

**Geologic CO₂ Sequestration and Subsurface Property Rights:
A Legal and Economic Analysis**

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Abstract

Carbon dioxide emissions (CO₂) from the combustion of fossil fuels must be reduced on a large scale to mitigate the effects of global climate change. Carbon capture and sequestration (CCS) has the potential to allow the continued use of fossil fuels with little or no emissions until alternative, low-to-zero emission sources of energy are more widely deployed. This thesis considers the legal and economic implications of securing the right to use geologic pore space—the microscopic space in subsurface rock matrixes—in an effort to sequester CO₂ deep underground to mitigate climate change. The findings and conclusions drawn in this thesis are intended to help guide discussion, research, and decision-making processes undertaken by policymakers and industry leaders with respect to the commercial-scale deployment of CCS. Prior to the commencement of sequestration, a project developer/operator must have authorization to access and use pore space to avoid liability for subsurface trespass. This authorization can be acquired via bilateral contract, where monetary compensation is remitted to the property owner in exchange for the right to use pore space. However, the question remains open as to whether the use of pore space for geologic CO₂ sequestration (GCS) is a trespass requiring compensation under the law. In fact, there is ample legal precedent in the context of underground injection activities such as enhanced hydrocarbon recovery, fluid waste disposal, and freshwater storage to support the supposition that the invasion of pore space by injected is compensable only when substantial harm or interference with an existing or non-speculative, investment-backed future use of the subsurface results from the injection of such fluids. This thesis shows that if CCS is widely deployed, the cost of electricity and power plant profitability could be adversely affected by a legal requirement that pore space owners must be compensated for GCS in all circumstances.

Moreover, absent unrealistically high electricity prices or some form of sequestration subsidy, pore space has no net-positive, intrinsic economic value to electric generators that can be passed along to property owners. Therefore, while paying property owners to use of pore space for geologic CO₂ sequestration may very well foster public acceptance and appease staunch private property rights advocates, there is no demonstrable legal or economic rationale for compensating property owners who have no current or non-speculative, investment-backed future use of the subsurface where pore space targeted for sequestration is located. A pragmatic and equitable solution for constraining the potential negative economic effects associated with acquiring pore space rights would be for state or federal legislatures, or courts, to limit required compensation to only those instances where the injection and migration of CO₂ materially impairs current or non-speculative, investment-backed future uses of the subsurface. Future work should include a detailed analysis of takings law and the anticipated long-term constitutional and economic implications of various approaches to pore space property rights governance before new CCS-specific laws are enacted. The models presented in this thesis should also be applied to additional site-specific geologic data for saline aquifer sequestration targets. Additionally, the implications of GCS paired with enhanced oil recovery (EOR) on power plant economics should be studied.

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Chapter 1: Introduction

Carbon dioxide emissions (CO₂) from the combustion of fossil fuels must be reduced on a massive scale to mitigate the effects of global climate change. Carbon capture and sequestration (CCS) has the potential to allow the continued use of fossil fuels with little or no emissions until alternative, low-to-zero emission sources of energy are more widely deployed. In fact, some electric power industry representatives believe that CCS “could reduce power plant emissions by about one-quarter in 2030.”¹ CCS involves the capture of CO₂ at a large industrial facility, such as an electric generation plant, and its transport, typically via pipeline, to an appropriate geologic formation where it is injected and sequestered. To geologically sequester CO₂, the gas is compressed to a supercritical fluid and injected approximately a kilometer or deeper into the microscopic pore space in deep subsurface rock matrixes. Injected CO₂ flows through and fills the pore spaces in permeable layers of the rock matrix, while its upward migration is prevented by less permeable rock layers. Depending on the formation geology and the depth, porosity, and permeability of the injection zone, sequestered CO₂ from a single project could potentially spread over hundreds to thousands of square kilometers, and subsurface pressure effects—affecting brine displacement—could be felt over an even greater area. Consequently, before a geologic CO₂ sequestration (GCS) field can be developed, the project developer will have to acquire the authorization to access and use pore space to avoid liability for subsurface trespass. Trespass is a legal theory that redresses property owners for physical invasions—including subsurface invasions—of their property by others or activities that substantially limit their ability to use

¹ Steven D. Cook, *Power Industry Officials Disagree on Future, Feasibility of Carbon Capture, Storage*, Daily Env’t Rep. (BNA) No. 186, at A-1 (Sept. 26, 2007).

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and enjoy their property fully.² This thesis considers the legal and economic implications of securing the right to use geologic pore space in an effort to sequester billions of metric tons of CO₂ deep underground to mitigate climate change. Specifically, this thesis explores and provides answers to the following set of novel questions:

- 1) Does the use of subsurface pore space for geologic CO₂ sequestration require compensation under the law?
- 2) Assuming compensation is required, what is the potential cost of compensating property owners?
- 3) Does compensation for the use of pore space affect power plant economics?
- 4) What is the economic value of pore space from the perspective of a power plant operator?
- 5) How can compensation costs be legally and equitably constrained?

The answers to these questions suggest that the use of subsurface pore space for the permanent geologic sequestration of CO₂ should not be compensable unless the owner of the pore space suffers actual and substantial damages. Furthermore, the federal or state governments should codify a formal process for managing the access and use of pore space for geologic CO₂ sequestration. This particular framework could facilitate the rapid development of commercial-scale CCS in response to climate change by standardizing procedures for acquiring the authorization to use pore space and constraining acquisition costs.

² RESTATEMENT (SECOND) OF TORTS § 159 (1965).

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1.1 Thesis Overview and Structure

The remainder of Chapter 1 provides an overview of CCS technology, its potential role in addressing climate change, recent federal, state, and industry efforts to promote CCS technology, and how the commercial-scale implementation of CCS might intersect with existing uses and established property rights in the subsurface. Chapter 2 turns to property rights in the context of permanent geologic sequestration of CO₂ and explores the extent to which surface owners and mineral owners have established and protected property rights in subsurface pore space. Chapter 3 examines the cost of acquiring subsurface property rights under the assumption compensation might be required to use pore space for CO₂ sequestration. Chapter 4 expands upon the analysis in the third chapter by exploring the effect of compensating property owners to use pore space for CO₂ sequestration on power plant economics. Chapter 4 also presents an engineering-economic approach for monetizing the value subsurface property rights in the context of CO₂ sequestration from the perspective of an electric generation facility owner/operator. Finally, Chapter 5 evaluates a range of common law and legislative approaches to managing the access and use of pore space for geologic sequestration of CO₂, and concludes by proffering a framework for addressing this issue that is fair and equitable to both GCS project operators and private property owners.

1.2 Climate Change, the Use of Coal, and CCS

Earth's climate is warming at an abnormal rate because of the accumulation of anthropogenic greenhouse gases (GHG) in the atmosphere, primarily CO₂. The average temperature of the earth is believed to have risen approximately 0.7 degrees Celsius in the past 100 years.³ The

³ Lenny Bernstein et al., *Summary for Policy Makers*, in CLIMATE CHANGE 2007: SYNTHESIS REPORT 2, Figure SPM.3 (Lenny Bernstein et al. eds. 2007), http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf.

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consensus of the United Nations Intergovernmental Panel on Climate Change (IPCC) participants is that it is very likely most of the temperature increases since 1950 are due to a rapid increase in the concentration of greenhouse gases in the atmosphere, the emissions of which rose from 28.7 gigatonnes (Gt) in 1970 to 49 Gt in 2004, an increase of over 70%.⁴ The IPCC warns that if the rate of increase in GHG emissions is not drastically slowed—or even reversed—substantial additional temperature increases will result, causing significant harm to environmental and human health.

Burning fossil fuels to generate electricity is a major contributor to CO₂ emissions. Demand continues to grow significantly, especially in developing nations such as India and China, where coal is overwhelmingly the primary fuel source used to generate electricity—roughly 70% of total generation for both countries.⁵ By 2030, the combined coal consumption of China and India is expected to account for nearly 70% of the incremental demand worldwide.⁶ A 2007 Massachusetts Institute of Technology study predicted that world coal use will double by 2030 without policy changes, and will increase dramatically in any realistic scenario because of its abundance and low cost.⁷ In the United States, roughly 50% of all electricity consumed is generated by combusting coal.⁸ In 2008, the U.S. electric power sector was responsible for roughly 43% of CO₂ emissions from fossil-fuel combustion and

⁴ *Id.* at 5. All mass units of CO₂ in this thesis are in metric tons (tonnes).

⁵ U.S. Energy Information Administration, ELECTRICITY GENERATION BY TYPE, CHINA (2006), <http://www.eia.doe.gov/cabs/China/Background.html> (accessed July 21, 2010); U.S. Energy Information Administration, ELECTRICITY GENERATION BY TYPE, INDIA (1986-2006), <http://www.eia.doe.gov/cabs/India/Electricity.html> (accessed July 21, 2010).

⁶ Ed Rubin et al., *Technical Summary*, in IPCC SPECIAL REPORT ON CARBON DIOXIDE CAPTURE AND STORAGE 17, 31 (Bert Mertz et al. eds. 2005), http://www.ipcc.ch/pdf/special-reports/srccs/srccs_technicalsummary.pdf (hereinafter referred to as IPCC SPECIAL REPORT ON CARBON DIOXIDE CAPTURE AND STORAGE).

⁷ James Katzer et al., THE FUTURE OF COAL: OPTIONS FOR A CARBON-CONSTRAINED WORLD, at 7, Table 2.3 (2007), http://web.mit.edu/coal/The_Future_of_Coal.pdf (accessed July 22, 2010).

⁸ U.S. Energy Information Administration, 1990-2008 NET GENERATION BY ENERGY SOURCE: NET GENERATION BY STATE BY TYPE OF PRODUCER BY ENERGY SOURCE (EIA-906), http://www.eia.doe.gov/cneaf/electricity/epa/generation_state.xls (accessed July 21, 2010).

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34% of total GHG emissions in the United States.⁹ Eighty percent of the 2.5 billion metric tons of CO₂ emissions associated with the U.S. electric power sector were emitted from coal-fired power plants in the same year.¹⁰

Effectively dealing with climate change will require a fundamental transition in how societies throughout the world will produce and use energy. Moreover, it is important to recognize that stabilizing the atmospheric concentration of GHGs is fundamentally different than stabilizing concentrations of traditional criteria air pollutants, like sulfur dioxide (SO₂) or nitrogen oxides (NO_x).¹¹ Most GHGs have long atmospheric lifetimes—decades to thousands of years—compared to hours or days for most criteria air pollutants.¹² CO₂ is a trace gas in the Earth's atmosphere at a global mean concentration of approximately 386 parts per million (ppm) (or 0.0386 %) as of 2009.¹³ During the past two million years, during which Earth's climate fluctuated repeatedly from ice age to interglacial conditions (such as are present today), CO₂ concentrations appear not to have exceeded 280 ppm.¹⁴ Over the past 200 years, the increase in the atmospheric concentration of CO₂ from 280 ppm to 386 ppm in 2009 has been due largely to human activity, particularly the burning of fossil fuels for electricity.¹⁵ If

⁹ See U.S. Environmental Protection Agency, INVENTORY OF U.S. GREENHOUSE GAS EMISSIONS AND SINKS: 1990-2008, Table ES-2 (Apr. 15, 2010), <http://epa.gov/climatechange/emissions/usinventoryreport.html> (accessed July 21, 2010).

¹⁰ U.S. Energy Information Administration, 1990-2008 ELECTRIC POWER INDUSTRY ESTIMATED EMISSIONS BY STATE (EIA-767 and EIA-906) http://www.eia.doe.gov/cneaf/electricity/epa/emission_state.xls (accessed July 21, 2010).

¹¹ See generally Rubin et al., *supra* note 6.

¹² Greenhouse gases include carbon dioxide, methane, nitrous oxide, and fluorinated gases. Piers Forster et al., *Changes in Atmospheric Constituents and Radiative Force*, in IPCC FOURTH ASSESSMENT REPORT: CLIMATE CHANGE 2007, THE PHYSICAL SCIENCE BASIS 1, 2-5, 10 (Susan Solomon et al. eds., 2007), <http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter2.pdf>.

¹³ National Oceanic & Atmospheric Administration Earth System Research Laboratory, TRENDS IN ATMOSPHERIC CARBON DIOXIDE (2009), <http://www.esrl.noaa.gov/gmd/ccgg/trends/> (accessed July 22, 2010).

¹⁴ Hervé Le Treut, et al., Historical Overview of Climate Change, in IPCC FOURTH ASSESSMENT REPORT: CLIMATE CHANGE 2007, THE PHYSICAL SCIENCE BASIS, *supra* note 11, at 100.

¹⁵ Lenny Bernstein et al., *supra* note 3, at 36.

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current rates of increase in CO₂ emissions continue, CO₂ concentrations by 2100 will be in excess of 1,500 ppm, which the IPCC estimates will cause global temperature increases of between 2.4 and 6.4°C, imposing severe adverse effects on weather, food, water supply, and habitat.¹⁶ According to the IPCC, to ensure the global mean temperature rises no more than 2°C would require an emissions reduction of between 50% and 80% from 2000 levels by 2050.¹⁷

While many energy technologies are available to make near-term reductions in CO₂ emissions, it will be necessary to deploy a full portfolio of all available low-carbon technologies to achieve the emissions reductions required to combat climate change.¹⁸

Research suggests that to mitigate the risk of climate change, humans must simultaneously increase reliance on renewable and other non-carbon-based energy, such as wind, solar, biomass, geothermal, and nuclear; increase the efficiency of energy production and use; and reduce CO₂ emissions from fossil fuel-burning power plants. As a result, governments and industry have begun to investigate the feasibility of sequestering CO₂ from power plants and other large emitting sources in deep geologic formations to allow the continued use of fossil

¹⁶ *Id.* at Table 3.1, 48-50.

¹⁷ See United Nations Framework Convention on Climate Change art. 2, *opened for signature* May 9, 1992, 1771 U.N.T.S. 107, <http://unfccc.int/resource/docs/convkp/conveng.pdf> (accessed July 22, 2010) (“The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.”) The United States is a signatory to the UNFCCC, but not to the later Kyoto Protocol, which establishes targets for GHG emission reductions.

¹⁸ See, e.g., Energy Tech. Assessment Ctr., Electric Power Research Inst., *THE POWER TO REDUCE CO₂ EMISSIONS: THE FULL PORTFOLIO 2009*, at 5-1 (2009), http://my.epri.com/portal/server.pt?Abstract_id=00000000001020389 (accessed June 15, 2010).

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fuels, namely coal, while reducing emissions to the atmosphere.¹⁹ Carbon capture and sequestration is emerging as a potentially promising yet contentious technology that could enable the continued use of fossil fuels while still allowing society to dramatically reduce accompanying CO₂ emissions. This technology could be deployed to reduce CO₂ emissions from a host of industrial facilities and, perhaps most importantly, coal-fired electric generation.

The IPCC published a comprehensive report on CCS in 2005.²⁰ This report outlines large sources of CO₂,²¹ capture technologies,²² transportation modes,²³ and geologic sequestration and its attendant risks;²⁴ covers cost and economic and potential;²⁵ and describes how CCS could fit within a larger GHG reduction effort.²⁶ Ultimately, it concludes that CCS could play a significant role in lowering the overall cost of deep emission cuts. Princeton University Professors Stephen Pacala and Robert Socolow analyzed potential technologies to mitigate CO₂ emissions.²⁷ Visualizing steeply increasing CO₂ emissions on a graph, they proposed

¹⁹ *Summary for Policymakers*, in IPCC SPECIAL REPORT ON CARBON DIOXIDE CAPTURE AND STORAGE 3 (Bert Mertz et al. eds. 2005), http://www.ipcc.ch/pdf/special-reports/srccs/srccs_summaryforpolicymakers.pdf (The authors state “no single technology option will provide all of the emission reductions needed to achieve stabilization, but a portfolio of mitigation measures will be needed.”).

²⁰ IPCC SPECIAL REPORT ON CARBON DIOXIDE CAPTURE AND STORAGE 195, 210 (Bert Mertz et al. eds. 2005), http://www.ipcc.ch/pdf/special-reports/srccs/srccs_wholereport.pdf (accessed July 21, 2010).

²¹ John Gale et al., *Sources of CO₂*, in IPCC SPECIAL REPORT ON CARBON DIOXIDE CAPTURE AND STORAGE, *supra* note 6, at 75, 75-103.

²² Kelly Thambimuthu et al., *Capture of CO₂*, in IPCC SPECIAL REPORT ON CARBON DIOXIDE CAPTURE AND STORAGE, *supra* note 6, at 105, 105-78.

²³ Richard Doctor et al., *Transport of CO₂*, in IPCC SPECIAL REPORT ON CARBON DIOXIDE CAPTURE AND STORAGE, *supra* note 6, at 179, 179-93.

²⁴ Benson et al., *Underground Geologic Storage*, in IPCC SPECIAL REPORT ON CARBON DIOXIDE CAPTURE AND STORAGE, *supra* note 6, at 195, 195-276.

²⁵ Howard Herzog et al., *Cost and Economic Potential*, in IPCC SPECIAL REPORT ON CARBON DIOXIDE CAPTURE AND STORAGE, *supra* note 5, at 339, 339-62.

²⁶ Balgis Osman-Elahsa et al., *Implications of Carbon Dioxide Capture and Storage for Greenhouse Gas Inventories and Accounting*, in IPCC Special Report on Carbon Dioxide Capture and Storage, *supra* note 5, at 363, 363-79.

²⁷ Stephen Pacala & Robert Socolow, *Stabilizing Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies*, 305 *Science* 968 (2004).

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that although no technology could solve the entire problem, each of several technologies could contribute a “wedge” of emission reduction.²⁸ Through the added effect of several emission reduction wedges, anthropogenic CO₂ emissions could be kept flat through 2050 and reduced thereafter. Geologic sequestration of CO₂ was one technology proposed as a wedge in this effort, yielding a reduction in CO₂ emissions of about 3.7 Gt/yr by 2050.²⁹ That is the equivalent of capturing and injecting 90% of the CO₂ emitted each year by 600 coal-fired power plants with one gigawatt (GW) capacity.³⁰ One of the largest current CO₂ projects, the Sleipner project operated by Statoil in the North Sea, injects about one million metric tons of CO₂ annually.³¹ About 3,700 projects of that size would be needed to fill out the CO₂ sequestration wedge.³²

1.3 CCS Technology

CCS assembles existing technologies that have been developed within the chemical, oil, and natural gas industries to capture and sequester large volumes of CO₂.³³ CCS involves capturing CO₂ during fossil fuel combustion,³⁴ transporting the CO₂ to a location with suitable geologic formations (typically by pipeline), and injecting the CO₂ into deep geologic

²⁸ *Id.*

²⁹ Pacala and Socolow refer to each “wedge” as yielding 1Gt/yr reduction in carbon emissions, which is the same as 3.7 GtCO₂ emissions.

³⁰ See Katzer, et al., *supra* note 7, at 43.

³¹ See T.A. Torp and J. Gale, *Demonstrating storage of CO₂ in geologic reservoirs: The Sleipner and SACS projects*, Energy, 2004. 29: p.1361-1369; T.A. Torp and K.R. Brown, *CO₂ Underground Storage Costs as Experienced at Sleipner and Weyburn*, in 7th International Conference on Greenhouse Gas Control Technologies, 2004. Vancouver, Canada: Elsevier Science.

³² Statoil estimates that the geologic formation being used could hold up to 600 GtCO₂—equivalent to the total CO₂ emissions from all European sources for 600 years. Statoil, Carbon Dioxide Storage Prize (2000), <http://carbonsequestration.us/News&Projects/htm/Statoil-Sleipner-12-18-2000.html> (accessed July 22, 2010).

³³ Rubin et al., *supra* note 6, at 40-41.

³⁴ The CCS process could also be applied to other industrial processes that have CO₂ streams, like ethanol plants or other industrial facilities.

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formations at least 800 meters below the surface.³⁵ The goal is to avoid the release of CO₂ to the atmosphere by permanently sequestering the captured CO₂ deep underground. CO₂ sequestration could take place in depleted natural gas reservoirs, oil fields where enhanced oil recovery can be achieved through the injection of CO₂, and saline aquifers.³⁶ During CO₂ injection, the pressure of CO₂ at the well bottom exceeds the pressure of the fluid in the formation, and CO₂ is forced into microscopic spaces in the rock matrix, displacing brine (or oil and gas) that originally occupied the pore space.³⁷ CO₂ will flow through and fill the pore spaces in permeable layers of the rock and be prevented from migrating upwards by less permeable rock layers.³⁸ CO₂ will be sequestered as a dense, supercritical fluid.³⁹ Natural geologic analogues, such as geologic formations containing crude oil, natural gas, and even CO₂, prove that anthropogenic CO₂ can be retained underground for millions of years.⁴⁰ CCS technologies would attempt to take advantage of this geologic capacity to reduce CO₂ emissions to the atmosphere.

³⁵ See Doctor et al., *supra* note 23, at 181; Rubin et al., *supra* note 6, at 17, 31-36; see also Sam Holloway, *An Overview of the Underground Disposal of Carbon Dioxide*, 38 Energy Conversion & MGMT. S193, S193 (Supp. 1997); Sam Holloway, *Storage of Fossil Fuel-Derived Carbon Dioxide Beneath the Surface of the Earth*, 26 Ann. Rev. Energy & Env't 145, 149 (2001) [hereinafter Holloway, *Storage of Fossil Fuel-Derived Carbon Dioxide*].

³⁶ See Holloway, *Storage of Fossil Fuel-Derived Carbon Dioxide*, in IPCC SPECIAL REPORT ON CARBON DIOXIDE CAPTURE AND STORAGE, *supra* note 6, at 148-49, 158.

³⁷ *Id.* at 149-50.

³⁸ *Id.* at 150.

³⁹ A supercritical fluid exists when a substance is above its critical temperature and critical pressure (the critical point). When a fluid is at its critical point, it exists as a gas and a liquid in equilibrium, giving it unique properties. CO₂ is considered a supercritical fluid at temperatures greater than 31.1 degrees Celsius and 7.38 MPa. See CRC HANDBOOK OF CHEMISTRY AND PHYSICS 6-39 (David R. Lide ed., 88th ed. 2008).

⁴⁰ See William Gunter et al., *The Role of Hydrogeological and Geothermal Trapping in Sedimentary Basins for Secure Storage of Carbon Dioxide*, in GEOLOGICAL STORAGE OF CARBON DIOXIDE 129, 135 (S.J. Baines & R.H. Worden eds., 2004).

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1.3.1 Depleted Gas Reservoirs

Depleted gas reservoirs have been used for storing natural gas imported by pipeline, and make up about 85% of gas storage capacity in America.⁴¹ The technology for natural gas storage in depleted reservoirs is well-understood. Gas reservoirs are likely to be high-quality sequestration sites; they have the demonstrated ability to contain natural gas, without leaking, over geologic time. The current capacity of all gas storage reservoirs in the United States (including depleted reservoirs, aquifers, and salt cavern storage) is about 8.5 trillion cubic feet (Tcf) of natural gas.⁴² That total capacity could sequester the CO₂ output from fewer than two electric generation facilities with one gigawatt (GW) capacity over a 50 to 60-year plant life. This suggests that the world would need to build the equivalent of over 100 times the United States' current gas storage infrastructure to achieve the desired CO₂ emissions reductions.

1.3.2 Enhanced Oil Recovery

Enhanced Oil Recovery (EOR) by injection of CO₂ has been operating for nearly 40 years in the United States.⁴³ EOR is in widespread use in the Permian Basin in western Texas, where more than 30 million metric tons of CO₂ have been injected—though not formally “sequestered”—in that area since 1985.⁴⁴ These amounts, however, are a mere fraction of the massive scale of injection required to implement CCS for climate change mitigation

⁴¹ See Jerry Fish & Robert A. Nelson, *Building Your Own Underground Gas Storage Project: From Leasing to Open Season Under FERC Order No. 636*, 40 Rocky Mtn. Min. L. Inst. 19-1, 19-12 (1994).

⁴² U.S. Energy Information Administration, UNDERGROUND NATURAL GAS STORAGE CAPACITY (2008), http://www.eia.gov/dnav/ng/ng_stor_cap_dcu_nus_a.htm (accessed July 23, 2010).

⁴³ Sean McCoy, THE ECONOMICS OF CO₂ TRANSPORT BY PIPELINE AND STORAGE IN SALINE AQUIFERS AND SALINE RESERVOIRS, Chapter 1, PhD Thesis, Carnegie Mellon (2008).

⁴⁴ Richard C. Maxwell et al., THE LAW OF OIL AND GAS 13-14 (8th ed. 2007) (discussing enhanced recovery technology); Steven D. Cook, *Researchers Optimistic on Prospects for Successful Carbon Capture, Storage*, Daily Env't Rep. (BNA) No. 94, at A-1 (May 16, 2007) (discussing eh use of enhanced recovery in Texas as a current example of subsurface injection of CO₂).

