undesirable impacts to public health and the environment[x]	not addressed
role of modeling	define AoR by projecting lateral and vertical migration of CO_2 plume and formation fluid over the life of project[w]	permit application must show the predicted extent of the CO_2 plume throughout the life of the project[y]	permit application must include projections of long-term CO_2 distribution, rate of dissolution, misibility, and migration rates, and reservoir modeling of the long-term movement of brine displaced by the CO_2[z]

TABLE 2. Continued

	EPA UIC Class VI[b]	Washington State[c]	Kansas[d]
monitoring			
baseline data	geochemical data on subsurface formations, including all USDWs in the AoR[aa]	formation pressure, background concentration in groundwater, surface soils, and chemical composition of in situ water within the geologic containment system and monitoring zones[bb]	geochemical data on the reservoir; evaluation of CO_2 concentrations in reservoir and adjacent formations[cc]
types of monitoring	track plume and pressure changes by either monitoring for pressure changes in the first formation overlying the confining zone or using indirect geophysical techniques; discretion to require surface air or soil gas monitoring [dd]	pressure responses immediately above caprock; monitoring plan must be able to identify failure in the containment system and release to atmosphere, degradation of groundwater or surface water resources, migration to oil or gas reservoirs[ee]	timely and permanent monitoring of soil, usable water, and the first porous zone immediately above the confining layer, should include monitoring wells[ff]
history matching with models	monitoring and operating data inform modeling for periodic AoR reevaluations[gg]	update modeling on basis of monitoring observations[hh]	not specified
mitigation and remediation plan	describe actions to be taken to address movement of CO_2 or formation fluids that may cause an endangerment to an USDW[ii]	identify trigger thresholds and corrective actions to be taken if the containment system fails, if water quality outside the geologic containment system is degraded, if $CO_2$is released to the atmosphere, or if any other factor poses an unacceptable risk to public health or the environment[jj]	emergency response plans and contingency plans for a loss of containment from the CO_2 storage facility[kk]
postinjection period	50 years, with discretion to lengthen or shorten on basis of performance[ll]	until modeling and monitoring demonstrate that there is little or no risk of future environmental impacts and there is high confidence in the effectiveness of the containment system[mm]	until CO_2 plume has stabilized, is contained in the storage reservoir, and is not a threat to public health and safety and usable water; storage reservoir pressure is stable [nn]
long-term care			
responsibility	not addressed	not addressed	assumed by state
funding	not addressed	no; any funds remaining in the financial assurance account shall be released to the operator at the completion of the post closure period[oo]	established CO_2 injection well and underground storage fund to pay for regulatory costs and long-term care; funded by fees of \$0.05/ton injected and \$1000 per storage well per year[pp]

[a] Well construction requirements and operating procedures are not included in this table because they do not vary significantly among these rules and because they have less bearing on the institutional design issues that are the focus of this article. [b] 73 FR 43491−43541, July 25, 2008. [c] ESSB 6001, enacted May 2007, and WAC 173-407-110 and WAC 173-218-115, adopted July 2008. [d] HB 2419 enacted March 2007, and draft KAR 82-3-1100 through KAR 82-3-1120. [e] 73 FR 43496, July 25, 2008. [f] WAC 173-218-115(a). [g] Draft 40 CFR §146.81(d). [h] WAC 173-218-115(b)(iii). [i] Draft KAR 83-3-1108(c). [j] Draft 40 CFR §146.81. [k] Ref *9*. [l] Safe Drinking Water Act USC 42 §300(h). [m] HB 2419 section 2(b). [n] Draft 40 CFR §146.83(a). [o] WAC 173-407-110. [p] Draft KAR 83-3-1100(t). [q] 73 FR 43495, July 25, 2008. [r] ESSB 6001 section 5(12)(b). [s] ESSB 6001 section 5(2)(j). [t] Draft 40 CFR §146.84(c). [u] WAC 173-218-115(2)(b). [v] Draft KAR 83-3-1100(g) and draft KAR 83-3-1101(c)(5). [w] Draft 40 CFR §146.84(c). [x] WAC 173-218-115(2)(l). [y] WAC 173-218-115(2)(d). [z] Draft KAR 83-3-115(c)(E,F). [aa] Draft 40 CFR §146.82(g). [bb] WAC 173-218-115(2)(j). [cc] Draft KAR 83-3-1101(c)(C,D). [dd] draft 40 CFR §146.90(g,h). [ee] WAC 173-218-115(2)(j). [ff] Draft KAR 83-3-1101(c)(5)(G) and (14)(J). [gg] Draft 40 CFR §146.84(b)(2). [hh] WAC 173-218-115(4)(g). [ii] Draft 40 CFR §146.94(a). [jj] WAC 173-218-115(8). [kk] Draft KAR 83-3-1101(c)(14)(E). [ll] Draft 40 CFR §146.94(b)(1). [mm] WAC 173-218-115(6). [nn] Draft KAR 82-3-1117. [oo] WAC 173-218-115(6). [pp] HB 2419 section 3 and draft KAR 82-3-1119.