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purposes.⁴⁵ For CCS to have a real effect on climate change, individual projects must sequester millions of metric tons of CO₂ per year and keep the injected CO₂ underground indefinitely. As of 2008, CO₂ was being used in approximately 100 EOR operations in the United States, producing close to 250,000 barrels of oil per day, slightly less than 5% of total U.S. domestic oil production.⁴⁶ In this context, CO₂ is a valuable commodity. Although EOR is financially feasible today in certain circumstances, too few opportunities exist near major power plants for EOR to play a major role in meeting the CO₂ sequestration goal.⁴⁷ What is more, the effectiveness of EOR with CO₂ sequestration as an emission reduction tool is more than questionable. The reason is because oil is a carbon rich fuel and 93% of the carbon in crude oil refined in the U.S. is converted into combustible products, which ultimately emit large quantities of CO₂ to the atmosphere.⁴⁸ In fact, the quantity of CO₂ emissions that result from the combustion of these petroleum-derived products is far greater than the emissions offset by CO₂ injected and sequestered in a typical EOR practice.⁴⁹ Jaramillo et al. estimated that between 3.7 and 4.7 metric tons of CO₂ are emitted—from EOR field operations, crude oil transport, crude oil refining, and petroleum product refining—to the atmosphere for every metric ton of CO₂ injected for EOR, and that 0.62 metric tons of CO₂ would need to be sequestered in order to entirely offset emissions associated with producing one barrel of oil.⁵⁰

⁴⁵ See Katzer, et al., *supra* note 7, at ix (“If 60% of the CO₂ produced from U.S. coal-based power generation were to be captured and compressed to a liquid for geologic sequestration, its volume would equal the total U.S. oil consumption of 20 million barrels per day.”).

⁴⁶ See More G. Moritis, *US EOR Projects Start but EOR Production Continues to Decline*, 106 Oil Gas J. 41-46 (2008).

⁴⁷ See Katzer, et al., *supra* note 7.

⁴⁸ Jaramillo et al., *Life Cycle Inventory of CO₂ in an Enhanced Oil Recovery System*, 43 Environ Sci. Technol. 8027 (2009).

⁴⁹ *Id.* at 8030.

⁵⁰ *Id.*

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1.3.3 Saline aquifers

Saline aquifers (having a salinity greater than 10,000 parts per dissolved salt per million (ppm), compared with 35,000 ppt for seawater) have the greatest potential for CO₂ sequestration. The DOE estimates that saline aquifers in the United States have a combined sequestration potential of roughly 3,300 to 12,700 Gt of CO₂.⁵¹ Thus, the available sequestration capacity could prove to be quite large when compared with the roughly 2 billion metric tons of CO₂ emitted from coal-fired power plants annually in the United States.⁵² Saline aquifers are large and ubiquitous, and underlie much of the eastern United States, where the majority of CO₂ from U.S. power plants is emitted. However, unlike oil and gas reservoirs, saline aquifers are not well characterized because, historically, they do not have much economic value, nor have they been widely targeted for commercial or industrial use.

Several CCS projects are underway in Norway, Algeria, and Canada, and more are planned in the United States, China, Australia, and other European countries.⁵³ There are currently four active CCS projects, each injecting roughly one million metric tons of CO₂ annually.⁵⁴ Three current CCS projects capture and inject CO₂ produced from natural gas production projects. Sleipner in the North Sea and Snøvit in the Barents Sea inject CO₂ captured from produced natural gas deep below the seafloor.⁵⁵ In Salah, in Algeria, injects the captured CO₂

⁵¹ See U.S. Dep't of Energy, CARBON SEQUESTRATION ATLAS OF THE UNITED STATES AND CANADA (2008), http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlas/ATLAS.pdf (accessed July 21, 2010).

⁵² U.S. Energy Information Administration, 1990-2008 ELECTRIC POWER INDUSTRY ESTIMATED EMISSIONS BY STATE (EIA-767 and EIA-906) http://www.eia.doe.gov/cneaf/electricity/epa/emission_state.xls (accessed July 21, 2010).

⁵³ See Rubin et al., *supra* note 6, at 19, 33 Table TS.5.

⁵⁴ See Int'l Energy Agency, CARBON CAPTURE AND STORAGE: FULL-SCALE DEMONSTRATION PROGRESS UPDATE 3-4 (2009), http://www.iea.org/G8/docs/ccs_g8july09.pdf (accessed July 22, 2010).

⁵⁵ *Id.* at 5.

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into a deep gas formation.⁵⁶ The Dakota Gasification Company plant in Beulah, North Dakota captures and transports CO₂ by pipeline over 200 miles across the U.S./Canadian border to the Weyburn Oil Field in Saskatchewan for enhanced oil recovery.⁵⁷

The United States Department of Energy (DOE) has funded seven regional carbon sequestration partnerships⁵⁸ with the aim of long-term research and development of the technology as well as six of seven anticipated large scale pilot projects to store one million metric tons or more of CO₂ in various geologic formations across the country.⁵⁹ The regional partnerships include more than 350 state agencies, universities, and private companies.⁶⁰ The American Recovery and Reinvestment Act will provide an additional \$3.4 billion for CCS demonstration projects, increasing federal support for CCS by 70% to over \$8 billion.⁶¹

Despite its significant potential to have a real impact on climate change, like any technology, CCS is not without risks. These include the risks to human health and the environment associated with unintended release of CO₂ during transportation by pipeline to sequestration sites, injection of CO₂ into the subsurface, or leakage of CO₂ to the surface or into overlying

⁵⁶ *Id.*

⁵⁷ *Id.*

⁵⁸ The goal of the partnerships is described as the completion of three technical study phases: 1) Characterization Phase (2003-05): characterize opportunities for carbon sequestration; 2) Validation Phase (2005-09): conduct small-scale field tests (some are currently underway); and Deployment Phase (2008-17): conduct large-volume sequestration tests. *See* U.S. Department of Energy, Fossil Energy, Carbon Sequestration Regional Partnerships, <http://fossil.energy.gov/sequestration/partnerships/index.html> (accessed July 22, 2010).

⁵⁹ U.S. Department of Energy, Fossil Energy, Carbon Sequestration Regional Partnerships, <http://fossil.energy.gov/sequestration/partnerships/index.html> (accessed July 22, 2010).

⁶⁰ *Id.*

⁶¹ *Flurry of U.S. State, Federal Policies Advance CCS*, Carbon Capture J., Feb. 20 2009, <http://www.carboncapturejournal.com/displaynews.php?NewsID=344&PHPSESSID=n6olicebdfb6gk99bp8nk3ms40> (accessed July 22, 2010).

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sources of drinking water.⁶² These risks can arise from improper transportation, leaking wells, unanticipated issues with the subsurface geology into which CO₂ is injected, or a failure to properly monitor and manage CO₂ once it is injected into the subsurface.⁶³ There are also climate risks associated with CCS. It is very possible that if significant quantities of CO₂ injected into the subsurface prematurely leak back into the atmosphere, it could limit the long-term climate benefit.⁶⁴

CCS has both its detractors and supporters within the environmental community. Greenpeace released a report in May 2008 entitled “False Hope,” in which it contends that CCS wastes energy, creates unacceptable risks of leakage, is too expensive, undermines funding for more sustainable solutions to potential climate change, carries significant liability, risks, and cannot be implemented in time to avoid dangerous climate change.⁶⁵ Greenpeace argues instead for investing in renewable energy technologies and increasing energy efficiency that can begin to reverse climate change today.⁶⁶ Other environmental nonprofit groups, however, such as the Environmental Defense Fund, Natural Resources Defense Council, World Resources Institute, and the Nature Conservancy, see CCS as a necessary technology to help mitigate the effects of climate change.⁶⁷ As one environmental nonprofit representative stated, CCS “is a terrible idea that we desperately need.”⁶⁸ Outside the environmental nonprofit

⁶² See Alexandra B. Klass & Elizabeth J. Wilson, *Climate Change and Carbon Sequestration: Assessing a Liability Regime for Long-Term Storage of Carbon Dioxide*, 58 Emory L.J. 103, 117-19 (2008).

⁶³ See Alexandra B. Klass & Elizabeth J. Wilson, *Carbon Capture and Sequestration: Identifying and Managing Risks*, 8 Issues L. Scholarship 1,1 (2009).

⁶⁴ *Id.* at 1-2.

⁶⁵ See Greenpeace, FALSE HOPE: WHY CARBON CAPTURE AND STORAGE WON'T SAVE THE CLIMATE 5 (2008).

⁶⁶ *Id.*

⁶⁷ Gabrielle Wong-Parodi et al., *Environmental Non-Government Organizations' Perceptions of Geologic Sequestration*, *Env'tl Research Letters*, at 1, 3, Table 3 Apr.-June 2008, <http://www.iop.org/EJ/abstract/1748-9326/3/2/0240071>.

⁶⁸ *Id.*

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community there is an equally significant range of views on the merits of CCS. Those who deny the fact of climate change technologies as an unnecessary expenditure of government and private resources.⁶⁹ Some in industry view CCS as a way to acknowledge the problem of climate change while allowing the world to continue to use coal long into the future.⁷⁰ Others see it as a transition technology that allows the world to make dramatic reduction in CO₂ emissions—and broker politically viable climate agreements—while alternatives to coal and fossil fuels are developed.⁷¹ Yet others oppose CCS because of potential risks to human health and the environment, the moral and ethical issues associated with injecting pollutants into the earth, and the fact that CCS enables the continued use of coal and may reduce the incentives and funding needed to transition to a more sustainable energy future.⁷²

The position one takes on a range of CCS-related issues—from human health and environmental health risks, to economics, to property rights—depends significantly on whether one wants to encourage or discourage the development of CCS as a tool to address climate change. The goal of this thesis is to explore how deep geologic sequestration of CO₂ may intersect with existing uses established property rights in the subsurface, the economics of acquiring subsurface property rights, as well as methods lawmakers and judiciaries may employ to constrain property conflicts and the cost of acquiring subsurface property rights.

⁶⁹ See, e.g., Nicholas Davidoff, *The Civil Heretic*, N.Y. Times Mag. Mar. 29, 2009, at 32 (profiling Institute for Advanced Study physicist Freeman Dyson, who has voiced doubts about both climate change and its potential for significant adverse effects on the planet).

⁷⁰ See Wong-Parodi, *supra* note 67, at 4.

⁷¹ See *id.* at 5-6.

⁷² See *id.* at 5.

1.4 The Intersection of Geologic CO₂ Sequestration and Existing Uses and Recognized Property Rights in the Subsurface

For CCS to enable the continued use of fossil fuels and simultaneous deep emission reductions, it must be widely deployed. To do this, the technology must be integrated into a larger industrial, legal, and regulatory scheme. Of key importance are 1) the amount of CO₂ to be injected—a 1 GW coal-fired power plant typically produces roughly 6 to 8 million metric tons of CO₂⁷³ annually; 2) the areal footprint over which the injected CO₂ will migrate; and 3) the need for injected CO₂ to remain in the subsurface hundreds to thousands of years, effectively occupying the subsurface pore space in perpetuity. Because of the potentially large size of geologic sequestration projects—injecting CO₂ could migrate over hundreds to thousands of square kilometers⁷⁴—other economic uses of the subsurface—hydrocarbon production, natural gas storage, fluid waste disposal, groundwater recovery and storage—could coincide with subsurface CO₂ injection.⁷⁵ Throughout the United States, subsurface activities vary extensively, as do the depths at which these industrial and commercial enterprises are carried out and CO₂ sequestration projects have been proposed. State legislatures, particularly in oil and gas producing states, are already attempting to create CCS-specific legislation that best avoids conflict with other economic uses of the subsurface.⁷⁶

⁷³ Corresponds to 1 kg/kWh captured at 60% and 90% capture efficiency, respectively.

⁷⁴ See *infra* Chapter 3, Section 3.3.1.

⁷⁵ See U.S. Dept' of the Interior, Report to Congress: Framework for Geological Carbon Sequestration on Public Land 1 (June 3, 2009) (“[C]arbon sequestration may potentially conflict with other land uses including existing and future mines, oil and gas fields, coal resources, geothermal fields, and drinking water sources.”)

⁷⁶ April Reese, *Climate: States Moving to Clarify Landowners' Rights over CO₂ Storage Space*, Land Letter, Feb. 26, 2009, <http://www.eenews.net> (noting that some states are also attempting to write clauses in CCS legislation that protect existing resources and property interests).

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Subsurface formations with hydrocarbon-bearing strata are typically well-characterized⁷⁷ and are often stacked between non-hydrocarbon-bearing saline aquifers.⁷⁸ Currently, oil and natural gas developers operate wells at average depths of 1,720 and 1750 meters, respectively, which are similar to the depths of proposed CO₂ sequestration projects.⁷⁹ The possibility of developing a CO₂ sequestration site above or below oil or natural gas reservoirs may have the advantage of reducing characterization and capital costs compared to an uncharacterized site, but doing so could also create potential interference between projects.⁸⁰ The potential subsurface impacts of CO₂ injection are varied. In a reservoir with active hydrocarbon resource production, particularly natural gas, migrating CO₂ could commingle directly with the resource and require efforts to remove the CO₂ from the production stream.⁸¹ Soluble CO₂ could cause the precipitation of carbonate minerals and plug flow paths, which would reduce the extraction efficiency for existing hydrocarbon production facilities.⁸² The pressure effects from the injection operation, particularly if multiple sites are used to inject CO₂ into a single basin, could adversely affect other injection operations by potentially altering injectibility, plume size and shape, and associated monitoring.⁸³

Hydrocarbon production also produces large amounts of waste water—an average of seven gallons of water is produced for each gallon of oil. The produced water must be separated

⁷⁷ See, e.g., Christine Doughty & Karsten Pruess, *Modeling Supercritical Carbon Dioxide Injection in Heterogeneous Porous Media*, 3 *Vadose Zone J.* 837 (2004).

⁷⁸ Carl L. Brassow, *Use of Solution—Mined Salt Caverns for the Disposal of Non-Hazardous Oil and Gas Waste* (Nov. 2001).

⁷⁹ U.S. Energy Information Administration, *Average Depths of Crude Oil and Natural Gas Wells*, http://tonto.eia.doe.gov/dnav/pet/pet_crd_welldp_s1_a.htm (accessed July 21, 2010).

⁸⁰ See Sally Benson et al., *supra* note 24, at 210 (stating that the presence of CO₂ in the basin can lead to corrosion problems and can change the composition such that plugging, erosion, and processing problems arise).

⁸¹ See *id.*

⁸² Sally M. Benson & David R. Cole, *CO₂ Sequestration in Deep Sedimentary Formations*, 4 *Elements* 325, 328 (2008); see also Gunter et al., *supra* note 39, at 136-38.

⁸³ Sarah Forbes et al., *World Res. Inst., CCS GUIDELINES 62-63* (2008), http://pdf.wri.org/ccs_guidelines.pdf.

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and disposed of safely, usually by underground injection.⁸⁴ Over 750 billion gallons of oil-produced waters⁸⁵ are injected into the subsurface through 150,000 disposal wells in the United States each year.⁸⁶ This volume of produced water is the rough equivalent of the volume that 2 Gt of CO₂ would occupy at a depth of one kilometer.⁸⁷ The waste water is generally handled on site, with approximately one-quarter of it being injected back into the oil producing formation, in part to increase oil production.⁸⁸ Other operators inject the produced waters into non-producing formations at varying depths where formations of adequate porosity and permeability are present.⁸⁹ Some waste water disposal wells inject below the hydrocarbon formation and other inject above it.⁹⁰ In Texas, produced water is injected into non-producing formations varying in depth from 300 to 3,000 meters, with 60% of these wells a kilometer or more deep.⁹¹ Both the practice and scale of handling produced water is similar to those expected for permanent geologic sequestration of CO₂.⁹²

Underground natural gas storage is another area where use of the subsurface for CO₂ sequestration may require coordination. Gas storage has helped to balance the supply and demand fluctuations of natural gas around the world for nearly 100 years. In many ways, it is

⁸⁴ John Veil et al., Argonne Nat'l Lab., A White Paper Describing Produced Water from Production of Crude Oil, Natural Gas, and Coal Bed Methane 17 (2004), <http://www.ead.anl.gov/pub/doc/ProducedWatersWP0401.pdf>.

⁸⁵ Produced water is the industry term for brine that is extracted as a part of oil or gas production.

⁸⁶ See Benson et al., *supra* note 24, at 212; see also M.G. Puder & J.A. Veil, Argonne Nat'l Lab., Offsite Commercial Disposal of Oil and Gas Exploration and Production Waste: Availability, Options, and Costs 39 (2006), <http://www.evs.anl.gov/pub/doc/ANL-EVS-R-06-5.pdf>.

⁸⁷ See Benson et al., *supra* note 24, at 212.

⁸⁸ See John Veil et al., *supra* note 84, at 49.

⁸⁹ *Id.* at 49-50.

⁹⁰ *Id.* at 34.

⁹¹ Melisa Pollak, *Produced Water Disposal: Comparison to Geological Sequestration of CO₂* 1 n.3 (Jan. 29 2009).

⁹² See Benson et al., *supra* note 24, at 234.

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useful analog for CO₂ sequestration.⁹³ Similar to sequestration, depleted hydrocarbon fields and saline aquifers are commonly used for natural gas storage.⁹⁴ Because injected CO₂ is readily mixed with natural gas, the two substances might commingle, degrading the quality of the natural gas, if natural gas storage and CO₂ sequestration are operated in close proximity within the same geologic formation.⁹⁵ Today, there are roughly 133 natural gas operators storing between 1,200 and 3,300 billion cubic feet (BCF) of natural gas through approximately 300,000 wells in the United States.⁹⁶

In addition, long-standing and new uses of the subsurface for activities wholly unrelated to hydrocarbon production may take place in formations and depths similar to CO₂ sequestration. For example, Environmental Protection Agency (EPA) Underground Injection Control Program (UIC) Class I waste injection well operators inject hazardous and non-hazardous fluid wastes and municipal wastewater below the lowest underground source of drinking water.⁹⁷ These waste injection wells are located in formations where freshwater is protected from the injection zone by an impermeable caprock or confining layer, much like what would be used for CO₂ sequestration. Injection zones typically range from slightly over 500 meters to more than 3,000 meters in depth.⁹⁸ There are roughly 550 Class I wells in the United States, mostly located in the sedimentary basins of the Gulf Coast and Great Lakes

⁹³ *Id.* at 211.

⁹⁴ *Id.*

⁹⁵ Stefan Bachu, *Sequestration of CO₂ in Geologic Media: Criteria and Approach for Site Selection in Response to Climate Change*, 41 *Energy Conversion & Mgmt.* 953, 964 (2000).

⁹⁶ U.S. Energy Information Administration, *Weekly Natural Gas Storage Report*, http://www.eia.doe.gov/oil_gas/natural_gas/ngs/ngs.html (accessed July 21, 2010); William Trapman, U.S. *Weekly Natural Gas Storage Data*, Slide 4 (Sept. 28, 2007), http://www.eia.doe.gov/pub/oil_gas/natural_gas/presentations/2007/ngsdata/ngsdata_files/frame.html.

⁹⁷ John Veil et al., *supra* note 84, at 34.

⁹⁸ *See* U.S. Environmental Protection Agency, *Class I Underground Injection Control Program: Study of Risks Associated with Class I Underground Injection Wells 12* (2001), http://www.epa.gov/safewater/uic/pdfs/study_uic-class1_study_risks_class1.pdf.

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regions.⁹⁹ While approximately 48% of the Class I wells are for non-hazardous wastes, another 30% of the wells are dedicated to municipal wastewater disposal in Florida, where over 3 billion metric tons of wastewater are injected annually.¹⁰⁰

Finally, compressed air energy storage (CAES) and underground aquifer storage and recovery of freshwater (ASR) both have become increasingly attractive uses of the subsurface. CAES could help manage complications imposed by the intermittency of large-scale electricity producing by wind. Electricity produce by wind that would otherwise flow into the electric grid could instead be used compress air that is pumped and stored in deep geologic reservoirs to be used later to make natural gas turbines operate more efficiently.¹⁰¹ A 290 MW CAES plant operating in Germany has been compressing roughly 300,000 cubic meters of air in a natural gas storage reservoir roughly 600 to 800 meters below the surface.¹⁰² A 110 MW CAES plant is also currently operating in the United States in McIntosh, AL.¹⁰³ The Battelle Memorial Institute suggested that future United States compressed air storage projects should be located in formations roughly 650 to 850 meters below the surface and at least 100 meters away from any dissimilar geologic formation.¹⁰⁴

⁹⁹ U.S. Environmental Protection Agency, Industrial & Municipal Waste Disposal Wells (Class I), http://www.epa.gov/safewater/uic/wells_class1.html (accessed July 21, 2010).

¹⁰⁰ *Id.*; see also David W. Keith et al., *Regulating the Underground Injection of CO₂*, Environ. 39 Sci. Technol. 499A, 501A (2005).

¹⁰¹ See Paul Denholm & Ramteen Sioshansi, *The Value of Compressed Air Energy Storage with Wind in Transmission-Constrained Electric Power Systems*, 37 Energy Pol'y 3149, 3149-50 (2009).

¹⁰² See Fritz Crotagino et al., *Huntorf CAES: More than 20 Years of Successful Operation* (Mar. 22, 2009), http://www.google.com/url?sa=t&source=web&cd=1&sqi=2&ved=0CBIQFjAA&url=http%3A%2F%2Fwww.uni-saarland.de%2Ffak7%2Ffze%2FAKE_Archiv%2FAKE2003H%2FAKE2003H_Vortraege%2FAKE2003H03c_Crotagino_ea_HuntorfCAES_CompresedAirEnergyStorage.pdf&ei=bhFHTIjbNsH_lgFA2aGeBQ&usg=AFQjCNFgy21WlCa0la4n59rjCmX2D_yXvg.

¹⁰³ *Id.*

¹⁰⁴ R.D. Allen et al., Battelle Memorial Institute, *Geotechnical Issues and Guidelines for Storage of Compressed Air in Excavated Hard Rock Caverns*, at xiii (1982), <http://www.google.com/url?sa=t&source=web&cd=2&ved=0CBYQFjAB&url=http%3A%2F%2Fwww.osti.go>

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ASR involves injecting water into deep underground reservoirs for later retrieval.¹⁰⁵ A handful of states have mature permitting regimes to facilitate the storage of freshwater underground so that it may be withdrawn during dry periods. ASR is thought to be a promising solution for the future of freshwater management.¹⁰⁶

Thus, there exists the very real potential for GCS operations to interfere with actual or reasonably foreseeable uses of subsurface pore space and. Currently, there is little to no federal or state statutory authority governing subsurface property rights issues in the context of CO₂ sequestration. What is more, many subsurface injection activities discussed in the preceding paragraphs are permitted and regulated by different federal and state agencies. The federal Safe Drinking Water Act (SDWA) gives the EPA authority to manage the UIC program, which regulates underground fluid waste injection activities and enhanced oil recovery, but not natural gas storage.¹⁰⁷ The EPA determined that its authority under the UIC program confers to the Agency the authority to regulate geologic sequestration of CO₂.¹⁰⁸ In July 2008, the EPA released for comment a draft CCS-specific rule under the UIC program.¹⁰⁹ The proposed rule contemplates provisions for on-site characterization, well construction and operation, post-injection monitoring, and post-closure stewardship.¹¹⁰ The

v%2Fbridge%2Fservlets%2Fpurl%2F5437632-pQfu9J%2F5437632.pdf&ei=ihNHTMCnL8P48Ab8rfHzBA&usg=AFQjCNHrgh8_n4Rjt_81XxZZsXEi5tEheQ.

¹⁰⁵ State of Washington Department of Ecology, Aquifer Storage and Recovery, <http://www.ecy.wa.gov/programs/wr/asr/asr-home.html> (accessed July 7, 2010).

¹⁰⁶ Peter J. Kiel & Gregory A. Thomas, *Banking Groundwater in California: Who Owns the Aquifer Storage Space?* 18-Fall, Nat. Res. & Env't 25 (2003).

¹⁰⁷ 40 C.F.R. §§ 144-146 (2008).

¹⁰⁸ See Safe Drinking Water Act, 42 U.S.C. § 300(h)(d) (2006); see also U.S. Environmental Protection Agency, Underground Injection Control Program, http://www.epa.gov/safewater/uic/wells_sequestration.html (accessed July 21, 2020).

¹⁰⁹ Federal Requirements Under the Underground Injection Control (UIC) Program for Carbon Dioxide (CO₂) Geologic Sequestration (GS) Wells, 73 Fed. Reg. 43,492 (proposed July 25, 2008).

¹¹⁰ *Id.*

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EPA stated, however, that the SDWA does not give the agency any authority to address CCS-specific property rights concerns, therefore these issues are not addressed in the new rule.¹¹¹

As noted above, several states have already begun to develop regulatory frameworks to manage geologic sequestration of CO₂, with specific attention directed towards the issue of pore space ownership. As shown in Table 1.1, Wyoming, Montana, and North Dakota passed legislation explicitly defining pore space ownership.¹¹² Wyoming H.B. 89 addressed the issue of property rights by stating that “[t]he ownership of all pore space in all strata below the surface lands and waters of this state is declared to be vested in the several owners of the surface above the strata.”¹¹³ In 2009, the Wyoming governor signed into law H.B. 57, which amends the pore space provision in H.B. 89 and clarifies that the mineral estate is till dominant over the surface estate.¹¹⁴ That same year, North Dakota S.B. 2139 similarly proclaimed that “[t]itle to pore space in all strata underlying the surface lands and waters vested in the owner of the overlying surface estate.”¹¹⁵ North Dakota’s bill further attaches pore space rights to the surface estate by prohibiting severance of pore space from the title to the overlying surface property.¹¹⁶ Montana S.B. 498 creates a presumption that the surface owner owns subsurface pore space if deeds or other severance documents do not demonstrate otherwise.¹¹⁷ Like Wyoming and North Dakota, Montana’s new statute explicitly does not

¹¹¹ *Id.*

¹¹² *See* S.B. 498, 61st Leg., Reg. Sess. (Mont. 2009) (codified at MONT. CODE ANN. § 82-11-180 (2009)); S.B. 2319, 61st Leg. Assem., Reg. Sess. (N.D. 2009) (codified at N.D. CENT. CODE § 47-31-01-08 (2006 & Supp. 2009)); H.B. 89, 59th Leg., Budget Sess. (Wyo. 2008) (codified at WYO. STAT. ANN. § 34-1-152 (2009)).

¹¹³ Wyo. H.B. 89 (codified at WYO. STAT. ANN. § 34-1-452(a); H.R. 57, 60th Leg., Gen. Sess. (Wyo. 2009).

¹¹⁴ WYO. STAT. ANN. § 34-1-452(a); H.R. 57, 60th Leg., Gen. Sess. (Wyo. 2009).

¹¹⁵ N.D. S.B. 2319 (codified at N.D. CENT. CODE § 47-31-04).

¹¹⁶ *Id.* (codified at N.D. CENT. CODE 47-31-05,-06 (2009)).

¹¹⁷ S.B. 498, 61st Leg., Reg. Sess. (Mont. 2009) (enacted at MONT. CODE ANN. § 82-11-180 (1009)).

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interfere with common law or the dominance of the mineral estate. West Virginia's new legislation creates a working group that will make recommendations to the legislature on pore space ownership by 2011.¹¹⁸

This assignment of subsurface pore space rights in Wyoming, Montana, and North Dakota has the potential to create a direct conflict between state subsurface property rights and any future state or federal efforts to facilitate the commercial-scale development of geologic sequestration of CO₂. The number of states moving to adopt similar legislation has recently increased considerably as legislators anticipate future greenhouse gas limits and try to settle potential property rights disputes to create a more stable and predictable environment for future geologic sequestration project development. The nature of subsurface property rights in general and the potential legal conflicts that arise from the intersection between state-created property rights and the ability of geologic CO₂ sequestration developers and operators to access and use pore space are addressed in Chapter 2.

¹¹⁸ H.B. 2860, 79th Leg., 1st Sess. (W. Va. 2009) (enacted in pertinent part at W. VA. CODE 22-11A-6 (2009)).

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Table 1.1: Existing state CCS legislation regarding subsurface property rights.¹¹⁹

	REGULATORY AUTHORITY	PORE SPACE OWNERSHIP	EMINENT DOMAIN	UNITIZATION	MINERAL RIGHTS DOMINANCE
LOUISIANA H.B. 1117 (2008); H.B. 1220 (2008); H.B. 661 (2009)	Office of Conservation, Department of Natural Resources	NA	CO ₂ sequestration declared to be in the public interest; public and private entities may exercise eminent domain subject to certain conditions	NA	NA
MONTANA S.B. 498 (2008)	Board of Oil and Gas Conservation, with comments from the Board of Environmental Review	Surface owner (severance allowed)	NA	Owners of 60 % or more of the pore space may apply to the Board of Oil and Gas Conservation to have the area treated as a unit	Common law and mineral estate dominance not altered by CCS legislation
NORTH DAKOTA S.B. 2095 (2009); S.B. 2139 (2009); N.D. Admin. Code 42-02-04.1 (proposed)	Industrial Commission	Surface owner (severance not allowed)	CO ₂ sequestration declared to be in the public interest	Owners of 60% or more of the pore space owners must consent	Common law and mineral estate dominance not altered by CCS legislation
OKLAHOMA S.B. 610 (2009); S.B. 1765 (2008)	Corporation Commission (for fossil fuel-bearing formation); Department of Environmental Quality for all other formations	NA	CO ₂ sequestration declared to be in the public interest	Corporation Commission will be the regulatory authority if a unitization process is adopted	Common law and mineral estate dominance not altered by CCS legislation
WEST VIRGINIA H.B. 2860 (2009)	Department of Environmental Protection	CO ₂ Sequestration Working Group to make recommendations in 2011	NA	NA	Common law and mineral estate dominance not altered by CCS legislation
WYOMING H.B. 89 (2008); H.B. 57 (2009); H.B. 58 (2009); H.B. 80 (2009); Water Qual. Rules & Regs. Chap. 24 (proposed)	Department of Environmental Quality	Surface owner (severance allowed)		Any interested person may apply to treat project area as a unit; Oil and Gas Conservation Commission may approve if owners of at least 80% of pore space owners consent	Affirms dominance of the mineral estate

¹¹⁹ Adapted from Klass & Wilson, *supra* note 63, at 383-84; Melisa Pollak & Elizabeth J. Wilson, *Regulating Geologic Sequestration in the United States: Early Rules Take Divergent Approaches*, 43 *Envtl. Sci. & Tech.* 3035, 3036-38 (2009).

Chapter 2: Does the Use of Subsurface Pore Space for Geologic CO₂

Sequestration of Require Compensation Under the Law?

Who, if anyone, currently owns the subsurface pore space to be used for geologic CO₂ sequestration? If rights to the pore are vested in either surface owners or mineral owners, can the government designate geologic CO₂ sequestration a “public use” and exercise the power of eminent domain under the Fifth Amendment to the United States Constitution in order to appropriate pore space for GCS? Can the government authorize the use of pore space for geologic CO₂ sequestration while at the same time establishing that just compensation is nominal or even zero? If the government restricts the use of private property to protect the integrity of geologic CO₂ sequestration sites, does that restriction constitute a regulatory taking, thus entitling the property owner to just compensation? If compensation is required, what metrics and methods should be used to determine pore space value? This chapter explores these questions in great detail in order to determine the extent to which surface owners and mineral owners have established and protectable property rights in subsurface pore space in the context of geologic CO₂ sequestration.

2.1 Who Owns the Pore Space?

The ever-increasing interest in developing commercial-scale geologic CO₂ sequestration has sparked an intense debate about the nature of pore space ownership. In fact, the commercial viability of CO₂ sequestration may, in large part, depend on how property rights issues are resolved.¹²⁰ Prior to injecting CO₂ into the subsurface for permanent geologic sequestration, the injector must either own the pore space, have permission from the owner, or have

¹²⁰ Owen. L. Anderson, Geologic CO₂ sequestration: *Who owns the pore space?* 9 Wyo. L. Rev. 97, 98 (2009).

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statutory or common law authorization to use the pore space. Today's reality is that there exists no uniformity in the way which the right to inject fluids of any kind into deep subsurface pore space is acquired or authorized. This lack of uniformity is largely predicated upon determining who owns the subsurface pore space hundreds or thousands of feet below the surface. Under the common law maxim *cujus est solum, ejus est usque ad coelum et ad inferos* (commonly known as the “*ad coelum doctrine*”),¹²¹ a fee simple¹²² owner of land holds title to the entire tract from the heavens to the depths of the earth. Under this maxim, a fee simple owner would own the subsurface pore space. The question of pore space ownership arises when the fee simple interest is severed into a surface estate and one or more separate mineral interests. As between the surface owner and mineral owner, few states have statutorily or judicially determined who owns the pore space. To date, only a handful of cases across the country have addressed this issue, with the majority holding (given the specific facts before the court) that the surface owner owns the pore space.¹²³ In many states, though,

¹²¹ 1 COKE, INSTITUTES, ch. 1, § 1(4a) (19th ed. 1832); 2 BLACKSTONE, COMMENTARIES 18 (Lewis ed. 1902); 3 KENT, COMMENTARIES 621 (Gould ed. 1896)).

¹²² Means the mineral and surface interests are held by a single owner. *See* Garner, B.A., BLACKS LAW DICTIONARY, 8th ed. 2004, St. Paul, MN: Thomson West.

¹²³ *Sunray Oil v. Cortez Oil Co.*, 112 P.2d 792 (Okla. 1941) (surface owner has the right to grant permission to inject wastewater into the subsurface as long as there is not interference with the mineral estate's recovery of oil and gas); *Central Kentucky Natural Gas Co. v. Smallwood*, 252 S.W.2d 866 (Ky. Ct. App. 1952) (the mineral owner has the authority to grant a gas storage lease); *Tate v. United Fuel Gas Co.*, 71 S.E.2d 65 (W. Va. 1952) (based on exception language in the deed, the oil and gas owner did not own “clay, sand, or stone,” and thus did not own the spaces in the storage formation, which were devoid of recoverable gas); *Emeny v. United States*, 412 F.2d 1319, 1324 (Ct. Cl. 1969) (ownership of “all gas in or under, or which may hereafter be found in or under and produced from the lands” did not include the right to store helium produced from other lands; such right remained with the non-mineral owner.); *Miles v. Home Gas Co.*, 316 N.Y. Supp. 2d 908 (N.Y. Sup. Ct. App. Div. 1970) (surface owner); *Humble Oil & Refining Co. v. West*, 508 S.W.2d 812, 815 (Tex. 1974) (surface owner, citing *Emeny v. United States*); *Ellis v. Arkansas Louisiana Gas Co.*, 450 F. Supp. 412 (E.D. Okla. 1978) (storage company must obtain permission from the surface owner to store natural gas); *United States v. 43.42 Acres of Land*, 520 F. Supp. 1042, 1043, 1046 (W.D. La. 1981) (stated “the mineral owner cannot be considered to have ownership of the subsurface strata containing the spaces where the minerals are found.”); *Rook v. James E. Russell Petroleum, Inc.*, 679 P.2d 158, 166-67 (Kan. 1984) (although Kansas has not directly addressed pore space ownership, such rights are considered severable from the right to produce oil and gas); *Miss. River Transmission Corp. v. Tabor*, 757 F.2d 662, 672 (5th Cir. 1985) (surface owner owns storage rights); *Grynberg v. City of Northglenn*, 739 P.2d 230 (Colo. 1987) (mineral owner); *Int'l Salt Co. v. Geostow*, 697 F. Supp. 1258 (W.D.N.Y. 1988) (mineral owner); *Mapco, Inc. v. Carter*, 808 S.W.2d 262 (Tex. App. 1991)

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this question would be one of first impression. This is somewhat surprising given that judiciaries in the United States have a long history of resolving subsurface property disputes that involved the unauthorized use of pore space resulting from the migration of injected fluids or stored natural gas.

In most countries of the European Union and their former colonies, all mineral rights are owned by the federal governments (or “crown”). In the United States, subsurface rights are largely held by private hands. Historically, property rights are defined by state law rather than federal law. In the United States, property ownership in its modern form is derived from English common law, and can be traced all the way back to Lord Halsbury, Lord Chancellor of England (1895-1905). Halsbury’s Laws of England asserts that “the ownership of land may be divided horizontally, vertically or otherwise either above or below the ground. Thus, separate ownership may exist in strata of minerals, in the space occupied by a tunnel, or in different stories of a building.” Common law property rights are generally viewed as a bundle of rights that together define how ownership of various resources are divided, and establish limitations on the use of each by the owner. A typical bundle of rights might be: 1) surface rights; 2) rights to coal; 3) rights to natural gas; 3) rights to oil; 5) rights to minerals other than coal, oil, and natural gas (sometimes referred to as residual mineral ownership); 6) rights to groundwater; 7) rights to storage (e.g., natural gas and freshwater).

(mineral owner); *Chance v. BP Chemicals, Inc.*, 670 N.E.2d 985 (Ohio 1996) (the court found that “ownership rights in today’s world are not as clear-cut as they were before the advent of airplanes and injections wells”); *Dep’t of Transp. v. Goike*, 560 N.W.2d 365, 365 (W.D. Mich. 2006) (court held that “the storage space, once it has been evacuated of the minerals and gas, belongs to the surface owner). *See also* Alan Stamm, *Legal Problems in the Underground Storage of Natural Gas*, 36 Tex. L. Rev. 161, 164-69 (1957); Roger R. Scott, *Underground Storage of Natural Gas: A Study of Legal Problems*, 19 Okla. L. Rev. 47, 56-63 (1966); Fred McGaha, *Underground Gas Storage: Opposing Rights and Interests*, 46 La. L. Rev. 871 (1986); Elizabeth J. Wilson & Mark A. de Figueiredo, *Geologic Carbon Dioxide Sequestration: An Analysis of Subsurface Property Law*, 36 ELR 10114, 10121-22 (2006); Anderson, *supra* note 1, at 99-109; Alexandra B. Klass & Elizabeth J. Wilson, *Climate Change, Carbon Sequestration, and Property Rights*, 2010 U. Ill. L. Rev. 363, 384-93 (2010).

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The lack of certainty regarding pore space ownership has led to the rational, yet inefficient, conclusion that the cautious approach for GCS project developers would be to obtain permission to use subsurface pore space from both surface owners and mineral owners.¹²⁴ In spite of this conclusion, it will most likely be the surface owner who holds title to pore space in the majority of circumstances.¹²⁵ Three Western states—Montana, North Dakota, and Wyoming—have already passed legislation declaring that subsurface pore space ownership is vested in the surface owner.¹²⁶ The emerging opinion that pore space rights generally belong to the surface owner is not founded on the idea that surface rights and pore space rights are inextricably bound together.¹²⁷ Instead, the opinion is based on the recognition that, as a historical matter: 1) fee simple estates tend to retain surface rights when carving out property interests to transfer to others, and 2) pore space rights are not specifically included in transfer instruments.¹²⁸ Thus, American jurisdictions, grounded in English Common Law, will most likely find that pore space is owned by surface owners.

¹²⁴ Owen L. Anderson, *supra note 1*, at 99.

¹²⁵ Recent white papers and law review articles have analyzed whether, in the first instance, the surface owner or the mineral owner on split-estate land has property rights in the pore space. While most of these papers and articles conclude that the surface owner would prevail over the mineral owner in most cases, the issue is far from resolved. See David Cooney, ANALYSIS OF PROPERTY RIGHTS ISSUES RELATED TO UNDERGROUND STORAGE SPACE USED FOR GEOLOGIC SEQUESTRATION OF CARBON DIOXIDE, IOGCC Task Force on Carbon Capture and Geologic Storage, Subgroup of State Oil and Gas Attorneys (2005); Wilson & de Figueiredo, *supra note 4*, at 10121-22 (stating that most courts have held that after the removal of underground minerals, oil, or gas, the surface owner retains the right to use the remaining space for storage but that mineral rights holders often retain some rights to access the pore space for continued exploration or extraction of minerals in other areas); Anderson, *supra note 1*, at 99-109 (stating that Texas and other jurisdictions have not specifically determined who owns subterranean pore space as between a mineral owner and a surface owner but, based on existing case law and legal doctrine, the most “likely” owner of the pore space is the surface owner); Klass & Wilson, *supra note 4*, at 384-93 (stating “there are protectable property interests in pore space that are vested in the surface owner, the mineral owner, or both”).

¹²⁶ See S.B. 498, 61st Leg., Reg. Sess. (Mont. 2009) (codified at MONT. CODE ANN. § 82-11-180 (2009)); S.B. 2319, 61st Leg. Assem., Reg. Sess. (N.D. 2009) (codified at N.D. CENT. CODE § 47-31-01-08 (2006 & Supp. 2009)); H.B. 89, 59th Leg., Budget Sess. (Wyo. 2008) (codified at WYO. STAT. ANN. § 34-1-152 (2009)).

¹²⁷ See Mark A. de Figueiredo, THE LIABILITY OF CARBON DIOXIDE STORAGE, Ph.D. Thesis, MIT Engineering Systems Division (2007); Wilson & de Figueiredo, *supra note 4*, at 10114.

¹²⁸ See Anderson, *supra note 1*, at 99-109; Ian Duncan, Scott Anderson, and Jean-Philippe Nicot, *Pore Space Ownership Issues for CO₂ Sequestration*, in the U.S. 1 Energy Procedia 4427, 4430 (2009).

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To support the conclusion that the most likely owner of pore space in Texas is the surface owner, Owen Anderson proffered a set of principals, which are I submit are generally applicable to all jurisdictions in the United States.¹²⁹ First, when a fee simple owner transfers the mineral estate or transfers the surface estate, reserving the minerals, two separate or several estates in land are created.¹³⁰ Accordingly, if A, the fee simple owner of Blackacre, conveys the “oil, gas, and other minerals” to B, A would retain as a part of the “surface estate” everything not granted by the severance deed—that is, everything but any oil, gas, and minerals. Likewise, if A conveyed Blackacre to B, reserving “oil, gas, and other minerals,” B would receive everything not reserved by A (i.e., the “surface estate”)—that is, everything but any oil, gas, and minerals not subsisting in Blackacre. Therefore, in either case, the owner of the surface estate would own the pore space. Anderson notes that a deed or reservation could expressly address ownership of pore space, but typically does not.¹³¹

Second, a property right not expressly conveyed is retained, or conversely, a property right not expressly reserved is conveyed.¹³² That is to say, owners of fee simple estates have historically been viewed to own everything on, above, or below the surface except to the extent particular rights have been granted to others. This is because owners tend to retain ownership of the surface with transferring property interests out of the fee to others.

Moreover, legal instruments used to transfer a portion of a fee owner’s property rights to others typically are very narrowly drafted; courts interpret these instruments as transferring

¹²⁹ Anderson, *supra* note 1, at 99-109.

¹³⁰ *Humphreys-Mexia Co. v. Gammon*, 154 S.W. 296, 299 (Tex. 923).

¹³¹ The granting clause of an oil or gas lease frequently conveys the right to store hydrocarbons. *See e.g., Ryan Consol. Petroleum Corp. v. Pickens*, 285 S.W.2d 201, 203 (Tex. 1955). However, the right to store oil or gas does not specifically address ownership of the pore space.

¹³² *Duhig v. Peavy-Moore Lumber Co.*, 144 S.W.2d 878, 880 (1940).

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only what is specifically mentioned together with whatever other rights are necessarily associated with the rights explicitly conveyed. For example, legal instruments conveying mineral interests typically use narrow and specific language such as “oil, gas, and other minerals” rather than broad language that would sever everything in the fee estate below the surface of the land and transfer it to a new owner. In Texas, an oil and gas lease is not a “lease,” but a conveyance of any oil and gas in place for the duration of the lease—typically a fee simple determinable.^{133, 134} Because a lease conveys a fee simple determinable, this same reasoning should also apply to the severance of minerals by a mineral deed or to a reservation of minerals in a deed that conveys the surface. Thus, while a mineral deed may expressly convey, and a reservation may expressly reserve, underground disposal and storage rights, such rights are not conveyed or reserved by implication. Accordingly, in a typical mineral deed, title to pore space is not conveyed by implication. Likewise, in a typical reservation of minerals, title to pore spaces is not reserved by implication.

Lastly, in common law, the mineral estate is dominant over the surface estate. In this context, “dominant” means that the mineral owner has the right to use as much of the airspace, surface, and subsurface as is reasonably necessary to explore for and exploit the minerals belonging to the mineral owner,¹³⁵ subject to the “accommodation doctrine.” The accommodation doctrine requires the mineral owner to accommodate the surface owner’s reasonable existing uses to the extent practicable while still being able to explore for and

¹³³ See *Cherokee Water Co. v. Forderhause*, 641 S.W.2d 522, 525 (Tex. 1982); *Stephens County v. Mid-Kansas Oil & Gas Co.*, 290, 292 (Tex. 1923).

¹³⁴ Means an estate that will automatically end and revert to the grantor if some specified event occurs. See Garner, *supra* note 122.

¹³⁵ *Getty Oil v. Jones*, 470 S.W.2d 618, 621 (Tex. 1971). See also *Ball v. Dillard*, 602 S.W.2d 521, 523 (Tex. 1980); *Humble*, 420 S.W.2d 133 (Tex. 1967) (discussing excessive use).

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produce minerals.¹³⁶ The doctrine also requires surface owners to reasonably accommodate exploration and production of minerals.¹³⁷ Thus, even though the surface owner may own the pore space, the mineral owner has broad rights to drill through or otherwise use them to facilitate mineral exploration and production. This right of use includes the right to inject substances such as CO₂ for the purpose of enhanced oil recovery. Anderson posits that the fact CO₂ injection might also result in the permanent sequestration of CO₂ should not alter the right of the mineral estate owner to engage in CO₂ injection for enhanced oil recovery.¹³⁸ Assuming this supposition holds true, the mineral owner's right to inject CO₂ for enhanced oil recovery, including the additional goal of permanent sequestration, falls within the mineral owner's right of reasonable use even though ownership of the pore space lies with the surface owner.

One might query how an understanding of mineral estate "dominance" helps to quiet the issue of pore space ownership? As Anderson explains, Texas courts categorize the mineral owner's right to use the surface, subsurface, and airspace to capture oil and gas owned by the mineral owner in fee simple determinable.¹³⁹ For example, in *Getty Oil Co. v. Jones*, the court ruled: "We now hold explicitly that the reasonably necessary limitation extends to the superadjacent airspace as well as to the lateral surface and subsurface of the land."¹⁴⁰ This holding indirectly recognizes the surface owner's title to the subsurface because the court

¹³⁶ *Getty Oil*, 470 S.W.2d at 621-22; *Sun Oil v. Whitaker*, 483 S.W.2d 808, 810-11 (Tex. 1972).

¹³⁷ *Moser v. U.S. Steel Corp.*, 676 S.W.2d 99, 103 (Tex. 1984).

¹³⁸ Anderson, *supra note 1*, at 101.

¹³⁹ *Id.* at 103.

¹⁴⁰ *Getty*, 470 S.W.2d at 621.

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expressly references the subsurface in the context of discussing the rights of the mineral owner to use that which belongs to the surface owner.¹⁴¹

To further complicate the matter, judicial resolution of pore space ownership could lead to different outcomes within same jurisdiction. Two Texas natural gas storage cases illustrate how different courts reached seemingly conflicting conclusions even though Texas law was applied in both situations. A close examination of these two cases reveals, however, that the holdings are not a result of disparate interpretations of Texas law, but instead direct products of the specific and unique facts of each case. In *Emeny v. United States*, a federal Court of Claims ruled in favor of the surface owner's title to storage rights.¹⁴² In this case, fee simple owners leased tracts "for the sole and only purpose of mining and operating for oil and gas and of laying pipelines...to produce, save, and take care of said products."¹⁴³ The lessees developed a stratum called the Bush Dome for natural gas. The gas contained small amounts of helium. Due to the strategic nature of helium, the United States acquired the leases by purchase or condemnation and later brought in helium-gas mixtures for storage in spaces in the Bush Dome, where some native gas had already been extracted.¹⁴⁴ The court concluded:

The surface of the leased lands and everything in such lands, except the oil and gas deposits covered by the leases, were still the property of the respective landowners... This included the geological structures beneath the surface, including any such structure that

¹⁴¹ *Id.* at 621 (Tex. 1971).

¹⁴² *Emeny*, 412 F.2d 1319.

¹⁴³ *Id.* at 1323.

¹⁴⁴ *Id.*

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might be suitable for the underground storage of
'foreign' or 'extraneous' gas produced elsewhere.¹⁴⁵

In contrast to *Emeny*, in *Mapco, Inc. v. Carter*, the Texas Appellate Court held that storage rights were vested in the mineral owners.¹⁴⁶ In *Mapco*, owners of certain fractional mineral interests brought a partition action against the surface owner, who also owned a fractional mineral interest and was storing gas underground.¹⁴⁷ The storage reservoir was created by partially leaching salt from a salt dome.¹⁴⁸ Salt is recognized as a mineral in Texas.¹⁴⁹ In awarding owelty damages to the mineral owner, the court reasoned:

Texas adopted the view that interest in minerals, such as oil, gas, salt and other minerals are susceptible of ownership in place in the ground prior to production of the minerals at or on the surface. The Texas rule is that this interest in minerals is an interest in real property. Thus, the fee mineral owners retain a property ownership, right and interest after the underground storage facility—here, a cavern—had been created. These same fee mineral owners are vested with ownership rights, including, of course, entitlement to compensation for the use of the cavern...¹⁵⁰

Thus, the *Mapco* court concluded that, because the mineral owner had title to the salt, the mineral owner also had title to the salt cavern. However, because the salt cavern was not a

¹⁴⁵ *Id.*

¹⁴⁶ *Mapco*, 808 S.W.2d 262.

¹⁴⁷ *Id.* at 264-65 (Tex. App. 1991).

¹⁴⁸ *Id.* at 274.

¹⁴⁹ *Id.* (citing *State v. Parker*, 61 Tex. 265, 268 (1884)).

¹⁵⁰ *Id.* at 274-75.