CO_2 for at least a thousand years (WAC 173-407-110). This appears to be the first instance, worldwide, where regulators have quantified, in rule, the meaning of permanent containment. The EPA UIC rules take a far more general approach in defining a suitable geological system for GS, whereas the Kansas rules frame this issue in terms of "loss of containment." There are, however, real questions about the scientific and technical basis for quantified reservoir performance standards and good arguments for and against their adoption at this time. A performance goal must be grounded in measurable outcomes, and the technology to monitor GS site performance is still evolving (*10, 11*). But implementers identify lack of technical performance standards by which projects can be evaluated as an important regulatory gap (*12*), likely because such standards could help to bound liability and cost estimates for GS projects.

Links between GS performance and GHG emissions are another area where these rules differ. The EPA UIC rules provide no link (because there is no federal law limiting GHG emissions and because the UIC's authority comes from the SDWA), whereas both Washington State and Kansas are explicit that GS must prevent CO_2 from re-entering the atmosphere. Providing a legal link between GS and GHG reduction goals is important for two reasons. First, GS regulations will need to establish GHG accounting procedures. Second, a GS regulatory framework will be more effective if it can balance the risks of GS against other important environmental objectives such as avoiding dangerous levels of climate change. In considering the design of the regulatory framework for GS, we find this illustrates that regulation through either a UIC program or under standalone legislation can provide the necessary links to GHG reduction goals, if the UIC rules are complemented by legislation setting mandatory GHG reduction goals.

Area of Review. The area of review (AoR) is the area where site characterization studies must be conducted and corrective action performed on wells that could serve as conduits for leakage. Obviously, cost of site characterization will be a function of the types of site characterization studies that are required and the size of the AoR. These rules take very similar approaches to the types of geological, geophysical, geochemical, geomechanical, and hydrogeological data required as part of a permit application but different approaches to the size of the AoR. Theoretically, the AoR could be based on either the projected maximum extent of the CO_2 plume or on the much larger area where the injected CO_2 will increase subsurface pressure and potentially cause brine movements. Depending on reservoir characteristics, the area of pressure effects may be 25 times larger than the size of the CO_2 plume (*13*). The EPA UIC rules set the AoR based on pressure effects and associated brine displacements, where as Washington State and Kansas use the size of the CO_2 plume.

Risk Assessment. Risk assessment requirements are radically different across these rules. While all agree that a permit applicant should identify potential hazards (such as wells, faults, or fractures), they disagree how this information and the data from site characterization studies should be used to estimate health or environmental impacts. At one end of the spectrum, Washington State demands a full quantitative risk assessment of all potential health or environmental impacts. At the other end, Kansas requires hazard identification only. The EPA UIC approach lies in the middle, requiring modeling to show that injection will not endanger underground sources of drinking water, but it is constrained from assessing any other potential health or environmental impacts.

It is not surprising that risk assessment emerges as a major source of disagreement because risk assessment methodologies for GS are still under development. A number of different approaches have been proposed. There is no consensus yet on the merits and shortcomings of the various methodologies, and no fully integrated GS risk assessment has yet been carried out (*12*). Most methodologies are variations on the features, events, and processes (FEP) method pioneered by the nuclear industry. The EPA has developed a vulnerability evaluation framework (VEF) for assessing risks of GS that applies the FEP method to GS (*14*); however, there is nothing in the proposed rule for UIC Class VI wells that that requires permit applicants to make comprehensive use of the VEF to assess all potential health and environmental impacts.