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naturally occurring storage space, but rather an excavated cavern with walls containing the very same mineral that had been partially extracted, *Mapco* arguably only applies when storage space is created by excavating a mineral-bearing strata. Still, had another jurisdiction been presented with the facts in *Mapco*, the outcome of the case could have been quite different. For example, the United States Court of Appeals for the Second Circuit, applying New York law, construed a conveyance of salt “mine” to mean that the grantee (i.e., the mine operator) of the mine held fee title to the salt and not the excavated cavern.¹⁵¹ In this case, *International Salt Co. v. Geostow*, the court concluded that the grantee retained the exclusive right to use cavern so long as salt was not exhausted and mining operations were not abandoned.¹⁵² While the issue of storage rights did not arise in *Geostow*, the case addressed the salt miner’s rights to use the mined caverns to transport salt from parts of the mine that were beneath other lands.

2.2 Delineating Established and Protectable Property Interests in the Airspace, Surface, and Subsurface

The Takings Clause of the Fifth Amendment to the U.S. Constitution instructs that private property shall not “be taken for public use, without just compensation.”¹⁵³ The Constitution does not create or define the scope of property interests that are protectable under the Fifth Amendment, but instead requires compensation in the event that an impairment of those property interests amounts to a taking.¹⁵⁴ To determine whether a protectable property interest exists, judiciaries look to “existing rules or understandings” and “background

¹⁵¹ *Int’l Salt Co.*, 878 F.2d at 574.

¹⁵² *Id.* at 575.

¹⁵³ U.S. CONST. amend. V.

¹⁵⁴ *Philips v. Wash. Legal Found.*, 524 U.S. 156, 164 (1998) (“[T]he Constitution protects rather than creates property interests...”).

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principles” derived from sources such as Federal and state common law.¹⁵⁵ Even though property rights typically fall under the purview of state law, state-created property rights may be limited by federal law.¹⁵⁶ The Supreme Court of the United States explained that the Takings Clause “was designed to bar Government from forcing some people alone to bear public burdens which, in all fairness and justice, should be borne by the public as a whole.”¹⁵⁷

However, courts by and large have rejected the notion that surface and mineral estate owners are entitled to an absolute protection of subsurface property rights that would allow them to enjoin uses of pore space which are deemed to be in the public interest. As Klass and Wilson note, “[W]hile the courts have regularly found that government-authorized physical use or invasion of private surface lands constitutes a *per se* taking, the courts have just as often taken a more nuanced approach to private property rights in both the airspace above and the subsurface below private lands.”¹⁵⁸ A review of Fifth Amendment takings law in addition to the existing case law involving property rights in air space, the surface, and the subsurface reveals that there is sufficient precedent available to reach at least two legal conclusions: one in favor of strong protection of property interests in the subsurface; another identifying limited or nonexistent protection of property interests in the subsurface.¹⁵⁹

¹⁵⁵ See *Lucas v. S.C. Coastal Council*, 505 U.S. 1003, 1030 (1992); *Klamath Irrigation Dist. v. United States*, 67 Fed. Cl. 504, 515 (Fed. Cl. 2005).

¹⁵⁶ *Lucas*, 505 U.S. at 1032 (stating that state law definitions of private property rights must be based on “an objectively reasonable application of relevant precedents” (emphasis omitted)); *Klamath Irrigation*, 67 Fed. Cl. at 515 n.15 (stating an objective basis in defining property rights is “vital if the integrity of the Takings Clause is to be preserved as against entirely novel and unprincipled definitions of property designed artificially to defeat or buttress a taking claim”) (citing *Webb’s Fabulous Pharmacies, Inc v. Beckwith*, 449 U.S. 155, 164 (1980)).

¹⁵⁷ *Armstrong v. United States*, 364 U.S. 40, 49 (1960).

¹⁵⁸ Klass & Wilson, *supra* note 4, at 365.

¹⁵⁹ *Id.* at 366.

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If a government action is challenged as having impaired an established property interest, a court must decide whether to analyze the action as a physical taking or as a regulatory taking.¹⁶⁰ A physical taking occurs when the government engages in, or authorizes a third party to engage in, a permanent physical occupation of private property.¹⁶¹ In the case of physical invasions, “no matter how minute the intrusion, and no matter how weighty the public purpose behind it,” a taking has occurred and just compensation is required.¹⁶² Even when there is no physical occupation of private property, a regulatory taking can occur if government regulation places too great a burden on the owner’s use of the property.¹⁶³ A regulatory taking can take place under two circumstances.¹⁶⁴ First, a regulatory action can be what is known as a *per se* taking when the regulation completely deprives a property owner of *all* economically beneficial use of his/her property.¹⁶⁵ Second, in the absence of a complete deprivation of all economic use of property, courts will consider whether the regulatory restriction rises to the level of a compensable taking under the multifactor balancing test prescribed in *Penn Central Transportation Co. v. New York City*.¹⁶⁶ The *Penn Central* balancing test, as it is commonly known, considers: 1) the character of the government action; 2) the severity of the economic impact; and 3) the extent to which the

¹⁶⁰ *Lingle v. Chevron U.S.A. Inc.*, 544 U.S. 528, 538 (2005).

¹⁶¹ *Chevron*, 544 U.S. at 538; *Loretto v. Teleprompter Manhattan CATV Corp.*, 458 U.S. 419, 426 (1982) (holding that state regulation requiring landlords to allow television cable companies to place cable facilities in their apartment buildings constituted a taking even though the facilities occupied at most only one and one-half cubic feet of the landlord’s property).

¹⁶² *Loretto*, 458 U.S. at 426; *Lucas*, 505 U.S. at 1015. *See also Brown v. Legal Found. of Wash.*, 538 U.S. 216, 233-34 (2003).

¹⁶³ *See Tahoe-Sierra Pres. Council, Inc. v. Tahoe Reg’l Planning Agency*, 535 U.S. 302, 326 (2002).

¹⁶⁴ *Chevron*, 544 U.S. at 538.

¹⁶⁵ *Lucas*, 505 U.S. at 1029 (holding that regulations which prohibit all economically beneficial use of land are just as much a taking requiring compensation as permanent physical occupations of land).

¹⁶⁶ *Penn Central Transportation Co. v. New York City*, 438 U.S. 104 (1978).

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regulation interferes with the property owner's distinct, "investment-backed" expectations.¹⁶⁷ However, even if a government action constitutes a physical taking or regulatory taking, a violation of the Fifth Amendment only occurs if the taking is without "just compensation."¹⁶⁸ Consequently, if a court concludes that the monetary value of property owner's net loss as a result of the taking is zero, the compensation due under the Constitution is also zero.¹⁶⁹

2.3 Airspace Rights & Subsurface Rights: Evolution of the *Ad Coelum* Doctrine

In the context of CO₂ sequestration, the threshold question is therefore whether a surface owner or mineral owner has sufficient interests in subsurface pore space to implicate the Takings Clause of the Fifth Amendment to the Constitution. There is little dispute that, subject to reasonable regulation, the property owners have significant rights to use their property as they see fit. Just as importantly, property owners have the right to exclude others from making use of their property without consent. If the federal or state governments wish to confiscate private property, condemn private property, or authorize third parties to confiscate or condemn private property for a public purpose, the government may do so through the exercise of eminent domain authority. Eminent domain authority is conditional, however, and requires that "just compensation" be paid to the property owner.

The questions of how far up into the sky and down into the earth do property rights extend and to what extent these rights are protected are also encountered. As noted above, the *ad coelum* doctrine instructs that the rights of the surface owner extend up to the heavens (*ad coelum*) and down to the center of the earth (*ad infernos*). However, ever since to the advent

¹⁶⁷ *Id.* at 124.

¹⁶⁸ *See Brown v. Legal Found. of Wash.*, 538 U.S. 216, 235 (2003).

¹⁶⁹ *Id.* at 237.

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of air travel in the early part of the 20th century, the doctrine no longer applies in absolute terms to ownership of airspace high above the ground. Courts continued to advance the expansive view of airspace rights invoked in the *ad coelum* doctrine until the invention of the airplane sparked litigation in the 1930s.¹⁷⁰ In general, the use of airspace by airplanes is not compensable unless a landowner suffers actual damages.¹⁷¹ In *Hinman v. Pacific Air Lines Transport Corp.*,¹⁷² the United States Court of Appeals for the Ninth Circuit observed that the *ad coelum* doctrine was “invented at some remote time in the past when the use of space above land actual or conceivable was confined to narrow limits, and simply meant that the owner of the land could use the overlying space to such an extent as he was able, and that no one could ever interfere with that use.”¹⁷³ The court further observed that the doctrine was “never taken literally, but was a figurative phrase used to express the full and complete ownership of land and the right to whatever superadjacent airspace was necessary or convenient to the enjoyment of the land... Title to the airspace unconnected with the use of land is inconceivable.”¹⁷⁴ The court then reasoned that any use of airspace that actually damages the land or interferes with the possession or beneficial use of the land would be a trespass, but that “any claim of the landowner beyond this cannot find precedent in law nor support in reason.”¹⁷⁵ The court also reasoned that a stricter rule would mean that “any use of airspace...without [landowner] consent would be a trespass either by the operator of an airplane... We will not foist any such chimerical concept of property rights upon the

¹⁷⁰ See John G. Sprankling, *Owning the Center of the Earth*, 55 UCLA L. Rev 979, 1000 (2008).

¹⁷¹ See, e.g., *Hinman v. Pac. Air Lines Transp. Corp.*, 84 F.2d 755, 158-59 (9th Cir. 1936) (holding that the use of airspace is not unlawful without proof of actual injury); *United States v. Causby*, 328 U.S. 256 (1946) (recognizing that airplanes may freely navigate airspace unless the flights are so low and constant as to make it impossible for the true owner to fully enjoy and use the surface estate).

¹⁷² *Hinman v. Pac. Air Lines Transp. Corp.*, 84 F.2d 755 (9th Cir. 1936).

¹⁷³ *Id.* at 757.

¹⁷⁴ *Id.* (responding to plaintiffs’ argument that they were entitled to absolute title to all airspace to such height as may become useful).

¹⁷⁵ *Id.* at 758.

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jurisprudence of this country.”¹⁷⁶ The court concluded that “traversing the airspace above appellants’ land is not, of itself, a trespass at all, but is a lawful act unless it is done under circumstances which will cause injury to appellants’ possession.”¹⁷⁷ The court then held that the plaintiffs “do not, therefore, in their bill state a case of trespass unless they allege a case of actual and substantial damages.”¹⁷⁸ Because the plaintiffs did not show actual damages, the court denied both money damages and injunctive relief.¹⁷⁹

The opinion that ownership of airspace rights “extended to the periphery of the universe” was laid to rest at the national level by the Supreme Court in 1946 in the case of *United States v. Causby*.¹⁸⁰ In *Causby*, the court concluded that the United States, by conducting nearly continuous, low-level flights of its military planes over a commercial chicken farm made the property unusable for that purpose.¹⁸¹ As such, these low-level flights amounted to a taking of an air easement for which compensation had to be paid to the farmer.¹⁸² Even though there was no actual physical invasion of the property, the court ruled that the low-level flying was “and intrusion so immediate and direct” as to deprive the farmer of his use and enjoyment of the property, and dispossess him of his ability to continue to use the property as a commercial chicken farm.¹⁸³

¹⁷⁶ *Id.*

¹⁷⁷ *Id.* at 758-59.

¹⁷⁸ *Id.* at, 759.

¹⁷⁹ *Id.*

¹⁸⁰ *Causby*, 328 U.S. at 256, 260-61 (“It is ancient doctrine that a common law ownership of the land extended to the periphery of the universe—Cujus est solum est usque ad coelum.” (citing 1 COKE, INSTITUTES, ch. 1, § 1(4a) (19th ed. 1832); 2 BLACKSTONE, COMMENTARIES 18 (Lewis ed. 1902); 3 KENT, COMMENTARIES 621 (Gould ed. 1896))).

¹⁸¹ *Causby*, 328 U.S. at 259.

¹⁸² *Id.*

¹⁸³ *Id.* at 265.

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The court distinguished a landowner's protectable property interest immediately above the surface of his or her land from the "public highway" in the higher regions of airspace.¹⁸⁴ The court recognized that to have full use and enjoyment of one's land, a landowner "must have exclusive control of the immediate reaches of the enveloping atmosphere," lest the construction of buildings or planting of trees be precluded.¹⁸⁵ Therefore, a surface owner owns at least as much airspace above the ground as s/he "can occupy or use in connection with the land."¹⁸⁶ Furthermore, intrusion into that airspace by an airplane or structure, even if it does not touch the ground, "is as much an appropriation of the use of land as a more conventional entry upon it."¹⁸⁷ Thus, an airplane may fly over private property without being subject to liability so long as it is not at such a low altitude as to interfere with a "then existing use to which the land or water, or the space over the land or water, is put by the owner."¹⁸⁸ Rather, "[f]lights over private land are not a taking, unless they are so low and frequent as to be a direct and immediate interference with the enjoyment and use of land."¹⁸⁹

In reaching its decision, the *Causby* court held that the *ad coelum* doctrine "has no place in the modern world."¹⁹⁰ The court explained that airplanes are "part of the modern environment and life," the inconveniences it causes are not normally compensable under the Fifth Amendment, and the airspace (apart from that immediately above the land) is part of the "public domain."¹⁹¹ With respect to the "public highway," "private claims to the airspace would clog [this highway], seriously interfere with their control and development in the

¹⁸⁴ *Id.* at 261-62.

¹⁸⁵ *Id.* at 264.

¹⁸⁶ *Id.*

¹⁸⁷ *Id.*

¹⁸⁸ *Id.* at 266.

¹⁸⁹ *Id.*

¹⁹⁰ *Id.* at 261.

¹⁹¹ *Id.* at 266.

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public interest, and transfer into private ownership that to which only the public has a just claim.”¹⁹² It was the Air Commerce Act of 1926 which enabled the court to declare that national airspace is a “public highway” despite years of adherence to the *ad coelum* doctrine by U.S. judiciaries.¹⁹³ The Act provided that the United States has “complete and exclusive sovereignty” of the airspace over the lands and waters of the United States, that “any citizen of the United States [has] a public right of freedom of transit in air commerce through the navigable airspace of the United States,” and that such “navigable airspace shall be subject to a public right of freedom of interstate and foreign air navigation.”¹⁹⁴

Causby and courts that tried subsequent cases involving airspace rights modified the *ad coelum* doctrine once a significant public interest in airspace developed and Congress responded by enacting legislation which explicitly recognized and protected that public interest.¹⁹⁵ These modifications constrained landowners’ protectable property interests to the portions of the airspace that could reasonably be used “in connection with the land.” *Causby* established a precedent which allows trespass and takings claims related to airspace use to prevail only in those circumstances where there was “a direct and immediate interference with the enjoyment and use of land.”¹⁹⁶

¹⁹² *Id.* at 261.

¹⁹³ *Id.* at 260 (citing the Air Commerce Act of 1926, 49 U.S.C. §§ 176(a), 180, 403 (1946)).

¹⁹⁴ *Id.*

¹⁹⁵ *Id.* at 256; see also *United Masonry, Inc. v. Jefferson Mews, Inc.*, 237 S.E.2d 171, 181 (Va. 1977) (stating that the common law *ad coelum* doctrine “has been modified so that now the landowner is generally held to own only that amount of airspace he can reasonably use”); *Griggs v. Allegheny County*, 369 U.S. 84 (1962); *State ex rel. Royal v. Columbus*, 209 N.E.2d 405, 408 (1965) (stating “[t]here exists a ‘taking’ in a constitutional sense of private property for public use under Section 19, Article I of the Ohio Constitution, whenever air flights ‘are so low and so frequent as to be a direct and immediate interference with the enjoyment and use of the land.’”)

¹⁹⁶ *Causby*, 328 U.S. at 264-66 (“The superadjacent airspace at this low altitude is so close to the land that continuous invasions of it affect the use of the surface land itself.”).

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It is the requirement that any interest in airspace be tied to a “reasonable and foreseeable”¹⁹⁷ use of the surface of the land that is specifically relevant to a discussion regarding the extent to which property interests in the subsurface are afforded protection. However, a conclusion regarding the degree to which the *ad coelum* doctrine remains applicable to deep subsurface property is not easily drawn. Courts have looked to *Causby* and other airspace cases when deciding subsurface property rights cases. It is important to note upfront, however, that the case law involving subsurface property rights is much broader and complicated than the body of airspace case law. The complication primarily arises from the three attributes of subsurface rights that fundamentally distinguish them from airspace rights.¹⁹⁸ The first distinction is that unlike airspace rights, subsurface rights have been severed, conveyed, bought, sold, used, and developed by private parties and federal, state, and local governments since the founding of this country. This has resulted in ownership, use, and exploitation of the subsurface in a manner far more diverse and tangible than ever existed for airspace rights. The second distinction is that in the airspace cases there was a single and very compelling “public interest”—national air travel—competing against surface interests. By contrast, in cases involving subsurface rights, the surface owner’s rights often clash with multiple competing uses such as oil and gas development, underground natural gas storage, groundwater production, underground storage of fresh water, and underground injection of fluid wastes. What is more, all of these competing uses are subject to a federal or state regulatory system designed to promote each activity in the public interest. A third and final distinction is Congress’ declaration that “airspace shall be subject to a public right of

¹⁹⁷ *Willoughby Hills v. Corrigan*, 278 N.E.2d 658, 664 (1972) (stating “the invasion of the superadjacent airspace has not been shown to have affected either the present use or any reasonably foreseeable use of the land itself”).

¹⁹⁸ *Klass & Wilson*, *supra* note 4, at 388-89.

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freedom of interstate and foreign air navigation.”¹⁹⁹ This singularly defined public benefit of the skies contrasts with the long history of subsurface rights being bought, sold, and privatized by the federal government, the states, and private parties for numerous and varied commercial and industrial purposes.

2.4 Surface Rights vs. Subsurface Rights

The preceding section indicates there is reason to believe that the judicial and legislative precedent which limited the protection of private property rights in airspace may not be entirely instructive in the context of subsurface property rights in general and subsurface pore space rights in particular. It is therefore necessary to turn to the body of case law pertaining to traditional property rights in surface lands and to ascertain whether such case law is dispositive or inapposite to the ownership and use subsurface property rights. *Loretto v. Teleprompter Manhattan CATV Corp.* is perhaps the seminal case in which the Supreme Court addressed the issue of permanent physical occupation of a surface owner’s property.²⁰⁰ The specific issue before the Court was whether a New York law requiring a landlord to permit the installation of a cable company’s cables on rental properties in order to furnish cable television services to tenants rises to the level of a taking without just compensation.²⁰¹ The Supreme Court ruled that the state statute amounted to a taking of a portion of the plaintiff’s property—around one and one-half cubic feet on the outside of the rental building, to be precise—for which she was entitled to just compensation under the Fifth Amendment.²⁰² The Court relied on *Causby* in reaching its decision in *Loretto* and used its

¹⁹⁹ See 49 U.S.C. § 180 (1946).

²⁰⁰ *Loretto*, 458 U.S. 419.

²⁰¹ *Id.* at 421.

²⁰² *Id.* at 441.

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previous ruling to distinguish between the government's permanent, physical occupation of property, which constitutes a *per se* taking in most circumstances, and a "regulation that merely restricts the use of property."²⁰³ The Court found that to the extent the government permanently occupies property, or grants a third party the right to do so, it effectively destroys the right to "possess, use, and dispose" of property and will amount to a taking in any such circumstance.²⁰⁴ The Court further concluded that in applying this *per se* taking rule for physical occupations, the size of the area occupied is irrelevant, as is whether the plaintiff previously occupied the space in question.²⁰⁵ The Court also relied *Causby* to support the proposition that "[a]n owner is entitled to the absolute and undisturbed possession of every part of his premises, including the space above, as much as a mine beneath."²⁰⁶ It is important to highlight, however, that on remand the Court of Appeals of New York²⁰⁷ ruled that the amount of compensation awarded could be nominal and predetermined (in *Loretto*, a \$1 one-time payment), provided that property owners had a mechanism available through which to seek more in compensation by proving special circumstances existed.²⁰⁸

There is undeniable language in *Loretto* to support the position that any and all physical occupation of subsurface pore space would be a taking, particularly the declaration that a plaintiff need not have previously occupied the space in question in order for a taking of private property without just compensation to be found.²⁰⁹ There is also the statement that

²⁰³ *Id.* at 430 (citing *Causby*, 328 U.S. at 261).

²⁰⁴ *Id.* at 435 (quoting *United States v. General Motors Corp.*, 323 U.S. 373, 378 (1945)).

²⁰⁵ *Id.* at 438 n.16.

²⁰⁶ *Id.* at 437 n.13.

²⁰⁷ *Loretto v. Teleprompter Manhattan CATV Corp.*, 446 N.E.2d 428, 432-33 (1983).

²⁰⁸ That is unless the property owner meets the burden of proof for establishing that the diminution in value of the property was materially different than the general assumption, and this therefore entitled to receive greater compensation.

²⁰⁹ *Id.* at 437 n.13 (quoting *Causby*, 328 U.S. at 256 n.10).

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there is a right of “undisturbed possession” of every part of a surface parcel, including the “space above” and the “mine beneath.”²¹⁰ On the other hand, the *Loretto* court relied heavily on *Causby* in supporting its ruling. *Causby* clearly abridged property interests in the high airspace (i.e., the “public highway”), yet continued to protect those property interests in the airspace which are necessary to enjoy unencumbered use of surface property.²¹¹ It is reasonable to assume that property interests in the subsurface which are necessary to the use of the surface or are currently being exploited for commercial or industrial uses would be protected under *Causby*. However, *Causby* could just as easily be interpreted to support the proposition that not all subsurface property, particularly that which is so far beneath the surface of the earth that it is inaccessible to all but a small proportion of landowners, is afforded protection from incursions. Thus, just as private airspace rights end at some non-enumerated distance above the surface of the earth, perhaps pore space rights are similarly truncated at some depth below the earth’s surface. Even so, any effort to use *Causby* to support a restricted view of subsurface property rights must account for fact that, unlike airspace rights, there is a long and established history of subsurface rights having been bought, sold, used, and developed by private parties.

While Congress or state legislatures may enact legislation to create a public right of freedom to use the subsurface for commercial development of CCS and declare CO₂ sequestration a public benefit, such legislation could face considerable opposition given there is arguably a much greater expectation for private property rights in the subsurface to be protected from encroachment and use than existed for airspace rights at the time when Congress passed the

²¹⁰ *Id.*

²¹¹ *Causby*, 328 U.S. at 266.

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Air Commerce Act of 1926. Ultimately, courts will be forced to grapple with *Causby* and *Loretto* regardless of any legislative effort to limit property rights in the subsurface.

Moreover, any attempt to define or limit protection of subsurface property rights will be subject to takings challenges. While no case specifically related to the encroachment of subsurface property rights has yet been argued before the Supreme Court, state courts have ruled on this issue in the context of various commercial and industrial subsurface injection activities that gave rise to both takings and trespass claims. Even though the holdings in these cases are far from being consistent with each other, several noteworthy legal concepts emerge from this body of case law.

2.5 Limitations on the Protection of Subsurface Property Rights

[F]rom the ancient common law maxim that land ownership extends to the sky above and the earth's center below, one might extrapolate that the same rule should apply two miles below the surface. But that maxim—cujus est solum ejus est usque ad coelum et ad inferos—“has no place in the modern world.” Wheeling an airplane across the surface of one's property without permission is a trespass; flying the plane through the airspace two miles above the property is not. Lord Coke, who pronounced the maxim, did not consider the possibility of airplanes. But neither did he imagine oil wells. The law of trespass need no more be the same two miles below the surface than two miles above.²¹²

Even though there is no clear national judicial precedent which appertains to the protection of subsurface pore space rights, there is a rich body of state case law concerning the protection of subsurface property rights over a range of commercial and industrial subsurface

²¹² *Coastal Oil and Gas Corp. v. Garza Energy Trust*, 268 S.W.3d 1, 11 (Tex. 2008).

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injection activities. The reality is that state courts have a history of balancing competing interests in the subsurface, and have placed great weight on the public interest and regulatory approval associated with certain activities. However, courts have only extended limited protection of the right of surface owners and mineral owners to use and exploit interests in the subsurface and recover money damages for measurable impairments caused by the migration of fluids injected underground. It is therefore useful to examine how courts have dealt with the issue of protecting subsurface trespass in the context of five subsurface injection activities that are frequently considered analogous to geological sequestration of CO₂: 1) licensed underground natural gas storage projects; 2) licensed underground fluid waste injection and disposal projects;²¹³ 3) state-authorized enhanced oil recovery and field unitization;²¹⁴ 4) horizontal fracturing for natural gas production; and 5) underground water storage and recharge.^{215,216} In each of these groups of cases, courts balanced the protection of private surface and subsurface property interests with public policy aimed at the promotion of activities deemed to be in the public interest in various ways. Most of the case law supports the proposition that takings and trespass claims will not stand absent actual and substantial damages. However, the case law is neither entirely unified nor coherent.

²¹³ The EPA and its delegated state counterparts regulate the underground injection of fluid wastes under the UIC program.

²¹⁴ In “enhanced” or “secondary” recovery operations, oil and gas producers inject fluids into the subsurface in order re-pressurize the reservoir so as to increase oil and gas production in exhausted fields, where primary production is no longer possible. This process can cause migration of the injected fluid, or the native oil and gas sought to be produced, into a neighboring production field and inhibit another producer’s ability to recover oil or gas resources.

²¹⁵ See Wilson & de Figueiredo, *supra* note 4, at 10119-10121 (2006); Anderson, *supra* note 120, at 97; Klass & Wilson, Climate Change, *supra* note 4, at 363.

²¹⁶ Cases involving ownership rights to oil, gas, coal, groundwater, and other subsurface natural resources are less instructive than cases involving subsurface waste injection, natural gas storage, enhanced oil recovery and field unitization, horizontal fracturing, and underground water storage and recharge. The reason being that oil, gas, coal, groundwater, etc. involve disputes over ownership of a valuable commodity found within the subsurface, whereas the latter set of cases deal with disputes over ownership of the subsurface strata itself.

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In the cases involving underground fluid waste injection, enhanced oil recovery, horizontal fracturing, and underground water storage, the courts consistently modified the *ad coelum* doctrine and limited the ability of surface owners and mineral owners to recover money damages for trespass or to establish that an uncompensated taking occurred as a result of a government-authorized use of subsurface pore space. In cases involving subsurface natural gas storage, project developers have generally proceeded under the Natural Gas Act to condemn subsurface property by eminent domain, thus implicitly acknowledging (or at least not expressly challenging) that the use of pore space requires compensation. Courts and lawmakers will undoubtedly look to these cases for guidance in order to determine whether the use of deep geologic pore space for permanent sequestration of CO₂ without compensation rises to the level of a trespass or unlawful taking.

2.5.1 Natural Gas Storage

*Underground storage is a lusty baby.*²¹⁷

Natural gas is frequently injected into the subsurface for temporary storage. If such gas migrates beneath neighboring lands then a technical trespass has occurred. Trespass issues arising in the gas storage context offer insight about how courts may analyze subsurface invasions of pore space in the geologic CO₂ sequestration context. In both contexts, whether a subsurface invasion caused by the injected fluid is an actionable trespass or rises to the level of an unlawful taking of private property will depend on public policy goals and the facts of the particular case at bar. Of course, gas storage and geologic sequestration of CO₂ are factually distinct: gas storage is an ongoing operation, involving an ongoing cycle of

²¹⁷ Stamm, *supra* note 4, at 161.

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injections and withdrawals of gas, whereas CO₂ sequestration involves injection for permanent disposal. Additionally, gas is a valuable commodity, while CO₂ is essentially a waste product. Moreover, a geologic sequestration reservoir will eventually reach its maximum capacity, at which time CO₂ injection will cease; the cyclical injection and withdrawal of natural gas for storage could continue indefinitely. These factual distinctions, however, do not render gas storage law useless in terms of signaling how legislatures and judiciaries will handle the use of subsurface pore space as it relates to geologic sequestration of CO₂.

In most jurisdictions, pipeline companies and gas utilities possess the state-authorized right of eminent domain, and often acquire storage rights to the entire subsurface reservoir using such authority. Under the Natural Gas Act and judicial decisions interpreting the Act, natural gas companies that obtain a “certificate of public convenience” from the Federal Energy Regulatory Commission (FERC) have the power of eminent domain to condemn private property for the purpose of constructing underground natural gas storage facilities.²¹⁸ Not surprisingly, when property is condemned, courts have been forced to resolve disputes over ownership and valuation of the pore space in which the natural gas is stored.

Within the realm of natural gas storage, most courts recognize the surface estate owner has the right to use the storage space once the mineral estate has been depleted of all mineral or

²¹⁸ See 15 U.S.C. § 717f(h); *Columbia Gas Transmission Corp. v. An Exclusive Gas Easement*, 776 F.2d 125, 128 (6th Cir. 1985); Steven D. McGrew, Note, *Selected Issues in Federal Condemnation for Underground Natural Gas Storage Rights: Valuation Methods, Inverse Condemnation, and Trespass*, 51 Case W. Res. L. Rev. 131 (2000).

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hydrocarbon resources.²¹⁹ If the storage space contains economically recoverable amounts of oil, gas, or other mineral resources, the mineral estate remains “dominant” over the right to store natural gas.²²⁰ As was discussed above, the term “dominant” means that the mineral estate owner has the right to use as much of the storage space as is reasonably necessary to explore for and exploit resources belonging to the mineral owner. Consequently, because gas storage operations are commonly carried out in a reservoir where some economically recoverable amount of oil and natural gas is still present, and because it is easy for owner of the storage space to successfully demonstrate that the storage rights could be leased to a competing developer, natural gas companies will typically acquire the storage rights from all persons holding an interest in the storage space, or include all interest-holders in a condemnation action.^{221, 222} That is to say, rather than take the risk that storing gas will materially compromise a property interest and trigger a lawsuit for subsurface trespass or an unlawful taking of private property, natural gas storage developers often chose to compensate property owners outright (via voluntary contract, or if negotiations reach an impasse, through the exercise of eminent domain authority) in exchange for control of the entire storage space.²²³

Two main types of disputes are found in natural gas storage cases. The first is where a natural gas company obtains a certificate of public convenience from FERC and then

²¹⁹ See *Mapco*, 808 S.W.2d 262; Stamm, *supra* note 4, at 161; Wilson & de Figueiredo, *supra* note 4, at 10121-22.

²²⁰ *Id.*

²²¹ Through judicial interpretation, it has been determined that the Natural Gas Act empowers natural gas operators who have obtained a “certificate of public convenience” from the Federal Energy Regulatory Commission to exercise the power of eminent domain to condemn property in order to develop underground natural gas storage facilities. See 15 U.S.C. § 717f(h); *Columbia Gas*, 776 F.2d at 128; McGrew, *supra* note 99, at 138-41.

²²² See Wilson & de Figueiredo, *supra* note 123, at 10121-22; Klass & Wilson, *supra* note 4, at 32.

²²³ Wilson & de Figueiredo, *supra* note 4, at 10121-22.

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attempts to contract with the surface owner to obtain the necessary storage rights and, if they are unable to reach agreement, exercise the power of eminent domain to take the subsurface within the area covered by the certificate. In this situation, there may be disputes over the valuation of the storage space, but it is well settled that compensation must be paid when the exclusive right to protect the storage strata by condemning all other exploitation of the strata and its contents is acquired by the natural gas storage company. The second type of dispute is where the natural gas company fails to obtain all of the storage rights within the area in which it intends to operate, creating a “window” in the storage field. In this case, the owner of a window property may attempt to sue for trespass once storage operations begin, or when a window owner threatens to drill into the storage field or surrounding area, the gas company may file a condemnation action to prevent the owner from either withdrawing the company’s stored gas or damaging the integrity of the storage field. At that point, the window owner may then counterclaim for trespass and seek an injunction, compensatory damages, and punitive damages.²²⁴ Fore sure, the Natural Gas Act and judicial decisions interpreting the Act recognize that the exclusive right to use pore space for natural gas storage must be acquired either voluntary contract or forced condemnation.

Even so, the body of authority for natural gas storage should not be construed to indicate that the unauthorized and uncompensated use of pore space for GCS will constitute an actionable subsurface trespass or unlawful taking in all circumstances. Historically, the motivation for condemning property and compensating surface and mineral owners in the context of natural

²²⁴ See McGrew, *supra* note 99, at 179-80 (discussing claims for punitive damages in subsurface trespass cases); Alexandra B. Klass, *Punitive Damages and Valuing Harm*, 92 Minn. L. Rev. 83, 105-07 (2007) (discussing availability of punitive damages in surface trespass cases). To the extent a property is in split estate, and the natural gas storage interferes with the mineral rights owner’s ability to develop the oil or gas then the mineral rights owner may also have a claim for trespass or a right to just compensation resulting from condemnation.

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gas storage has more to do with protecting the integrity of the storage field and retaining exclusive control of the stored natural gas than the value of the subsurface pore space being utilized for storage. In *Hammonds v. Central Kentucky Natural Gas Co.*, the court impolitically reasoned that natural gas injected for storage was really released back to nature—in essence, abandoned.²²⁵ Because the gas was abandoned, the gas had no owner.²²⁶ Comparing injected gas to captured wild animals that were returned to nature, the court found that no trespass occurred when the released gas migrated to neighboring property.²²⁷ The court further ruled that when the gas was returned to nature, it became “subject to appropriation by the first person” to capture the gas.²²⁸ Thus, the only way the storage company could protect its interest in the injected gas was to acquire the exclusive right to explore for and produce the gas it reinjected into the subsurface.

The *Hammonds* Doctrine, as it is known, has been widely criticized and rejected by numerous courts, but it arguably influenced the trend among natural gas storage companies to often include both surface owners and mineral owners in voluntary negotiations or, if necessary, condemnation actions to develop natural gas storage fields, providing compensation to both sets of property owners.²²⁹ Moreover, as a practical matter, *Hammonds* has not been overruled in Kentucky. In *Texas American Energy Corp. v. Citizens Fidelity Bank & Trust Co.*, the court reasoned that “in those instances when previously extracted oil and gas is subsequently stored in underground reservoirs capable of being defined with

²²⁵ *Hammonds v. Central Kentucky Natural Gas Co.*, 75 S.W.2d 204, 205-06 (Ky. Ct. App. 1934).

²²⁶ *Id.*

²²⁷ *Id.* at 206.

²²⁸ *Id.*

²²⁹ See Stamm, *supra* note 4, at 161; *Lone Star Gas Co. v. Murchison*, 353 S.W.2d 870, 880 (Tex. Civ. App.—Dallas 1962); *White v. New York State Natural Gas Corp.*, 190 F. Supp. 342 (E.D. Pa. 1960); *Humble Oil & Ref. v. West*, 508 S.W.2d 812, 817 (Tex. 1974); *ANR Pipeline Co. v. 60 Acres of Land*, 418 F. Supp.2d 933, 940 (W.D. Mich. 2006).

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certainty and the integrity of said reservoirs is capable of being maintained, title to such oil and gas is not lost and said minerals do not become subject to the rights of owners of surface above the storage fields.²³⁰ On its face, the opinion may seem to reject the previous holding in *Hammonds*. However, the language about maintaining the integrity of the reservoir seems to suggest that the injector must control all the rights of access to the reinjected gas throughout the full extent of the storage reservoir (the facts in *Texas American*) in order to maintain title to the stored gas, therefore *Hammonds* is not overruled because the injector in that case did not have full control of the reservoir.

Kansas courts have also been reluctant to dismiss the *Hammonds* doctrine in the following circumstance: “where a natural gas utility was not involved, where no certificate authorizing an underground natural gas storage facility had been issued by the Kansas Corporation Commission, and where a landowner had used the property of an adjoining landowner for gas storage without authorization or consent.”²³¹ Such was the circumstance in *Anderson v. Beech Aircraft*.²³² In *Beech*, the Supreme Court of Kansas the court was reluctant to find a trespass occurred because, since the defendant, as the owner of non-native natural gas, lost title thereto when it injected the non-native gas into a common natural gas-containing

²³⁰ *Texas American Energy Corp. v. Citizens Fidelity Bank & Trust Co.*, 736 S.W.2d 25, 28 (Ky. 1987).

²³¹ *Anderson v. Beech Aircraft*, 699 P.2d 1023, 1032 (Kan. 1985); see also *Union Gas Sys., Inc. v. Carnahan*, 774 P.2d 962, 967 (Kan. 1989). These cases were distinguished in *Reese Exploration, Inc. v. Williams Natural Gas Co.*, 983 F.2d 1514, 1523 (10th Cir. 1993).

Parties having the power of eminent domain may protect their rights by securing a state certificate and by condemning the reservoir, and such parties are further protected from the rule of capture if they can prove by a preponderance of the evidence that injected gas had migrated to adjoining property or to a stratum that has not been condemned. See KAN. STAT. ANN. §§ 55-1205 to 1210 (2007); see *Williams Natural Gas Co. v. Supra Energy, Inc.*, 931 P.2d 7 (Kan. 1997); *Union Gas*, 774 P.2d at 967. For the meaning of “adjoining,” see *N. Natural Gas Co. v. Nash Oil & Gas Inc.*, No. 04-1295-JTM, 1005 U.S. Dist. LEXIS 10181, at *7 (D. Kan. May 16, 2005). If gas migrates into another stratum, further condemnation may be pursued, but landowners’ damages for the pre-condemnation trespass and unjust enrichment are measured by the fair rental value of such stratum. *Beck v. Natural Gas Co.*, 170 F.3d 1018, 1024 (10th Cir. 1999).

²³² *Beech Aircraft*, 699 P.2d 1023.

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reservoir underneath adjoining property without consent, the neighboring landowner was free to produce the non-native gas, and thus suffered no damages.²³³

Certain jurisdictions have rejected the *Hammonds* doctrine outright. In *Lone Star Gas Co. v. Murshison*,²³⁴ a Texas appellate shrewdly rejected the *Hammonds* line of reasoning, ruling that natural gas injected for storage is not abandoned, but remains the personal property of the injecting party, and as such, is no longer subject to capture by neighboring landowners even if the gas migrates beneath neighboring tracts.²³⁵ The *Lone Star* case did not, however, squarely address the question of whether the invasion of stored gas is compensable because no actionable case for trespass was presented by the neighboring landowner. The court explained: “Appellees expend a great deal of space in their brief to the argument that appellant has trespassed upon their property. The status of this record is such, however, that we must, as Ulysees ‘lash ourselves to the mast and resist Siren’s songs’ of trespass, or similar contention. This, for the simple reason that no action seeking redress or claimed trespass is here presented.”²³⁶

An Oklahoma statute, which permits natural gas companies to obtain storage rights by condemnation, established that injected gas remains the property of the injector, even if gas migrates beneath other lands.²³⁷ Under the statute, retention of ownership to stored gas is contingent upon the injector proving migration as well as compensating the owner of the

²³³ *Id.* at 1032.

²³⁴ *Lone Star*, 353 S.W.2d 870.

²³⁵ *Id.* at 880.

²³⁶ *Id.* at 875.

²³⁷ OKLA. STAT. ANN. Tit. 52, §§ 36.1-36.7 (1951).

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invaded stratum.²³⁸ In *Oklahoma Natural Gas Co. v. Mahan & Rowsey, Inc.*,²³⁹ the United States Court of Appeals for the 10th Circuit effectively upheld the Oklahoma statute when it implicitly concluded that the storage operator retained title to injected gas that migrated to neighboring lands.²⁴⁰ In this case, however, ownership of the injected gas was easily determinable because the stored gas was confined to an identifiable and well-defined formation, plus the gas was distinguishable, due to helium content and a lack of certain organic compounds, from native gas in the area.

In *ANR Pipeline Co. v. 60 Acres of Land*,²⁴¹ the U.S. District Court for the Western District of Michigan signaled its intention to patently reject the *Hammonds* doctrine. Specifically, the court stated, “Injected gas which has previously been produced, reduced to possession, and then reinjected into the ground is not subject to the rule of capture. Once severed from the realty, gas becomes personal property, and title to that property is not lost when it is injected into underground gas storage reservoirs.²⁴² Accordingly, if injected gas moves across boundaries there may be a trespass.”²⁴³ Moreover, intrusions onto private property caused by the actions of a gas storage company with condemnation authority may be the basis of an inverse condemnation claim.²⁴⁴ The court concluded, however, that migration of native gas (caused by the injection of non-native gas) beneath the defendant’s property did not amount to an inverse condemnation because ANR’s actions did not cause “any diminution in the value of [defendant’s] land, and serious injury to their property, or any interference with the

²³⁸ *Id.* at § 36.6.

²³⁹ *Oklahoma Natural Gas Co. v. Mahan & Rowsey, Inc.*, 786 F.2d 1004 (10th Cir. 1986).

²⁴⁰ *Mahan & Rowsey, Inc.*, 786 F.2d at 1007-07.

²⁴¹ *ANR Pipeline*, 418 F. Supp. 2d 933 (2006).

²⁴² *Id.* at 939 (citing *Ellis*, 450 F.Supp. at 419); *White*, 190 F.Supp. at 349.

²⁴³ *ANR Pipeline*, 418 F. Supp. 2d at 939.

²⁴⁴ *Id.*

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use of their property.”²⁴⁵ The court explained that even if native gas beneath the defendants' property had been impressed into public service, that alone is insufficient to support an action for an unjust taking.²⁴⁶ “An inverse condemnation claim requires more than a showing that private property has been put to some public use.”²⁴⁷ Citing two earlier cases decided by the Michigan Court of Appeals, one of which was relied upon by the defendants, the court asserted that the “taking property for a public use must be accompanied by harm before it will be cognizable as a taking subject to an inverse condemnation claim.”²⁴⁸

At least two courts submitted that state trespass claims are preempted by the Natural Gas Act, and therefore the only remedy available is an action in inverse condemnation. In the first case, *Columbia Gas Transmission Corp. v. An Exclusive Natural Gas Storage Easement*,²⁴⁹ Columbia Gas brought an action to condemn an underground natural gas storage easement beneath the property of a neighboring landowner.²⁵⁰ As Columbia Gas' storage of gas under the landowner's property predated the filing of the condemnation action, the landowners counterclaimed, seeking compensatory and punitive damages for trespass.²⁵¹ The United States District Court for the Northern District of Ohio, reversing a position it previously took on similar issues,²⁵² concluded that "the landowner's remedies with respect to the taking of his property by the United States Government or by a private corporation authorized to

²⁴⁵ *Id.* at 942.

²⁴⁶ *Id.* at 941-42.

²⁴⁷ *Id.* at 941.

²⁴⁸ *Id.* (citing *Fox v. Ogemaw County*, 528 N.W.2d 210, 214-15 (Mich. App. 1995); *Jones v. East Lansing-Meridian Water and Sewer Auth.*, 296 N.W.2d 202, 204-05 (Mich. App. 1980).

²⁴⁹ *Columbia Gas v. Exclusive Natural Gas Storage E.*, 747 F. Supp. 401 (N.D. Ohio 1990).

²⁵⁰ *Id.* at 402.

²⁵¹ *Id.*

²⁵² *Bowman v. Columbia Gas Transmission Corp.*, 850 F.2d 692 (6th Cir. 1988). In *Bowman*, the United States District Court for the Northern District of Ohio allowed, over Columbia's objection a similar trespass action to be prosecuted and allowed the jury to assess punitive damages.

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exercise the power of eminent domain are controlled and limited by federal substantive law.”²⁵³ “The conclusion that Ohio law regarding the taking of property for public use is not applicable because it is preempted by federal law is dispositive of [the landowner's] counterclaim for trespass and punitive damages. It will not be allowed to proceed.”²⁵⁴ The landowners were, however, granted leave to file an amended counterclaim seeking compensatory damages for inverse condemnation.²⁵⁵ The *Columbia Gas* court also held that the landowner bore the burden of establishing actual damages in order to prevail on an inverse condemnation claim.²⁵⁶ The court went even further to suggest that the natural storage operator has no incentive to condemn property into which its gas has migrated unless the integrity of the company’s storage field is threatened.²⁵⁷

The second case, *Mississippi River Transmission Corp. v. Tabor*,²⁵⁸ the Fifth Circuit rejected on two separate grounds the property owner's trespass claims against the gas company for its purported use of his property as a gas storage reservoir before it was legally expropriated.²⁵⁹ First, the court of appeals opined that the landowner had failed to prove that any trespass on his particular interest in the property had occurred.²⁶⁰ Second, the court of appeals concluded that even if a trespass had occurred, the property owner was entitled to no additional compensation for that trespass in addition to the condemnation award.²⁶¹ As the circuit court explained, “Once the Louisiana Department of Conservation issued its order authorizing the

²⁵³ *Columbia Gas*, 747 F. Supp. at 405.

²⁵⁴ *Id.*

²⁵⁵ *Id.* at 406.

²⁵⁶ *Id.* at 405.

²⁵⁷ *Id.*

²⁵⁸ *Tabor*, 757 F.2d 662.

²⁵⁹ *Id.* at 665.

²⁶⁰ *Tabor*, 757 F.2d at 672-73.

²⁶¹ *Id.* at 673.

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construction of the [storage facility], [natural gas] production... within the storage area was forever halted; Tabor's sole right as a mineral servitude owner from that point forward, therefore, was the right to have his mineral interests legally expropriated and to receive just compensation for the recoverable reserves in the reservoir."²⁶² The measure of just and adequate compensation to which Tabor is entitled "is to be estimated by the same standard whether the property taken is formally expropriated in accordance with law or appropriated by the condemning authority so long as it is intentionally taken for a public use."²⁶³

The notion that state trespass claims are preempted by the Natural Gas Act has been criticized by legal commentators and rejected by the United State's District Court for the District of Kansas.²⁶⁴ In *Humphries v. Williams Natural Gas Company*,²⁶⁵ the district court held that a condemnation action under the Natural Gas Act "does not preempt all of Humphries' pre-condemnation state law claims. Humphries may seek damages on his pre-condemnation state law claims against WNG to the extent that those damages are separate and distinct from the compensation he may receive in the condemnation proceedings."²⁶⁶

2.5.1.1 Natural Gas Storage Implications for GCS

While the natural gas storage case law is instructive of how courts may treat the use of subsurface pore space in the context of geologic CO₂ sequestration, the number of opinions

²⁶² *Id.*

²⁶³ *Id.* (citing Article 1, § 4 of the Louisiana Constitution of 1974 15 (previously Article 1, § 2 of the Louisiana Constitution of 1921), and La.Rev.Stat. Ann. § 19:9 (West 1979); *Gray v. State Through Department of Highways*, 202 So.2d 24, 26 (La. 1967)).

²⁶⁴ See *Humphries v. Williams Natural Gas Company*, 48 F. Supp. 2d 1276 (Kansas 1999); McGrew, *supra* note 99, at 172-74; George H. Genzel, *Award of, or Pending Proceedings for, Compensation for Property Condemned, as Precluding Action for Damages Arising From Prior Trespasses Upon It*, 33 A.L.R. 3d 1132 (1971)

²⁶⁵ *Humphries*, 48 F. Supp. 2d 1276.

²⁶⁶ *Id.* at 1283.

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available for review is sparse. What is more, most judicial decisions that address subsurface invasions caused by the storage of natural gas either: 1) focus on ownership of the stored gas, not the invasion itself; or 2) treat trespass allegations as actions in inverse condemnation²⁶⁷ because gas storage rights may be acquired by eminent domain.²⁶⁸ Thus, any attempt to distill from this body of jurisprudence definitive legal principles for addressing the use of pore space in the context of geologic CO₂ sequestration is, at best, of limited utility; at its worst, conclusions drawn from such an analysis could lead, and have led, lawmakers dangerously astray. Arguably, the practice of compensating property owners to use subsurface pore space for storing natural gas developed as much out of industry custom and the need to maintain possession and control of injected gas as it has from adherence to legal and regulatory requirements. Because natural gas is a valuable commodity, a gas storage operator has the compelling motivation to compensate the owner of the storage space to ensure complete control of the storage reservoir and limit subsurface migration of the stored gas so that none is lost before it can be recovered and sold or traded on the open market. When a natural gas storage developer enters into a lease agreement with landowners, the value of the lease is primarily the difference between the market price of the stored natural gas in the summer and winter months (from which dollar per acre lease rate is derived), not an assessed value of the storage space itself. While there is no project without pore space, the value of the storage space arises from this arbitrage. Similarly, if the storage developer acquires the storage right through a condemnation action, compensation is typically based on the market value of a deprived, economically measurable interest – e.g., the market value of oil and gas or other mineral resources remaining in the storage space, or the value of the future income stream the

²⁶⁷ See, e.g., *Columbia Gas*, 747 F. Supp. at 405.

²⁶⁸ See, e.g., *Pac. Gas & Electric Co. v. Zuckerman*, 234 Cal. Rptr. 630 (Ct. App. 1987); *Iroquois Gas Corp. v. Gernatt*, 281 N.Y.S.2d 896 (N.Y. App. Div. 1967).

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landowner would have received from a competing gas storage developer.²⁶⁹ In either case, the market value of a commodity serves a proxy for calculating the “value” of the storage space.

By contrast, GCS operators will not be concerned with maintaining the integrity of the sequestration field for the purpose limiting migration of injected CO₂ so that it can be easily recovered at a later time to be traded and sold. Quite the contrary, the sole purpose of GCS is to keep CO₂ underground and out of the atmosphere permanently. While there is a commodity market for the CO₂ used in numerous industrial processes and consumer products, the CO₂ captured from large anthropogenic sources as a result of regulation of CO₂ emissions would very likely far exceed the market demand, making it virtually valueless as a commodity.²⁷⁰ Greenhouse gas regulations will not create a true market value for CO₂ like there is for natural gas either. Depending on the form it takes, regulation of CO₂ could create a market for tradable emissions allowances, but allowances are not commodities by the true definition of the term. Instead, CO₂ allowances would represent the value of preventing a harmful waste from being emitted into Earth’s atmosphere. Moreover, an allowance market should not be designed as a mechanism through which CO₂ emitters could substantially increase profit margins by sequestering CO₂ in the ground. In fact, all the allowance market should be designed to do is provide enough financial incentive to large emitters to stimulate investment in carbon capture and sequestration technologies, or other low carbon electricity generation systems, instead of emitting CO₂ into the atmosphere.