A question for regulatory design is whether risk assessment methodologies for GS have matured to the point where more elaborate risk assessment translates into increased ability to predict site performance or whether uncertainties are still too great to warrant the cost. Risk assessment is an area of regulation where an adaptive approach may be necessary (*3*), allowing early projects to go forward to inform development of risk assessment methodologies that can characterize risk in a way that is useful to all stakeholders.

Monitoring. Differences between these rules regarding monitoring center on how much baseline information and monitoring are required. While consensus emerges that monitoring should focus on the storage reservoir and the first permeable formation above the confining zone, Washington State goes much further in requiring monitoring that can detect leakage into the atmosphere. The EPA UIC rules give the director discretion to require surface or soil gas monitoring, but it remains to be seen whether this option will survive into the final rule, given the tenuous link of the program's statutory authority to any impacts beyond those to drinking water. Another noteworthy and unique aspect of the Washington State rules is that they require a permit applicant to propose a definition of leakage (which would essentially set detection limits for monitoring) and trigger thresholds for corrective actions as part of the mitigation and remediation plan. This type of specificity is important for practical implementation and will help bound liability and cost estimates.

Postinjection Period. All three of these rules set the length of the postinjection period based on site performance. Essentially, the postinjection period, during which the operator has ongoing responsibilities, lasts until the CO_2 plume and reservoir pressure have stabilized and the site is behaving predictably and posing no threat. The EPA UIC rules put a twist on this approach by setting 50 years as the default postinjection period, with discretion to shorten or lengthen the period on the basis of site performance.

Long-Term Stewardship. For GS to be effective, the injected CO_2 must remain underground for hundreds or thousands of years, a time scale well beyond the average life span of most companies, so many suggest that governments should assume responsibility after the site is closed (*1, 15*). The advantages of having GS regulation written under the authority of stand-alone GS regulation, as in Kansas, are apparent when it comes to clarifying issues related to long-term stewardship. By law, the state of Kansas will assume responsibility for closed GS sites (after the end of the postinjection period), and it has established a fund to pay for associated costs. Neither the EPA nor Washington State UIC rules address funding for long-term stewardship or potential transfer of responsibility. Indeed, under Washington State and EPA rules, operators need to demonstrate financial assurance through site closure but retain liability in perpetuity.

Other states have proposed (but not passed) legislation to assume responsibility for long-term stewardship and create trust funds for this purpose (OH, HB 487; MI, SB 707; and MT, HB 55). Clearly, having long-term care issues defined is better than leaving them undefined, but it is not clear that this model of having many individual state trust funds, as

originally proposed by the IOGCC (*16*), is the optimal regulatory framework for the United States. It could fail to provide effective risk pooling because an individual state may have too few GS projects to accumulate adequate funds to cover a problem site, and because it does not spread the risk across different geological conditions.

Gaps. There are several issues of importance to the successful deployment of GS that are not covered by these rules. Clarification of how state property rights law regarding pore space applies to GS will be crucial for siting, operating, and managing the liability of GS projects. Currently, pore space ownership rights differ depending on the type of injection activity such as natural gas storage, enhanced hydrocarbon recovery, or hazardous/nonhazardous waste disposal (*17*).Washington State and Kansas both leave questions of pore space ownership to be settled under existing law.

Monitoring to validate GHG inventory accounting is a crucial element of GS site monitoring because the financial viability of these projects will depend on the integrity of the emissions avoided using GS. Neither the EPA rule nor the Kansas rule include provisions to accomplish this objective. The Washington rules take some important steps toward GS site GHG inventory accounting. First, the law authorizing these rules states that geologically sequestered CO_2 shall not be counted toward power plant emissions when determining compliance with the state electricity portfolio standard [ESSB 6001 section 5(b)(7)]. Second, as described above, the rules create de facto leakage detection limits; a key element in establishing a monitoring program capable of quantifying leakage (*11*). Technological limitations to GHG inventory accounting for GS remain, however, because practical monitoring technologies to effectively quantify low rates of leakage are still under development (*10, 11*).