²⁶⁹ See *Columbia Gas Transmission Corporation v. An Exclusive Natural Gas Storage Easement*, 620 N.E.2d 48 (1993). See also McGrew, *supra* note 99, at 150-163.

²⁷⁰ See V. Kuuskraa & R. Ferguson, *STORING CO₂ WITH ENHANCED OIL RECOVERY*. National Energy Technology Laboratory, Pittsburgh, PA, Table 15 (2008).

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Despite the several important distinctions which can be readily drawn between natural gas storage and the permanent geologic sequestration of CO₂, the Interstate Oil and Gas Compact Commission (IOGCC) issued a model statute for GCS based on existing state laws for natural gas storage.²⁷¹ The IOGCC Model Statute recommends that the acquisition of property rights for GCS be undertaken in the same manner as for natural gas storage projects: “The Model General Rules and Regulations propose the required acquisition of these storage rights and contemplate use of state natural gas storage eminent domain powers or oil and gas unitization processes to gain control of the entire storage reservoir.”²⁷² On first impression, this might seem to be a logical extension of an established regulatory framework. The IOGCC Model Statute has the advantage of working through well-understood mechanisms of state oil and gas agencies that are familiar with drilling and underground injection regulations. However, the potentially very large scale of property rights necessary for GCS, coupled with the perceived urgency to develop commercial-scale GCS rapidly, could make the natural gas storage model unwieldy at best, unworkable at worst.

To facilitate the development of natural gas storage projects, many states adopted condemnation statutes, which allow gas storage companies to condemn rights in underground storage reservoirs. However, many of these states allow condemnation only in reservoirs where minerals can no longer be produced in commercial quantities.²⁷³ When a gas storage

²⁷¹ IOGCC, STORAGE OF CARBON DIOXIDE IN GEOLOGIC STRUCTURES: A LEGAL AND REGULATORY GUIDE FOR STATES AND PROVINCES (2007) (IOGCC Guide).

²⁷² *Id.* at 11.

²⁷³ Colo. Rev. Stat. Ann. § 34-64-104 (Condemnation is not allowed unless the formation is nonproductive of gas in commercial quantities under either primary or secondary recovery methods.); 220 Ill. Comp. Stat. 15/2 (The same as Colorado.); Mo. Rev. Stat. § 601.401(a)(1) (No condemnation of a formation for gas storage purposes is allowed unless the original recoverable gas reserves within a proposed storage area have been depleted or exhausted by at least 80%.); W. Va. Code § 54-1-2(a)(3) (Condemnation of underground storage facilities is permitted when previous exploration has shown the formation has ceased to produce, or has been

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facility is developed and is later found to interfere with active mineral production operations, most state condemnation statutes are not designed remedy the problem.²⁷⁴ Often times, the only solution may be to discontinue storage operations.

Of course, state condemnation statutes used to develop underground gas storage facilities do not currently address geologic sequestration of CO₂. Legislation, either state or federal, is needed to provide condemnation authority for GCS. The IOGCC Model Statute provides such rights, but it does not authorize GCS in formations containing commercial quantities of oil, gas, or other valuable resources. The IOGCC Model Statute requires GCS project developers to identify and negotiate in good faith with all property owners “having property interests affected by the storage facility.”²⁷⁵ In addition, all property owners within one-half mile of the proposed project boundary must be notified by first-class mail and given an opportunity to participate in hearings.²⁷⁶ For a GCS project covering hundreds or thousands of square miles, with an equal number of affected landowners, this could be a very onerous task to be sure. It is therefore doubtful that the required statutory amendments, individual landowner negotiations, and subsequent condemnation proceedings required under the IOGCC Model Statute would effectively foster the rapid deployment of large-scale GCS.

proved to be nonproductive of, gas in substantial quantities.); Ark. Code Ann. § 15-72-604(a)(1) (No condemnation is permitted if the formation is producing, or is capable of producing, in paying quantities through any known recovery method.); Mont. Code Ann. § 82-10-303(1)(b) (Gas-bearing formations are not subject to condemnation unless recoverable volumes of native gas have been produced, or the formation has greater value or utility as storage than for production of relatively small amounts of remaining native gas compared with original volumes.); Okla. Stat. Ann. tit. 52 § 36.3(b) (No condemnation of a formation is permitted unless the volume of native gas originally in place is substantially depleted, and the formation has greater utility as a storage facility than for production of relatively small volumes of remaining gas.); Neb. Rev. Stat. § 57-605 (If any recoverable native gas remains, the use of a formation for storage must be determined to be in the public interest because the formation has greater value as storage facility than for production of remaining volumes of native gas.).

²⁷⁴ See, e.g., *Beech Aircraft*, 699 P.2d 1023.

²⁷⁵ IOGCC Guide, *supra* note 152, at § 3(a)(2).

²⁷⁶ IOGCC Guide, *supra* note 152, at § 5(b)(3).

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2.5.2 *Underground Fluid Waste Injection*

We therefore extend the reasoning ... that absolute ownership of air rights is a doctrine which “has no place in the modern world,” to apply as well to ownership of subsurface rights. [A landowner’s subsurface right to exclude others extends only to invasions that] actually interfere with the [landowner’s] ... reasonable and foreseeable use of the subsurface.²⁷⁷

An activity perhaps more closely analogous to CO₂ sequestration than natural gas storage is underground fluid waste injection. Fluid wastes are often disposed of by injecting them into deep subsurface formations. The EPA and delegated state agencies have regulated the underground injection of fluid wastes under the UIC program by creating “classes” of injection wells and setting standards for injection to protect underground sources of drinking water. There are 119 Class I hazardous waste and 439 Class II non-hazardous waste and municipal waste injection wells operating in 20 states, most injecting at depths of about 1,400 meters (4,500 feet).²⁷⁸

While there is no physical difference between the subsurface pore space used for underground waste injection and natural gas storage, and in fact both activities are often carried out in the same geologic formations (where the geology may also be suitable for geologic sequestration of CO₂), the judicial protection afforded to subsurface property rights in the context of waste injection is quite different than for natural gas storage. In much of the nation, it appears that most underground waste injection operations conducted pursuant to federal or state authorization under the UIC program that do not cause actual harm (physical

²⁷⁷ *Chance*, 670 N.E.2d 985.

²⁷⁸ EPA UIC website: http://www.epa.gov/ogwdw000/uic/pdfs/inventory_uic_well_inv_by_state.pdf (Accessed June 8, 2010).

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or economic) to adjacent properties are permitted to be carried out without compensation being paid to the surrounding landowners because the activity is considered necessary and in the public interest. For example, municipalities in Florida appear to be injecting roughly 3 billion tons a year²⁷⁹ of treated wastewater without the consent of subsurface property owners.

Courts faced with attempts by landowners to prevent or exclude subsurface waste disposal have not been successful in the absence of establishing actual and substantial harm to use and enjoyment of their property. For example, in *Chance v. BP Chemicals, Inc.*,²⁸⁰ BP Chemicals secured a Class I underground injection well permit to dispose of hazardous chemical waste.²⁸¹ Subsequently, neighboring landowners initiated a class action suite wherein they asserted that the injected waste trespassed into their subsurface pore space.²⁸² In *Chance*, the plaintiffs sought an injunction against further wastes disposal along with \$1 billion in damages.²⁸³ To support their claim, the plaintiffs cited a 1993 decision of the Ohio Supreme Court, *Columbia Gas Transmission Corp. v. An Exclusive Natural Gas Storage Easement*, which involved the determination of compensation due for the appropriation of an underground gas storage easement.²⁸⁴ The Ohio Supreme court found this earlier decision in the natural gas storage context to be inapplicable to the situation in *Chance*, which involved the injection and disposal of hazardous waste over 2,600 feet underground into a saline

²⁷⁹ Three billion tons/year is about the same as the mass of CO₂ produced/year by between 750 and 1000 medium-sized (500Mw) coal-fired power plants.

²⁸⁰ *Chance*, 670 N.E.2d 985.

²⁸¹ *Id.*

²⁸² *Id.* at 986.

²⁸³ *Id.*

²⁸⁴ *Chance*, 670 N.E.2d at 991 (citing *Columbia Gas*, 620 N.E.2d 48).

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aquifer.²⁸⁵ The court explained:

We find that the situation before us is not analogous to those present in the oil and gas cases, around which a special body of law has arisen based on special circumstances not present here. [These cases are] fundamentally dissimilar to the unique situation before us, which involves the injection of waste byproducts from the production of industrial chemicals.²⁸⁶

The *Chance* court ultimately concluded that a landowner's subsurface right to exclude others extends only to invasions that "actually interfere with the [landowner's] reasonable and foreseeable use of the subsurface."²⁸⁷ The court expressly found that the trial court did not err in refusing to allow the plaintiff to present evidence that "environmental stigma associated with the deepwells had a negative effect on appellants' property values due to the public perception there may have been injectate under appellants' property and that the injectate may be dangerous."²⁸⁸ The Ohio Supreme Court placed significant weight on the fact that the plaintiffs had no specific evidence that defendant's wells were causing any problems, only opinion testimony that problems may arise in the future. In other words, a landowner may not recover damages for mere loss of speculative value. Since the injection of hazardous waste by BP Chemicals was not interfering with any reasonable and foreseeable use of plaintiff's property, the court held that migration of the waste into neighboring pore space was not compensable.

²⁸⁵ *Id.* at 989-991.

²⁸⁶ *Id.* at 991.

²⁸⁷ *Id.* at 992.

²⁸⁸ *Id.* at 993.

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Relying on *Willoughby Hills v. Corrigan*,²⁸⁹ the *Chance* court found that “ownership rights in today’s world are not as clear-cut as they were before the advent of airplanes and injection wells.”²⁹⁰ Although landowners may assert that ownership of land extends from heavens to the depths of the earth, their subsurface rights are limited. The court reasoned, “Just as a property owner must accept some limitations on the ownership rights extending above the surface of the property, we find that there are also limitations on property owners’ subsurface rights. We therefore extend the reasoning of *Willoughby Hills*, that absolute ownership of air rights is a doctrine which ‘has no place in the modern world,’ to apply as well to ownership of subsurface rights.”²⁹¹

The *Chance* court did note, however, that even though BP Chemicals was operating pursuant to valid state and federal permits, that in itself did not shield the company from liability.

Although the class claims were ultimately deemed too speculative, the court did indicate that one class member might have a valid claim because the subsurface migration waste forced that member to abandon plans to drill for natural gas.²⁹² Thus, a mineral owner may have a valid trespass claim when the injected waste migrates across property lines and unreasonably interferes with access to recoverable minerals.

The District Court for the Eastern District of Louisiana reached a similar conclusion in *Raymond v. Union Texas Petroleum Corporation*.²⁹³ In *Raymond*, the plaintiffs claimed

²⁸⁹ *Willoughby Hills*, 278 N.E.2d at 664 (“[T]he doctrine of the common law, that the ownership of land extends to the periphery of the universe . . . has no place in the modern world.”) (citing *Causby*, 328 U.S. 256).

²⁹⁰ *Chance*, 670 N.E.2d at 992.

²⁹¹ *Id.*

²⁹² *Id.* at 994.

²⁹³ *Raymond v. Union Texas Petroleum Corporation*, 697 F. Supp. 270 (E.D. La. 1988).

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saltwater injected under adjacent lands had migrated to their subsurface property.²⁹⁴ Because the state regulatory agency issued a permit for the saltwater injection, the federal district court in Louisiana concluded that migration of the saltwater into neighboring pore space “it is not unlawful and does not constitute a legally actionable trespass.”²⁹⁵ However, in dictum, the court did instruct that a permit does not preclude recovery for actual damages and for inconvenience.²⁹⁶

In *Mongrue v. Monsanto*, the United States Court of Appeals for the Fifth Circuit concluded that migrating wastewater did not cause the injecting party to be liable for a taking without just compensation.²⁹⁷ In so doing, the Fifth Circuit affirmed the United States District Court for the Eastern District of Louisiana decision that the appellants (Mongrue) did not establish a claim of unconstitutional taking because Monsanto was not a “private entity authorized by law to expropriate” for a “public and necessary purpose,” as required by the Louisiana Constitution.²⁹⁸ Despite this ruling, the Fifth Circuit indicated they could seek remedies on other grounds.²⁹⁹ To elucidate its holding, the Fifth Circuit cited the district court’s conclusion that “upon a proper showing of damages, appellants may recover under a state unlawful trespass claim against Monsanto regardless of the permit allowing for injection.”³⁰⁰ Unfortunately for the appellants, although they asserted at the district court level that the injector had committed subsurface trespass, the Fifth Circuit did not rule on the issue because

²⁹⁴ *Id.* at 271.

²⁹⁵ *Id.* at 274.

²⁹⁶ *Id.* The court concluded there was no legally actionable trespass in this case, but that a permit does not preclude a landowner from recovering compensation for damage to property or measurable inconvenience (citing *Nunez v. Wainoco Oil & Gas Co.*, 488 So. 2d 955, 964 (La. 1986)).

²⁹⁷ *Mongrue v. Monsanto*, 249 F.3d 422, 432 (5th Cir. 2001).

²⁹⁸ *Id.* at 429-32.

²⁹⁹ *Id.* at 432 n.17.

³⁰⁰ *Id.*

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the appellants agreed to the dismissal (with prejudice) of their trespass claim against Monstanto.³⁰¹ In the same year the *Mongrue* case was decided, the Fifth Circuit affirmed *Raymond* in *Boudreaux v. Jefferson Island Storage & Hub, L.L.C.*, reasoning that migration of injected wastewater is not “unlawful” if a valid regulatory permit authorizes the action.³⁰²

In an Oklahoma case, *West Edmond Salt Water Disposal Ass’n v. Rosecrans*, the defendant injected salt water into a stratum already containing salt water.³⁰³ The Oklahoma Supreme Court found that a neighboring landowner had no cause of action for trespass because the owner had suffered no actual damages. The court explained that no oil or gas was under the plaintiff’s property and “if the formation into which such valueless substance [salt water] is injected is already filled with a similar or identical valueless substance, a portion of which is displaced by the water migrating from the lands of the defendants into and under the lands of the plaintiffs, we are unable to see where any injustice has been done to plaintiffs, or the value of their property or their rights in their property in any wise diminished.”³⁰⁴ The court additionally concluded that underground disposal is the most practical solution for dealing with wastewater and reasoned “[i]f such disposal of salt water is forbidden unless oil producers first obtain the consent of all persons under whose lands it may migrate or percolate, underground disposal would be practically prohibited.” Even so, the Oklahoma Supreme Court recognized a cause of action when actual damages resulting from saltwater injection were proved. In *West Edmond Hunton Lime Unit v. Lillard*, saltwater injected into a formation migrated onto adjacent land and interfered with the plaintiff’s oil and gas

³⁰¹ *Id.*

³⁰² *Boudreaux v. Jefferson Island Storage & Hub, LLC*, 255 F.3d 271, 274 (5th Cir. 2001).

³⁰³ *West Edmond Salt Water Disposal Ass’n v. Rosecrans*, 226 P.2d 965, 970 (Okla. 1950).

³⁰⁴ *Id.*

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operations.³⁰⁵ In affirming an award for the plaintiff, the court characterized the action as a trespass.³⁰⁶

Another example of how interference with oil and gas production resulting from wastewater disposal led a court to conclude an actionable trespass occurred can be found in the case of *Cassinos v. Union Oil Company*.³⁰⁷ Union Oil, the oil and gas lessee on adjacent lands, secured permission from the surface owner to inject wastewater, and obtained the necessary injection well permit from the State of California. The injected wastewater was targeted for a saline aquifer not believed to contain any hydrocarbons. Such did not turn out to be the case. The mineral owner, Cassinos, initiated suit claiming that Union Oil trespassed on its mineral rights by injecting wastewater into oil and gas-producing strata and interfered with oil and gas production. The court was presented with evidence that the wastewater “communicated” with and affected oil wells and other oil and mineral producing areas. Thus, the court held this to be a trespass against the mineral estate and issued an injunction against any further wastewater injection along with a damage award of \$5 million. The *Cassinos* court distinguished this situation from one in which injected wastewater invades strata that are devoid or depleted of mineral resources. Citing *Sunray Oil Co. v. Cortez Oil Co.*,³⁰⁸ the *Cassinos* court suggested that the mineral owner would have no actionable damage claim under the aforementioned circumstances. In *Sunray*, the court found “there is no probability that any possible oil producing formation exists in the land in question which would be materially affected to plaintiff’s detriment by the use of the well in question for the disposal

³⁰⁵ *West Edmond Hunton Lime Unit v. Lillard*, 265 P.2d 730, 731 (Okla. 1954).

³⁰⁶ *Id.*

³⁰⁷ *Cassinos v. Union Oil Company*, 18 Cal. Rptr. 2d 574 (Cal. Ct. App. 1993).

³⁰⁸ *Sunray*, 112 P.2d 792.

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of salt water by defendant.”³⁰⁹ Consequently, the *Sunray* court declined to find an actionable trespass against the mineral estate.

Finally, in an unreported Texas case, *FPL Farming Ltd. v. Texas Natural Resource Conservation Commission*,³¹⁰ the Texas Court of Appeals for the Third District adjudicated plaintiff’s claim that the Texas Natural Resource Conservation Commission’s grant of two permits for injection of waste 7,350 to 8,200 feet below the surface into a salt water formation under the plaintiff’s property constituted a taking of private property without just compensation. The court noted the legal trend that “property owners do not have the right to exclude deep subsurface migration of fluids” and rejected the argument that “migration alone will impair [their] existing rights.” “[B]ecause of [the agency’s]...expertise in the geological effects of subsurface migration of injectates,” the court deferred to the agency’s finding that no existing rights would be impaired by the injection. The court did, however, indicate that landowners could seek damages from the injector if the waste migrated and caused some measure of harm. Although the plaintiff testified that the two permits issued by the Conservation Commission (which were the heart of the controversy) precluded the plaintiff from acquiring its own permit to store salt water or inject waste into the pore space beneath its property, the court found there was no evidence that the existing permits would impede the plaintiff’s ability to use the pore space for such purposes in the future.

As for the takings claim itself, the court rejected the argument that the act of issuing the permits on the part of the Conservation Commission amounted to a *per se* taking under

³⁰⁹ *Id.* at 795. The court also cited *Rosecrans*, 226 P.2d 965.

³¹⁰ *FPL Farming, Ltd. v. Texas Natural Res. Conservation Comm’n*, No. 03-02-00477-CV, 2003 WL 247183 (Tex. App. Ct.—Austin 2003 Feb. 6, 2003, rev. denied).

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*Loretto v. Teleprompter Manhattan CATV Corp.*³¹¹ The court found that *Loretto* did not apply because the plaintiff could not show that migration of the waste would prevent it from engaging in brine mining or waste injection operations. In other words, the plaintiff failed to establish it lost the right or the ability to use the property. The court concluded that plaintiff could seek damages from the well operator for any actual harm caused by the migration of injected waste into the plaintiff's pore space because the mere possession of a permit did not shield operator from civil liability.

2.5.2.1 Fluid Waste Implications for GCS

Unlike the natural gas storage case law, the underground waste injection cases show that courts have consistently rejected any notion that property owners have the absolute right prevent the underground migration of fluid waste into their pore space, or are entitled to compensation for such use of their pore space, when the waste injection is conducted pursuant to regulatory approval. In each case, the courts placed great weight on the public interest and regulatory approval associated with the underground injection of fluid wastes, modifying the common law doctrines relating to subsurface property rights accordingly. At the same time, though, each of the courts held open the possibility that a plaintiff could recover damages if it could show that the migration of injected waste caused actual harm to, or interference with the use of, its property.

While the *Chance* court's logic for drawing a distinction between the gas storage and waste injection contexts is scant, the practical effect of the decision is sound. For instance, no structural or geophysical difference exists between the pore spaces at issue in *Columbia Gas*

³¹¹ *Loretto*, 458 U.S. 419.

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Transmission and Chance.³¹² In fact, gas storage facilities have been constructed in the same sandstone formation, the Mt. Simon, as was used for the particular hazardous waste wells at issue in *Chance*. Thus, while one could reasonably argue that geologic strata are of little use to most surface owners, an expectation on the part of a landowner to have the opportunity to lease or sell pore space for natural gas storage is “reasonable and foreseeable” under the *Chance* standard for finding an actionable trespass occurred. Even so, in *Chance*, notice to potential members of the class affected by BP Chemical’s hazardous waste injection operation had to be sent to more than 20,000 landowners. Those property owners not wishing to be involved sent in requests to opt out of the class. Considering the enormous number of plaintiffs involved in this case, if the court concluded that all class members were entitled to compensation for the mere migration of hazardous waste into their pore space, the entire practice of underground fluid waste injection would most likely have been curtailed in Ohio. Such an outcome would be detrimental because of the public safety benefits derived from having fluid wastes disposed of thousands of feet underground instead of in surface tanks or pools.

Today, use of the Mt. Simon has been proposed for geologic sequestration of CO₂ as well. Since sequestered CO₂ could migrate laterally over a very sizeable area (e.g., 100s to 1,000s of square-miles),³¹³ requiring project developers to obtain consent from all pore space owners within the migratory path of the CO₂ plume could have the practical effect of prohibiting the development of many sequestration projects due to potentially crippling cost of such an

³¹² See *Columbia Gas*, 620 N.E.2d 48; *Chance*, 670 N.E.2d 985.

³¹³ See Pruess, K.; Xu, T.; Apps, J.; Garcia, J. *Numerical Modeling of Aquifer Disposal of CO₂*. In SPE/EPA/DOE Exploration and Production Environment Conference, Society of Petroleum Engineers; San Antonio, TX (2001); Brennan, S.T.; Burruss, R.C. *Specific Storage Volumes: A Useful Tool for CO₂ Storage Capacity Assessment*. Nat. Resour. Res. 2006, 15(3), 165, 182.

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obligation. If *Chance* is followed, sequestration project developers would not need to acquire pore space rights prior to commencing operations, only an injection permit. However, should injected CO₂ cause actual damages to neighboring properties or impair “reasonable or foreseeable” uses of pore space owned by neighboring property-owners, the sequestration project operator would be liable for trespass.

2.5.3 Enhanced Hydrocarbon Recovery, Field Unitization, and Hydraulic Fracturing

We conclude that if, in the valid exercise of its authority to prevent waste, protect correlative rights, or in the exercise of other powers within its jurisdiction, the Commission authorizes secondary recovery projects, a trespass does not occur when the injected, secondary recovery forces move across lease lines, and the operations are not subject to an injunction on that basis.³¹⁴

For decades, oil and gas production companies have injected fluids (often water or CO₂) into the subsurface to increase production from depleted fields. This process, known as enhanced oil recovery (EOR), or secondary recovery, re-pressurizes the reservoir and can significantly increase oil recovery. Trespass issues can arise when an EOR operator injects fluids into the subsurface of its own property and the fluid then invades the subsurface of neighboring property. Compensable damages can result when oil reserves on the invaded property are displaced, or when the invasion makes recovery of such reserves more difficult or expensive. Judicial decisions addressing subsurface trespass allegations in the enhanced-recovery operations are mixed, but several cases suggest that a compensable trespass claim is less

³¹⁴ *Railroad Commission v. Manziel*, 361 S.W.2d 560, 568 (Tex. 1962).

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likely to succeed if a regulatory agency authorized the particular operation brought before the bench for trial.

Most enhanced-recovery operations take place in a field that has been “unitized” pursuant to state regulatory board orders. With “field unitization,” individual production leases are combined, with production being carried-out by a designated unit operator, while the profits are shared by the unit members. The property rights of landowners in the unitized area are addressed by state unitization laws, which may allow the unit operator to proceed regardless of whether they are able to reach agreement with all landowners. Most states require agreement by a minimum percentage (ranging from 50% to 85%) of owners in a reservoir to authorize compulsory unitization.³¹⁵ Some states have no such requirement.³¹⁶ Even when unitization of entire reservoir does not occur, regulatory officials may approve agreements creating a partially unitized field. In those states allowing for unitization, common law has evolved to protect unit operators against trespass claims made by “hold-out” landowners who decline the opportunity to participate in the unit. This protection, sometimes referred to as the “negative rule of capture,” is based on the public interest in efficient oil production. Allowing hold-outs within the unit area to sue for damages would defeat the state’s goal of facilitating resource conservation through unitized production.

As with title issues, regulatory bodies have no general authority to authorize trespasses or other torts. However, an early Texas cases suggests that regulatory orders may provide some

³¹⁵ *See, e.g.*, Cal. Pub. Res. Code § 3643(b) (allowing forced unitization if 75% of royalty interests and working interests agree to unitize).

³¹⁶ *See, e.g.*, 16 Tex. Admin. Code § 3.40.