Discussion

These three rules represent an early stage in the evolution of a GS regulatory framework in the United States. Comparative analysis reveals areas of emerging consensus, areas of disagreement, regulatory gaps, and unresolved questions. Consensus is emerging that protection of groundwater is paramount, pressure effects from CO_2 injection are important, monitoring should include testing in the storage reservoir and the first permeable formation overlying the confining zone, and site performance should be a factor in determining the length of the postinjection period. There is still substantial disagreement, however, regarding the allowable composition of the CO_2 stream, the size of the area of review, reservoir performance goals, risk assessment methods, and management of risks other than those to groundwater. Gaps include ownership of subsurface pore space and monitoring to quantify leakage for GHG accounting. Postclosure liability and funding is another important gap in states (other than Kansas), where it remains undefined. CCS deployment may be hampered unless regulatory development on property rights and liability issues can keep pace with the progress being made on siting and permitting requirements.

The divergent approaches taken with these early rules raise two overarching questions about design of a regulatory framework for GS in the United States: (1) Should policy makers create GS regulations by modifying and supplementing UIC rules or through new enabling legislation? (2) What should be the relative roles of state and federal governments?

As we consider these questions, it is worth noting that worldwide (Australia, Canada, and Europe), countries generally first enact climate change policy, then create legal and regulatory frameworks for GS as a means of meeting their emissions reductions goals. In the United States, however, at the federal level, policy is currently proceeding in the reverse order.

Policy makers must decide on whether to draft new enabling legislation for GS (the Kansas approach) or whether to craft GS regulations by modifying and supplementing UIC regulations (the Washington State approach). New enabling legislation could subsume UIC rules under a broader umbrella and directly address issues such as pore space ownership and long-term stewardship. If freestanding GS legislation is enacted, theoretically it should be simultaneous with or subsequent to climate change legislation. If policy makers decide to base GS regulations on the UIC rules, more changes will be needed than the proposed Class VI rules or even what Washington State has done. Additional modifications include amending the SDWA to permit the UIC program to balance potential impacts to groundwater with impacts from climate change. The UIC rules would also need to be supplemented by new rules, either under the authority of climate change legislation or the Clean Air Act, to establish GHG accounting protocols for GS, and new legislation would likely be required at the state or federal level to settle issues of pore space ownership and long-term stewardship.

As with climate policy and energy policy, there is tension between the relative roles of state and federal government in GS regulation. Trade offs exist between the consistency and coordination that federal involvement could offer and the practicality and political feasibility of state-based action. Each will be needed to some extent. Under a state-based system, at a minimum, some federal or regional coordination mechanisms would be needed to provide consistency and to coordinate projects that cross state borders (*18*). Indeed, many important geologic basins contain formations suitable for GS that underlie several states, with the Mount Simon Formation in the Illinois Basin and the Frio Formation in the Gulf Coast Basin as two prominent examples.

Under a federal system, states would play important roles in implementation because of the states' control of property rights issues, their considerable local geological expertise, and their regulatory experience with the UIC program, oil and gas production, and natural gas storage. But that does not necessarily mean that the regulatory framework must be designed by individual states. A patchwork of state regulations has proved problematic and difficult to coordinate on other issues of national scope such as air quality. Differences on issues of substance such as the allowable composition of the CO_2 stream or the required reservoir retention standard that are evident in these first few rules could impede CCS deployment by making coordination across jurisdictions difficult and raising questions over whether the value of emissions avoided by GS would be fully fungible. A relatively strong federal role (with state implementation) could help provide consistency, offer a broader forum for deliberation on difficult issues such as risk assessment, and establish durable funding mechanisms that more effectively pool risk for long-term stewardship.

These early proposals show there are still fundamentally unresolved questions about how to design an effective regulatory framework for GS in the United States. They also illustrate the importance of state CCS policy activism. States are serving as policy laboratories, and they are also establishing "facts on the ground" that will need to be integrated into whatever GS regulatory framework evolves. Because states will play such an important role in implementing GS regulations, national policy makers would do well to draw on the early experiences of the states as they consider questions of institutional design and the relative roles of federal and state governments. Effective national action on GS, however, will be hard pressed to encompass approaches as divergent as those taken by Kansas and Washington State. Federal involve-

ment beyond the proposed EPA Class VI rules is needed to provide coordination and consistency in regulating GS and to create the climate policy that is ultimately the rationale for carbon capture and sequestration.

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