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protection. In *Railroad Commission v. Manziel*,³¹⁷ the plaintiff landowners sought to set aside a commission order authorizing the operator of an adjacent tract to drill an exception-location well close to their tract to inject water for EOR.³¹⁸ The exception well was permitted under the auspices of a commission-approved voluntary-unitization plan.³¹⁹ The landowners sought to set aside the order on the ground that water injected at that location would inevitably cross ownership lines, resulting in a trespass and the early watering-out of one of their oil wells.³²⁰

The court stated that it was presented with the issue of “whether a trespass is committed when secondary recovery waters from an authorized secondary recovery project cross lease lines.”³²¹ After discussing the utility of EOR operations the court stated, “We conclude that if, in the valid exercise of its authority to prevent waste, protect correlative rights, or in the exercise of other powers within its jurisdiction, the Commission authorizes secondary recovery projects, a trespass does not occur when the injected, secondary recovery forces move across lease lines, and the operations are not subject to an injunction on that basis. The technical rules of trespass have no place in the consideration of the validity of the orders of the Commission.”³²² To apply the general rules of surface invasions would interfere with the public policy considerations behind secondary recovery operations which, the court found, should be encouraged as a matter of “public necessity.”³²³ In reaching its decision, the court referenced Professors Howard Williams and Charles Meyers:

³¹⁷ *Manziel*, 361 S.W.2d 560.

³¹⁸ *Id.* at 561.

³¹⁹ *Id.*

³²⁰ *Id.* at 561-65.

³²¹ *Id.* at 567.

³²² *Id.* at 568-69.

³²³ *Id.* at 568.

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What may be called a “negative rule of capture” appears to be developing. Just as under the rule of capture a landowner may capture such oil or gas as will migrate from adjoining premises to a well bottomed on his own land, so also may he inject into a formation substances which may migrate through the structure to the lands of others, even if it thus results in the displacement under such land of more valuable substances...³²⁴

The *Manziel* case might be more assuring if it had been brought against the unit operator rather than having been an action to set aside a Railroad Commission order. While the consideration of trespass may have “no place” in a proceeding to determine the validity of a Commission order, trespass would be apposite in a private tort action. The *Manziel* court appeared to acknowledge this distinction:

[W]e are not confronted with the tort aspects of such practices. Neither is the question raised as to whether the Commission’s authorization of such operations throws a protective cloak around the injecting operator who might otherwise be subjected to the risks of liability for actual damages o the adjoining property...³²⁵

Even so, the *Manziel* court did discuss trespass in detail, and was sympathetic to the view that traditional rules of trespass may not be appropriate for subsurface invasions that are the result of an activity carried-out in the public’s best interest. The court seems to suggest that a

³²⁴ *Id.* at 569 (quoting Howard Williams & Charles Meyers: Oil and Gas Law, § 204.5 (1995)).

³²⁵ *Id.* at 566.

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regulatory approval, issued in the public interest, is required if traditional trespass rules are to be avoided.

The Alabama Supreme Court reached a similar decision in *Phillips Petroleum Co. v. Stryker*,³²⁶ where enhanced-recovery through injection of dry gas within a unitized oil and gas field allegedly drained the plaintiff's oil reserves.³²⁷ In reversing a jury award of \$26.9 million to the plaintiff based on claims of trespass, negligence, fraud, and nuisance, the court found that to hold the defendant liable would be against the state's policy to promote secondary recovery in order to prevent oil and gas waste.³²⁸ Instead of suing for damages, the court explained that the plaintiff should have engaged in his own recovery operations, or sought to participate in the unit.³²⁹

The Louisiana Supreme Court has also allowed the public interest in field unitization to trump the absolute protection of subsurface property rights. In *Nunez v. Wainoco Oil & Gas Co.*,³³⁰ the court rejected a landowner's trespass claim against a well operator where the operator drilled a well that allegedly bottomed out on the plaintiff's property two miles below the surface.³³¹ Notably, the plaintiff's property was within a unitized area created by the Commissioner of Conservation, but the plaintiff declined to lease his land to the defendant, who was authorized to create and operate the unit.³³² In rejecting the plaintiff's trespass claim, the *Nunez* court recognized that Louisiana law historically allowed claims of

³²⁶ *Phillips Petroleum Co. v. Stryker*, 723 So. 2d 585 (Ala. 1998).

³²⁷ *Id.* at 586.

³²⁸ *Id.* at 591.

³²⁹ *Id.*

³³⁰ *Nunez*, 488 So.2d 955.

³³¹ *Id.* at 956-58.

³³² *Id.* at 956.

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subsurface trespass where a well bottoms out on the land of another without his or her consent.³³³ Here, though, the court found that the state's creation of the Conservation Commission, along the state's policy to ensure that "an irreplaceable natural resource should not be subjected to avoidable waste,"³³⁴ created "a qualification of sorts in one's rights in private property."³³⁵ In light of these statutory developments and the current regulatory structure favoring unitization as the method to reconcile the correlative rights of resource owners in a common pool, the court found there was no legally actionable trespass in the case.³³⁶

In *Crawford v. Hrabe*,³³⁷ the Kansas Supreme Court found that a lessee (Crawford) was not prohibited from injecting off-site wastewater into the lessor's (Hrabe) subsurface for the secondary recovery of oil, nor was he liable for trespass.³³⁸ The court surveyed other jurisdictions' treatment of subsurface trespass of wastewater, discovering that the orthodox rules of trespass applied to surface trespass do not usually apply to the subsurface, and that when water is injected to increase production on the lessor's land, no actionable trespass occurs.³³⁹ The Kansas Supreme Court reasoned that injecting wastewater for enhanced-recovery operations was a practical and efficient use of a potentially hazardous waste product.³⁴⁰

³³³ *Id.* at 958-59.

³³⁴ *Id.* at 960.

³³⁵ *Id.* at 962.

³³⁶ *Id.* at 964.

³³⁷ *Crawford v. Hrabe*, 44 P.3d 442 (Kan. 2002).

³³⁸ *Id.* at 452 (citing *Holt v. Sw. Antioch Sand Unit, Fifth Enlarged*, 292 P.2d 998 (Okla. 1955)).

³³⁹ *Id.* at 448-50; *Manziel*, 361 S.W.2d 560; *Geo-Viking, Inc. v. Tex-Lee Operating Co.*, 817 S.W.2d 357 (Tex. Civ. App. 1991)).

³⁴⁰ *Crawford*, 44 P.3d at 583.

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In *Syverson v. North Dakota Industrial Commission*,³⁴¹ the court upheld the North Dakota Industrial Commission's order authorizing a unitized enhanced-recovery operation over the objection of a small number of lessors where the record indicated that they were given a fair opportunity to join the unit but refused to do so.³⁴² The court noted that the unit operations were ultimately designed to increase recovery from the reservoir, and that the lessors were not entitled to complain in the absence of any evidence showing actual damages.³⁴³ The lessors presented no evidence whatsoever to support their opposition to the formation of the unit.³⁴⁴

In *Tidewater Oil Co. v. Jackson*,³⁴⁵ the United State Court of Appeals for the 10th Circuit held that the injection of wastewater for enhanced-recovery constitutes an actionable trespass when the injected water flooded the neighboring plaintiff's oil wells, even though the operator held a regulatory permit authorizing the operations.³⁴⁶ The court explained:

[T]hough a water flood project in Kansas be carried on under color of public law, as a legalized nuisance or trespass, the water flooder may not conduct operations in a manner to cause substantial injury to the property of a non-assenting lessee-producer in the common reservoir, without incurring risk of liability therefor.³⁴⁷

³⁴¹ *Syverson v. North Dakota Industrial Commission*, 111 N.W.2d 128 (N.D. 1961).

³⁴² *Id.* at 131,134.

³⁴³ *Id.* at 131.

³⁴⁴ *Id.* at 134.

³⁴⁵ *Tidewater Oil Co. v. Jackson*, 320 F.2d 157 (10th Cir. 1963).

³⁴⁶ *Id.* at 162.

³⁴⁷ *Id.* at 163.

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To establish liability, “[i]t is sufficient that the water flooding activities were intentional and the consequences foreseeable. They were actionable, even though lawfully carried on, if they caused substantial injury to the claimants.”³⁴⁸ But because the activity was lawful under a conservation agency order, the 10th Circuit reversed an award for punitive damages.

Similarly, in *Hartman v. Texaco Inc.*,³⁴⁹ the New Mexico Court of appeals concluded that an oil and gas operator who suffered actual damages from a water flooding operation conducted on neighboring lands had a cause of action for trespass.³⁵⁰ However, the court rejected the plaintiff’s claim for statutory recovery of double (punitive) damages, concluding that the statute did not apply in the case of a subsurface trespass.³⁵¹

Oklahoma recognizes a cause of action for private nuisance when injected water actually injures a neighbor, even though the injection is authorized by the Corporation Commission for secondary hydrocarbon recovery.³⁵² This supports the idea that if there is actual interference with commercial use of the subsurface, some recovery under tort law may be warranted even if the defendant’s operations are authorized by a regulatory commission or agency. This is consistent with case law in other states, where plaintiffs have been able to recover for actual damages resulting from enhanced-recovery operations.³⁵³

³⁴⁸ *Id.* at 164.

³⁴⁹ *Hartman v. Texaco Inc.*, 937 P.2d 979 (N.M. Ct. App. 1997).

³⁵⁰ *Id.* at 980.

³⁵¹ *Id.* (construing N.M. STAT. § 30-14-1.1 (1978)).

³⁵² See *Gulf Oil Corp. v. Hughes*, 371 P.2d 81 (Okla. 1962); *Boyce v. Dundee Healdton Sand Unit*, 560 P.2d 234 (Okla. Civ. App. 1975); *Greyhound Leasing & Fin. Corp. v. Joiner City Unit*, 444 F.2d 439 (10th Cir. 1971).

³⁵³ See *Boyce*, 560 P.2d at 237 (granting recovery for nuisance claim for damages caused by water flooding); *Greyhound Leasing*, 444 F.2d at 440 (granting recovery based on private nuisance for damage caused by salt water encroachment associated with secondary recovery operations).

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In a decision by the United States Court of Appeals for the Eighth Circuit, the court found that a claim of trespass will succeed when a mineral owner seeks to recover for damages in the circumstance where the mineral owner's tract lies within the unit area of injection wells used for enhanced-recovery operations.³⁵⁴ This holding was embraced by the Arkansas Supreme Court in *Jameson v. Ethyl Corp.*³⁵⁵ The court required the unit operator to account and pay damages for production drained from the plaintiff's (a fee mineral owner) property that was attributable to the enhanced-recovery operations, though the court did permit water-flooding operations to continue on public policy grounds.³⁵⁶ The court explained:

[W]e are unwilling to extend the rule of capture further. By adopting an interpretation that the rule of capture should not be extended insofar as operations relate to lands lying within the peripheral area affected, we, however, are holding that reasonable and necessary secondary recovery processes of pools of transient minerals should be permitted, when such operations are carried out in good faith for the purpose of maximizing recovery from a common pool. The permitting of this good faith recovery process is conditioned, however, by imposing an obligation on the extracting party to compensate the owner of the depleted lands for the minerals extracted in excess of natural depletion, if any, at the time of taking and for any special damages which may have been caused to the depleted property.³⁵⁷

³⁵⁴ *Young v. Ethyl Corp.*, 521 F.2d 771, 774 (8th Cir. 1975).

³⁵⁵ *Jameson v. Ethyl Corp.*, 609 S.W.2d 346 (Ark. 1980).

³⁵⁶ *Id.* at 351.

³⁵⁷ *Id.* at 351.

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In *Baumgartner v. Gulf Oil Corp.*,³⁵⁸ the Nebraska Supreme Court found that no trespass results from water-flooding when the plaintiff (the holder of an oil and gas lease) rejected a fair and reasonable offer to participate in a unitization plan approved by the Nebraska Oil and Gas Conservation Commission.³⁵⁹ The court did, however, indicate that the plaintiff may be entitled to recover any profits he could prove would have been realized through continued primary recovery operations uninhibited by the neighboring enhanced-recovery operations, in which he declined to participate.³⁶⁰

In contrast to water-flooding operations for enhanced-recovery of hydrocarbons, trespass issues posed by hydraulic fracturing, or fracing, did not until recently receive favorable treatment by the courts. The process of fracing stimulates “tight” formations containing oil or natural gas by pumping fluid (typically water) and proppants (sand, ceramic beads, or bauxite that follow the fluid and prop open the cracks in the rock) down the production well at high pressure in order to create cracks in the rock, which increase the permeability of the formation, thus allowing the oil and gas contained therein to flow. In *Gregg v. Delhi-Taylor Corp.*, the Texas Supreme Court held that courts, not the Railroad Commission, have primary jurisdiction to determine whether a fracturing operation may result in a trespass and whether relief is appropriate.³⁶¹ By analogizing cracks that result from fracing operations and cross property lines to drill bits that cross property lines, the *Gregg* court characterized the cracks as a direct and intentional invasion and could thus constitute a subsurface trespass.³⁶²

³⁵⁸ *Baumgartner v. Gulf Oil Corp.*, 168 N.W.2d 510 (Neb 1969).

³⁵⁹ *Id.* at 516.

³⁶⁰ *Id.* at 519.

³⁶¹ *Gregg v. Delhi-Taylor Oil Corp.*, 344 S.W.2d. 411, 415 (Tex. 1961).

³⁶² *Id.* at 416-17.

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In *Geo-Viking, Inc. v. Tex-Lee Operating Co.*,³⁶³ the Texas Supreme Court initially upheld its ruling in *Gregg*. In this case, the operator of an oil well, Tex-Lee, sued a well-service company, Geo-Viking, for improperly fracing a well.³⁶⁴ On appeal, Geo-Viking argued that the trial court should have instructed the jury to disregard the amount of oil production obtained from fractures extending beyond the boundaries of the production unit leased by Tex-Lee.³⁶⁵ The Texas Court of Appeals for the Sixth District rejected Geo-Viking's argument, citing the rule of capture, which "permits the owner of a tract to drill as many wells on his land as the Railroad Commission will allow and provides that he is not liable to adjacent landowners whose lands are drained as a result of his operations."³⁶⁶ As noted earlier in this paragraph, the Texas Supreme Court originally reversed the appellate court's decision, finding that the rule of capture is precluded in the context of hydraulic fracturing, and that a trespass therefore occurs when adjacent lands are fractured.³⁶⁷ However, the Texas Supreme Court eventually withdrew its opinion and its writ of error at the request of the parties, declaring that the "application [of the writ of error] was improvidently granted"³⁶⁸ and concluded that "we should not be understood as approving or disapproving the opinions of the court of appeals analyzing the rule of capture or trespass as they apply to hydraulic fracturing."³⁶⁹ Unfortunately, the Texas Supreme Court's decision created more confusion than clarity as to whether hydraulic fracturing across property boundaries amounts to a trespass.

³⁶³ *Geo-Viking*, 839 S.W.2d 797 (Tex. 1992).

³⁶⁴ *Geo-Viking, Inc. v. Tex-Lee Operating Co.*, 817 S.W.2d 357, 364 (Tex. App. 1991).

³⁶⁵ *Id.* at 363-64.

³⁶⁶ *Id.* at 364 (citing *Brown v. Humble Oil & Ref. Co.*, 83 S.W.2d 935, 940 (Tex. 1935)).

³⁶⁷ *Geo-Viking*, 839 S.W.2d 797.

³⁶⁸ *Id.* at 798.

³⁶⁹ *Id.*

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In 2005, in the case of *Mission Resources, Inc. v. Garza Energy Trust*,³⁷⁰ the Texas Court of Appeals for the Thirteenth District held that Texas recognizes a cause of action for trespass resulting from hydraulic fracturing operations that cross property lines.³⁷¹ The *Mission* court rejected the decision of the Court of Appeals for the Sixth District in *Geo-Viking*,³⁷² relying on the Texas Supreme Court's holding in *Gregg*.³⁷³

In 2008, the Texas Supreme Court revisited the issue of hydraulic fracturing and this time reversed the ruling in *Mission*, holding that hydraulic fracturing was not an actionable trespass because the drainage of hydrocarbons by this means of production was protected by the rule of capture.³⁷⁴ The case, *Coastal Oil & Gas Corp. v. Garza Energy Trust*,³⁷⁵ presented the Texas Supreme Court with the question of whether a defendant well operator engaged in fracturing would be liable for trespass if proppants used in the process migrated to the plaintiff's land two miles below the surface and drained the oil and gas on the plaintiff's property. The court reasoned that trespass requires actual injury and that trespass injury should not be inferred when the physical invasion occurs far below the surface. The court also explained that it should not usurp the lawful authority of the Texas Railroad Commission to decide to regulate or not regulate fracturing; should not allow the litigation process to determine the extent of harm (drainage) that is caused by fracturing; and should not allow an actionable trespass (by changing the rule of capture) when the oil and gas industry does not "want or need the change."³⁷⁶ Moreover, the court reasoned, allowing litigation over recovery for

³⁷⁰ *Mission Resources, Inc. v. Garza Energy Trust*, 166 S.W.3d 301 (Tex. App. 2005).

³⁷¹ *Id.* at 310

³⁷² *Geo-Viking*, 817 S.W.2d at 364.

³⁷³ *Mission Resources*, 166 S.W.3d at 311.

³⁷⁴ *Garza*, 268 S.W.3d 1.

³⁷⁵ *Id.*

³⁷⁶ *Id.* at 14-16.

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draining resulting in fracking would force judges and juries to make difficult factual determinations based on proof “hidden below miles of rock” and render decisions without taking into account “social policies, industry operations, and the greater good,” which are important in determining to what extent fracking should subject to tort liability.³⁷⁷ The court ultimately held that subsurface draining of oil and gas through fracking was not actionable in tort, but that non-draining damages to wells or the oil and gas formation might be. In a concurring opinion, Justice Willett indicated he would have gone further and held that, not only was fracturing not an actionable trespass, it was not a trespass at all.³⁷⁸ His concurring opinion discussed the necessity of hydraulic fracturing to the recovery of hydrocarbons.

2.5.3.1 Enhanced Hydrocarbon Recovery & Hydraulic Fracturing Implications for GCS

In all of these cases, the courts placed great emphasis on the states’ statutory policies encouraging enhanced-recovery operations to promote the public’s interest in efficient production of natural resources. The courts focused on the existence of a state regulatory body to balance the needs of various rights-holders, and refused tort recovery for those who declined to participate in unitization. These cases do, however, signal willingness by the courts to allow future plaintiffs recovery where there is actual damage to, or interference with the use of, plaintiff’s tangible property. Simply stated, the courts have refused any absolute protection of property rights in the deep subsurface, but have preserved limited protection that would allow property owners to recover monetary compensation for damage to property caused by actual and substantial harm or interference. Allowing recovery for actual damage to property is different from finding that a landowner possesses the type of property right in

³⁷⁷ *Id.* at 16.

³⁷⁸ *Garza*, 268 S.W.3d at 29 (Willett, J., concurring).

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the subsurface that empowers the him/her to prevent others from injecting fluids into the pore space underlying the landowner's property; it is this type of absolute ownership doctrine the courts seem to have clearly rejected in the context of enhanced hydrocarbon recovery. This judicial approach to pore space rights supports the notion that GCS project developers could be authorized to access and use pore space without being required to seek permission from landowners, or compensate landowners for the right, to permanently sequester CO₂ in the deep subsurface.

2.5.4 Groundwater Storage and Recharge

*Pore space is subject to a "public servitude for water and water conserving purposes."*³⁷⁹

A handful of states have mature permitting regimes to facilitate the storage of freshwater underground so that it may be withdrawn during dry periods. Aquifer storage and recovery (ASR), as this method of water storage is commonly known, is a promising solution for the future of freshwater management.³⁸⁰ However, in spite of relatively well-developed permitting programs in several states, Courts have rarely discussed the issue of subsurface property rights in the context of underground storage of fresh water.³⁸¹ California and Colorado are the exception. Both states have dealt with the issue directly, and both concluded that aquifer storage space is a public resource.³⁸²

³⁷⁹ *Alameda County Water District v. Niles Sand & Gravel Co.*, 112 Cal. Rptr. 846, 851 (Ct. App. 1974).

³⁸⁰ Peter J. Kiel & Gregory A. Thomas, *Banking Groundwater in California: Who Owns the Aquifer Storage Space?* 18-Fall, Nat. Res. & Env't 25 (2003).

³⁸¹ Tara L. Taguchi, Comments, *Whose Space is it Anyway? Protecting the Public Interest in Allocating Storage Space in California's Groundwater Basins.* 32 Sw. U. L. Rev. 117, 119 (2003), quoting Scott Slater, *California Water Law and Policy* 11-51 (1995).

³⁸² See *Alameda County*, 112 Cal. Rptr. at 851; *Board of County Commissioners v. Park County Sportsmen's Ranch, LLP*, 45 P.3d 693 (Colo. 2002).

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2.5.4.1 California

The constitution of the State of California confers broad powers on the state to safeguard its water supply and to apply it to maximum beneficial use. Article X, section 2 provides in part:

...because of the conditions prevailing in this State the general welfare requires that the water resources of the State be put to beneficial use to the fullest extent of which they are capable, and that the waste or unreasonable use or unreasonable method of use of water be prevented, and that the conservation of such waters is to be exercised with a view to the reasonable and beneficial use thereof in the interest of the people and for the public welfare.³⁸³

Although this constitutional provision continues by explicitly referring to surface waters, it has been judicially interpreted as applying to all natural waters in the state,³⁸⁴ including waters artificially stored underground.³⁸⁵ With such a broad constitutional sanction allowing police power regulation of California's water resources, it is not surprising that California courts established a public right to use subsurface pore space for storage.³⁸⁶

The leading case is *City of Los Angeles v. City of Glendale*.³⁸⁷ In *Glendale*, the California Supreme Court held that Los Angeles could inject water into an underground aquifer and

³⁸³ CAL. CONST. art. X, § 2 (West Supp. 1977) (formerly art. XIV, § 3).

³⁸⁴ *Joslin v. Marin Mun. Water Dist.*, 429 P.2d 889 (1967).

³⁸⁵ *See Alameda County*, 112 Cal. Rptr. 846.

³⁸⁶ *See generally* Krieger & Banks, *Ground Water Basin Management*, 50 CALIF. L. REV. 56 (1962).

³⁸⁷ *City of Los Angeles v. City of Glendale*, 142 P.2d 289 (Cal 1943).

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retain its senior rights to that water as against other cities pumping water from aquifers.³⁸⁸ In analogizing the use of underground storage space to use of a stream bed, the *Glendale* court relied on a California statute that codified a rule of law which had been developed during the mining days.³⁸⁹ The statute provides that any person may transport imported water in a natural stream bed and later reclaim it as long as his reclamation does not thereby diminish the water already lawfully appropriated by another.³⁹⁰ The court explained that the purpose of that rule was to avoid the construction of artificial waterworks when natural water facilities would accomplish the same purpose, and applied the logic of that rule to underground storage facilities, stating that “[i]t would be as harsh to compel plaintiff to build reservoirs when natural ones were available as to compel the construction of an artificial ditch beside a stream bed.”³⁹¹

The ruling in *Glendale* was reaffirmed in the California Supreme Court’s landmark decision in *City of Los Angeles v. City of San Fernando*.³⁹² The court extended *Glendale* by holding, in effect, that under another section of the California Water Code,³⁹³ mutual prescription³⁹⁴ of public water rights was barred.³⁹⁵ The effect of *San Fernando* was to prevent any private

³⁸⁸ *Id.* at 294.

³⁸⁹ *Id.*

³⁹⁰ CAL. WATER CODE § 7075 (2009).

³⁹¹ *Glendale*, 142 P.2d at 294.

³⁹² *City of Los Angeles v. City of San Fernando*, 537 P.2d 1250, 1297 (Cal. 1975) (holding that the City of Los Angeles “is entitled to use the San Fernando basin for temporary storage of its water by means of artificial recharge and subsequent recapture.”)

³⁹³ CAL. CIV. CODE § 1007 (West Supp. 1977).

³⁹⁴ Mutual prescription is a groundwater doctrine stating that in the event of an overdraft of a ground-water basin, the available ground water will be apportioned among all the users in amounts proportional to their individual pumping rates. The doctrine was first proclaimed in *City of Pasadena v. City of Alhambra*, 207 P.2d 17 (1949). The *Pasadena* court held that the commencement of an overdraft created a situation of adverse use against existing pumpers sufficient to establish rights in all users after the statutory period had run, necessitating pro rata reductions in the amounts which all pumpers were permitted to extract.

³⁹⁵ *San Fernando*, 537 P.2d at 1297-1313.

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rights from attaching to public waters by prescription.³⁹⁶ As a consequence of *San Fernando*, a public body in California can import waters and use such waters to recharge groundwater basins without concern that third parties might, by capturing and using some of the artificially stored waters, establish prescriptive rights to the continued use of a portion of those waters. This judicial protection of a public entity's investment in underground storage and transmission was a significant factor in reducing the cost of such projects.

Neither *Glendale* nor *San Fernando* expressly discussed ownership of aquifer pore space, rather the ability to use pore space for ASR without compensating the owner was assumed. At least one commentator believes that *San Fernando*'s "reaffirmation of [*Glendale*] manifests a clear judicial recognition of the right to store imported waters underground so long as that storage does not impair native groundwater rights."³⁹⁷ What is more, neither case directly considered trespass as a barrier to aquifer storage and recovery. Instead, these cases focused on a water user's right to store surface waters underground and subsequently recapture that water without interference from other groundwater appropriators. That is, real property rights in pore space may only be implied by the holdings in *San Fernando* and *Glendale*. However, "[t]he California Supreme Court's sanctioning of such storage without any recognition of a proprietary right on behalf of overlying owners suggests that overlying owners cannot object to groundwater storage beneath their property absent a showing of harm to a recognized right associated with their property ownership..."³⁹⁸

³⁹⁶ *Id.* at 1307.

³⁹⁷ Victor E. Gleason, *Water Projects Go Underground*, 5 Ecology L.Q. 625, 640 (1976).

³⁹⁸ Kiel & Thomas, *supra* note 261, at 28.

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Perhaps the most significant California decision for ASR is *Alameda County Water District v. Niles Sand & Gravel Co.*³⁹⁹ While *San Fernando* established a public right to transport and store imported waters underground, *Niles* extended underground public storage rights to limit overlying private property rights. *Niles* expressly recognized that the protection of underground storage capacity and a basin's water supply may require that otherwise legitimate activities overlying landowners be regulated.⁴⁰⁰ *Niles* involved the activity of a private company engaged in sand and gravel mining. As part of its operation, it pumped large quantities of groundwater out of its pits and into a flood control channel that flowed into the San Francisco Bay.⁴⁰¹ After *Niles* engaged in its mining activity for ten years, the Alameda County Water District began recharging the groundwater basin with imported water. In seven years, the recharge raised the water table in the basin to the point at which the flow of groundwater into the pit seriously threatened the mining operation. Eventually, *Niles* instituted an inverse condemnation suit against the Water District claiming damages to his mining operation allegedly caused by the seepage of recharged groundwater into the gravel pit.⁴⁰² The Water District countered by asking the court to enjoin *Niles* from pumping groundwater out of its pit and to award damages for groundwater previously pumped from the pit.⁴⁰³ The trial court ruled in favor of the Water District,⁴⁰⁴ and the court of appeal affirmed.⁴⁰⁵ The trial court concluded that *Niles*'s pore space was subject to a "public servitude for water and water conservation purposes."⁴⁰⁶ The court of appeal explained that because the ASR program was a legitimate exercise of the Water District's police power, the

³⁹⁹ *Alameda County Water District*, 112 Cal. Rptr. 846.

⁴⁰⁰ *Id.* at 855.

⁴⁰¹ *Id.* at 847.

⁴⁰² *Alameda County*, 112 Cal. Rptr. at 847.

⁴⁰³ *Id.* at 847-48.

⁴⁰⁴ *Id.* at 848.

⁴⁰⁵ *Id.* at 846.

⁴⁰⁶ *Id.* at 851 (quoting the trial court).

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adverse effect on Nile's property was not compensable.⁴⁰⁷ Furthermore, the *Niles* court denied damages to the gravel pit for inverse condemnation and held instead that Niles was making an unreasonable use of underground storage space.⁴⁰⁸ By linking property rights in underground storage space to groundwater rights, the *Niles* court relied on the broad police power to protect water resources given to the state by the California constitution.⁴⁰⁹ By relying on the fact that water has been generally singled out for special treatment,⁴¹⁰ California has been able to treat underground storage rights in a significantly different manner than it might have if it had been faced with the question of underground storage rights for other minerals.

Interestingly, California codified the common law rule that surface owners have the rights in anything permanently situated beneath the surface.⁴¹¹ In developing the doctrine of correlative rights, however, California courts have refused to apply the doctrine of absolute ownership⁴¹² to groundwater since groundwater is not permanently situated beneath the surface. This enabled the *Niles* court to find a servitude in the form of an underground storage right to predicated on the correlative rights exception carved out of the common law rules.⁴¹³ This public servitude was held to restrain overlying landowners from discharging more than their reasonable share of groundwater found in the basin.⁴¹⁴

⁴⁰⁷ *Id.* at 855.

⁴⁰⁸ *Id.* at 853.

⁴⁰⁹ Clark, Western Ground Water Law, in 5 WATERS AND WATER RIGHTS §§ 18.1-18.2 (R. Clark ed. 1972).

⁴¹⁰ Comprehensive statutes provide extensive regulation of all waters in California. The general state policy, to regulate all waters in a manner that will maximize their beneficial use, is found in CAL. WATER CODE §§ 100-108 (West 1971).

⁴¹¹ The statute provides: "RIGHTS OF OWNER. The owner of land in fee has the right to the surface and to everything permanently situated beneath or above it." CAL. CIV. CODE § 829 (West 1954).

⁴¹² *Katz v. Walkinshaw*, 74 P. 766 (1903).

⁴¹³ *Alameda County*, 112 Cal. Rptr. at 853.

⁴¹⁴ *Id.*

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2.5.4.2 Colorado

The Colorado Supreme Court ruled that storing water in aquifer pore does not constitute a trespass. In *Board of County Commissioners v. Park County Sportsmen’s Ranch, LLP*,⁴¹⁵ the plaintiffs tried, by analogy to mineral law,⁴¹⁶ to assert their ownership of the pore space under their property. Like the Ohio Supreme Court in *Chance*, the Colorado Supreme Court in *Park County* relied on the reasoning of the U.S. Supreme Court in *Causby*, holding that “[j]ust as a property owner must accept some limitations on the ownership rights extending above the surface of the property, we find that there are also limitations on property owners’ subsurface rights.”⁴¹⁷ The court rejected the application of mineral law, holding that mineral law is a special body of law distinct from water law.⁴¹⁸ The court also noted that “Water is a public resource, and any rights to it are usufructuary.”⁴¹⁹

2.5.4.3 ASR Implications for GCS

The ASR cases highlight that courts often treat the protection of property rights somewhat like a moving target, one which is contingent upon and balanced against the promotion of important and well-defined public interests. If California’s ASR approach to subsurface property rights is applied to GCS, federal or state legislatures would declare that the permanent sequestration of CO₂ in geologic formations furthers an important public interest—reducing greenhouse gas emissions to the atmosphere—and impose, through a valid exercise of police power, a public servitude over deep geologic formations suitable for

⁴¹⁵ *Board of County Commissioners*, 45 P.3d 693.

⁴¹⁶ Those two cases, *Walpole v. State Board of Land Commissioners*, 163 P. 848, 849-50 (Colo. 1917), and *Wolfley v. Lebanon Mining Co.*, 4 Colo. 112, 114 (1878), stand for the proposition that property ownership extended “to the center of the earth.”

⁴¹⁷ *Board of County Commissioners, LLP*, 45 P.3d at 701.

⁴¹⁸ *Id.* at 709 (holding that mineral cases “are clearly distinguishable from water cases”).

⁴¹⁹ *Id.* at 710.

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permanent sequestration of CO₂. If an ASR framework is applied, a GCS project developer may not need to compensate property owners to use pore space for CO₂ sequestration. This is especially likely if no harm to or interference with the use of subsurface property is caused by the migration of injected CO₂; it might also be true even if damage be caused should the California standard be followed.

2.6 CO₂ Sequestration vs. The Fifth Amendment to the Constitution

Any large-scale development of underground geologic CO₂ sequestration will, in all likelihood, affect some protectable property interests in areas of the country where existing economic uses of the subsurface are widespread at the depths where CO₂ sequestration is suitable. It is therefore possible that that the injection of CO₂ for permanent sequestration could trigger physical and regulatory takings claims. As for physical takings, the first question to ask is whether the surface owner or mineral owner has a protectable interest in the subsurface to support a takings claim. If a protectable interest exists, a physical taking could occur if a GCS project operator injects CO₂ directly into the pore space underlying the owner's property, or injected CO₂ migrates, or causes formation brine to migrate, and invade(s) the pore space underlying the landowner's property. In both of these circumstances, a court would be called on to determine whether such invasions of pore space constitute a permanent, physical occupation of property as per the *Loretto* standard. With regard to regulatory takings, there may be circumstances where no physical invasion of pore space by injected CO₂ or displaced formation brine occurs, but federal or state regulations prevent the surface owner or mineral owner from conducting any number of commercial subsurface

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activities (e.g., oil and gas exploration and development, or natural gas storage) in order to ensure the integrity of a CO₂ sequestration project is not compromised.

2.6.1 Physical Takings

Provided there are at least limited private property rights in subsurface pore space, any action by the government or private parties to inject and sequester CO₂ in that pore space without the owner's consent could amount to a *per se* physical taking without just compensation.

Recapping *Loretto v. Manhattan CATV Corp.*, the Supreme Court held that a New York state law requiring a landlord to allow television cable companies to place cables and other equipment in their apartment buildings constituted a taking, even though the equipment occupied at most only one and one-half cubic feet of the landlord's property.⁴²⁰ In its analysis, the Court found the cable law's purpose—to ensure tenants had access to cable television and communication services—was in the public interest, but held that the state action, which authorized the permanent invasion of private property by a third party, had so prejudiced the plaintiff's property interest that a taking occurred.⁴²¹ Even though it was ultimately determined that one dollar⁴²² was all that was owed to the plaintiff, the Court's ruling is significant in that it established that a permanent physical invasion, regardless of how small and without regard to the owner's historic use of the property, constitutes a *per se* taking.⁴²³ Moreover, both before and after *Loretto*, the Court distinguished between a

⁴²⁰ *Loretto*, 458 U.S. at 438.

⁴²¹ *Id.* at 425.

⁴²² *Loretto*, 446 N.E.2d at 435 (fixing compensation for the taking at one dollar).

⁴²³ *Loretto*, 458 U.S. at 437-38.

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“permanent” physical invasion, which will always constitute a taking, and a temporary physical invasion, which will only sometimes constitute a taking.⁴²⁴

The Court has found many infrastructure installations to be permanent occupations of land that rise to the level of a taking—the laying of telephone lines, pipelines, and train rails—but these are typically concrete invasions of the surface estate.⁴²⁵ The question relevant to geologic CO₂ sequestration is whether the invasion of subsurface pore space by injected CO₂ is comparable to these other physical invasions? Hopefully, the occupation of pore space by CO₂ will indeed be permanent, so as to keep this greenhouse gas from saturating the atmosphere. However, I posit that injecting a benign compound nearly a mile underground is less like the more tangible, physical placement of cables, telephone wires, or pipes on surface property where the owner has bona fide access to the property being occupied, and is therefore far less likely to frustrate the owner’s use of his or her property in the absence of actual damage or interference. Ultimately, as a practical matter, the question may come down to whether the property owner had reasonable expectations with respect to the use of the subsurface even though, as a doctrinal matter, the reasonableness of a property owner’s expectations historically have not been considered (as they have in the *Penn Central*

⁴²⁴ *Id.* at 428 (“Since these early cases, this Court has consistently distinguished between flooding cases involving a permanent physical occupation, on the one hand, and cases involving a more temporary invasion, or government action outside the owner’s property that causes consequential damages within, on the other. A taking has always been found only in the former situation.”); see also *City of St. Louis v. W. Union Tel. Co.*, 148 U.S. 92, 99 (1893) (holding that the installation of telephone poles are in the public interest, but noting that the action “effectually and permanently dispossesses the general public as if it had destroyed that amount of ground”); *McKay v. United States*, 199 F.3d 1376, 1381-83 (Fed. Cir. 1999) (holding that the installation by federal agencies of groundwater monitoring wells extending into the plaintiffs’ mineral estate for several years interfered with their mining prospects because it was a physical occupation of private property by the government, and distinguishing other cases involving test hole borings which did not interfere with the mineral estate and were discrete, transitory invasions rather than a permanent invasion).

⁴²⁵ *Loretto*, 458 U.S. at 430 (“Later case, relying on the character of a physical occupation, clearly establish that permanent occupations of land by such installations as telegraph and telephone lines, rails, and underground pipes or wires are takings even if they occupy only relatively insubstantial amounts of space and do not seriously interfere with the landowner’s use of the rest of his land.”)

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balancing test, discussed in the next section) in the application of the *Loretto per se* takings test.

As noted earlier in this chapter, the Supreme Court established in *Causby* that there is no reasonable expectation among property owners that they can control the airspace high above their property. This position is practical for at least two reasons. For one, most surface owners have no legitimate expectation to use the airspace far above their property for any purpose. A few of the exceptions are commercial building developers (think skyscrapers), wind farm developers, and telecom companies (think cellular towers). Secondly, as the Supreme Court explained in *Causby*, “private claims to the airspace would clog [this highway]” and gravely impede development of an industry—commercial air travel—that is in the public interest.⁴²⁶ As with airspace, there is no legitimate purpose for which the majority of property owners will ever have to use the deep subsurface. A minority of property owners—primarily mineral owners engaged in mineral resource exploitation—are already making use economic use of the subsurface at the same depth where CO₂ sequestration is being proposed. Indeed, this second subset of property owners is in a very strong position to argue that a government action, or an authorization by the government issued to a private party, to permanently sequester CO₂ in the same pore space where minerals are being extracted constitutes a taking. Likewise, a surface owner or mineral owner affected by the displacement of native in situ fluids by injected CO₂ could may have a valid takings claim as well.

⁴²⁶ *Causby*, 328 U.S. at 261.

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Whether the permanent sequestration of CO₂ in the deep subsurface is a physical taking is a difficult question to resolve. No consensus exists among courts and lawmakers regarding the extent to which surface owners and mineral owners have rights in pore space that could be physically invaded in the *Loretto* sense. Nevertheless, regardless of whether the property owner is affected directly by injected CO₂ or the associated displacement of other fluids, it is plausible that courts will require the property owner to demonstrate actual and substantial damages occurred,⁴²⁷ or that reasonably foreseeable and substantial damages will occur, as a result of CO₂ sequestration in order to prevail on a takings claim. While the Supreme Court found that the permanent flooding of surface property amounts to a physical taking requiring just compensation,⁴²⁸ the Court has yet to rule whether the physical occupation of deep subsurface pore space by injected fluids is commensurate with a taking. However, with the exception of natural gas storage, the analysis of the application of state law presented in Section 2.5 seems to indicate that CO₂ sequestration will amount to a physical taking requiring just compensation only when actual and substantial harm is caused to economically valuable resources or uses of the subsurface. It is the author's view that the answer to the takings question in the context GCS should turn on a property owner's reasonable expectations with respect to use of deep subsurface pore space, notwithstanding the absence of this consideration from the *Loretto per se* takings test. The most effective way to reduce uncertainty regarding property owner expectations is for Congress to establish a presumption that CO₂ sequestration does not constitute a physical taking unless it causes actual and

⁴²⁷ See *Hinman*, 84 F.2d at 759; See also *supra* Section 2.5.

⁴²⁸ *Loretto*, 458 U.S. at 437-38 (“Since these early cases, this Court has consistently distinguished between flooding cases involving a permanent physical occupation, on the one hand, and cases involving a more temporary invasion, or government action outside the owner’s property that causes consequential damages within, on the other. A taking has always been found only in the former situation.”).

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substantial damages to mineral resources or current uses of the pore space, or impairs non-speculative, investment-backed expectations to use the pore space.

2.6.2 *Regulatory Takings*

Takings within the meaning of the Fifth Amendment are not limited to the physical appropriation of property. Regulatory actions that place too great a burden on a surface owner's or mineral owner's use of property is a taking in the constitutional sense. A regulatory action can be a *per se* taking just like a permanent physical occupation when the regulation deprives a landowner of *all* economically beneficial uses of his/her property.⁴²⁹ In *Lucas v. South Carolina Coastal Council*,⁴³⁰ the Court announced that *per se* regulatory takings occur when the government denies all economic use of property unless "background principles" of nuisance and property law would have precluded the activity in question.⁴³¹ Since the controversial ruling in *Lucas*, however, the Supreme Court and lower courts generally have declined to apply the *per se* regulatory takings rule. Instead, courts either have declined to sever property interests in space or time in a way that would result in a denial of all economic value of the property, or relied on the "background principles" exception in *Lucas* to uphold the regulation in question.⁴³² In fact, there is a respectable argument that

⁴²⁹ See *Lucas v. South Carolina Coastal Council*, 505 U.S. 1003, 1029 (1992) (holding regulations that prohibit all economically beneficial use of land require compensation just as if it were a permanent physical occupation of land).

⁴³⁰ *Id.*

⁴³¹ *Id.* at 1028-32.

⁴³² See, e.g., *Tahoe-Sierra*, 535 U.S. 302 (holding that a moratorium imposed on development as part of land using planning was not a *per se* taking on the ground that after the moratorium was lifted, claimants could pursue their development rights); *Esplanade Props., LLC v. City of Seattle*, 307 F.3d 978 (9th Cir. 2002) (holding that the city's denial of a shoreline development permit application was not a taking based on the "background principles" of Washington law, which restricted the type of development at issue under the public trust doctrine); *Palazzolo v. Rhode Island*, No. WM 88-0297, 2005 LEXIS 108 (R.I. Super. Ct. July 5, 2005) (finding that the state's denial of a permit to fill eighteen acres of salt marsh was not a *per se* taking based on "background principles" of state law including the public trust doctrine); Michael C. Blumm & Lucas Ritchie, *Lucas' Unlikely Legacy: The Rise of Background Principles as Categorical Takings Defenses*, 29 Harv. Envtl.

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owners of less-than-fee interests in property—i.e., coal, oil, gas, or other minerals—do not deserve the protection of the *Lucas* categorical rule.⁴³³ Commentators posit that an examination of a takings claimant’s distinct investment-backed expectations, as was done in *Penn Central Transportation Co. v. New York City*,⁴³⁴ should be applied to claims of regulatory takings of property interests severed from fee simple estates in land. The *Penn Central* balancing test, as it is commonly known, considers: 1) the character of the government action; 2) the severity of the economic effect; and 3) the extent to which the regulation interferes with the property owner’s distinct, “investment-backed” expectations.⁴³⁵

Although there is substantial uncertainty at this point what regulations governing CO₂ sequestration will ultimately look like, it is likely that these regulations will prohibit activities that would compromise the integrity of the sequestration reservoir. For example, regulations might prohibit a surface owner or mineral owner from penetrating a GCS reservoir when doing so would pose the risk that CO₂ will escape the subsurface and enter the atmosphere. Thus, the first question to ask is whether such a regulatory prohibition would deprive a surface owner or mineral owner of *all* economically beneficial use of the property. If the answer is no, the *Penn Central* balancing test should be applied to determine the extent to which the regulatory restriction unreasonably interferes with the property owner’s investment-backed expectations for use of the property. To answer these questions, it is necessary to first consider the nature of the property interest. If a court were to determine that

L. Rev. 321, 325-26 (2005) (discussing *Lucas* and arguing that courts have interpreted the “background principles” of nuisance and property law expansively to avoid per se regulatory takings claims).

⁴³³ Patrick C. McGinley, *Bundled Rights and Reasonable Expectations: Applying the Lucas Categorical Taking Rule to Severed Mineral Interests*, 11 Vt. J. Envtl. L. 525, 529 (2010).

⁴³⁴ *Penn Central Transportation Co.*, 438 U.S. 104 (1978).

⁴³⁵ *Id.* at 124.

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the pore space is a property interest separate and distinct from either the surface estate or mineral estate, it would be possible to conclude that regulations restricting use of or access to the pore space would be a complete deprivation of economic use.⁴³⁶ Supreme Court decisions on this issue are somewhat mixed, particularly in the area of subsurface property rights associated with coal mining.

In *Pennsylvania Coal Co. v. Mahon*,⁴³⁷ the plaintiffs owned the surface rights under their home, but not the mineral rights, which were previously severed and conveyed to the defendant coal company.⁴³⁸ A state law, the Kohler Act, prohibited the mining of anthracite coal within city limits in such a manner as would cause the subsidence of any dwelling or other building.⁴³⁹ When the plaintiffs sued, pursuant to the Kohler Act, to enjoin further mining of coal under their property, the defendant contended that application of the law amounted to an unconstitutional taking of its property (i.e., the coal that could not be mined in order to provide surface support) without just compensation.⁴⁴⁰ The Supreme Court ruled in favor of the defendant, finding that application of the law was a taking.⁴⁴¹ In reaching its decision, the Court balanced the extent of the defendant's deprivation against the private interest of the plaintiffs rather than the state's interest in preventing a public nuisance, which was a defense to a similar takings claim in the past.⁴⁴² The Court found that the extent of the

⁴³⁶ See *Lucas*, 505 U.S. at 1029.

⁴³⁷ *Pennsylvania Coal Co. v. Mahon*, 260 U.S. 393 (1922).

⁴³⁸ *Id.* at 394-95.

⁴³⁹ *Id.* at 412-13.

⁴⁴⁰ *Id.* at 412.

⁴⁴¹ *Id.* at 414 (“To make it commercially impracticable to mine certain coal has very nearly the same effect for constitutional purpose as appropriating or destroying it.”).

⁴⁴² *Id.* at 413 (1922) (focusing on the fact that this is a case “of a single private house” and not a public nuisance); *id.* at 417-18 (Brandies, J., dissenting) (stating that the Kohler Act did not work an unconstitutional taking of property because the restriction “is merely the prohibition of a noxious use” and citing precedent that such legislation is not a taking even if it deprives the owner of all economic use of the property).

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deprivation was “great” because the law purported to abolish the entire “support” estate in coal, which was a separately recognized estate under Pennsylvania law.⁴⁴³ The Court concluded by stating, “[W]hile property may be regulated to a certain extent, if regulation goes too far it will be recognized as a taking.”⁴⁴⁴

Several decades later, in *Keystone Bituminous Coal Ass’n v. DeBenedictis*,⁴⁴⁵ the Court reached a different conclusion when it revisited issue of subsurface takings related to the regulation of coal mining. In this case, coal companies challenged the Pennsylvania Subsidence Act, which required 50% of the coal beneath surface structures to be left in place to provide surface support.⁴⁴⁶ In finding that the law did not amount to an unconstitutional taking, the Court distinguished *Mahon* and applied the *Penn Central* balancing test.⁴⁴⁷ In finding that *Mahon* did not apply, the Court focused on the important public purpose of the law in promoting public health and safety and found that when balanced against the extent of economic deprivation caused by the law, the regulation did not go “too far” and did not result in a taking.⁴⁴⁸

In departing from *Mahon*, the Court refused to consider the support estate a stand-alone estate in property when it determined the extent of the deprivation.⁴⁴⁹ The Court found that the 27 million tons of coal owned by the plaintiffs that would need to be left in place under

⁴⁴³ *Mahon*, 260 U.S. at 414 (1922).

⁴⁴⁴ *Id.* at 415.

⁴⁴⁵ *Keystone Bituminous Coal Ass’n v. DeBenedictis*, 480 U.S. 470 (1987).

⁴⁴⁶ *Id.* at 476-77.

⁴⁴⁷ *Id.* at 481-82.

⁴⁴⁸ *Id.* at 485-93.

⁴⁴⁹ *Id.* at 501.

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the law did not “constitute a separate segment of property for takings law purposes.”⁴⁵⁰ Instead, the regulation limiting the extraction of coal was no different than other widely-accepted restrictions that place limits on the property owner’s right to make profitable use of some segments of his or her property in promotion of some public interests.⁴⁵¹ Examples included a requirement that a building occupy no more than a specific percentage of the lot on which it is located and zoning setback requirements.⁴⁵² In reaching its decision in *Keystone Bituminous*, the Court relied heavily its previous ruling in *Penn Central*, which refused to sever the plaintiff’s “air rights” from the surface estate.⁴⁵³ The Court reasoned that even though Pennsylvania Law recognized the support estate as a separate property interest, that estate could not be used profitably by one who does not also possess either the mineral estate or the surface estate, and thus it must be considered together with those other estates for purposes of conducting a takings analysis.⁴⁵⁴

Since the decision in *Keystone Bituminous*, the Court has continued to struggle with how to delineate property interests for the purpose of determining whether a regulation amounts to a complete elimination of economic use of property resulting in a *per se* taking, as well as for the purpose of determining the extent of deprivation under the *Penn Central* balancing test.⁴⁵⁵ In the context of permanent geologic sequestration of CO₂, it would appear to very difficult for a surface owner or mineral owner to show that a regulatory restriction, or even outright prohibition, on pore space use would eliminate all economically beneficial use of the

⁴⁵⁰ *Id.* at 498.

⁴⁵¹ *Id.* at 498-99.

⁴⁵² *Id.*

⁴⁵³ *Id.*

⁴⁵⁴ *Id.* at 501.

⁴⁵⁵ Jesse Dukenminier et al., PROPERTY 989 (6th e. 2006) (discussing uncertainty over the idea of “conceptual severance” in regulatory takings jurisprudence).

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property and result in a *per se* taking under *Lucas*. With regard to severance of property estates, while the authority in this area seems to favor the proposition that pore space could not be reasonably severed from either the surface estate or mineral estate for the purpose of takings analysis, Montana and Wyoming have enacted laws that recognize pore space as a discrete, severable property estate.⁴⁵⁶ By contrast, North Dakota's CCS legislation does not allow pore space to be severed from the surface estate.⁴⁵⁷ Even if one were to accept concept of severability for extractable resources that can be physically separated (such as coal), it is difficult to assert that pore space should be an unqualified property interest distinct from the geologic rock formation as there quite literally is no "pore" without the surrounding rock.

It is critical to consider the effect of a regulatory restriction on the mineral owner's use of his or her property when assessing whether a regulatory taking has occurred. A regulatory restriction that prohibits the ability of a mineral owner to access or exploit the *entire* mineral estate provides a strong basis for arguing that the regulation has resulted in a deprivation of *all* economic value of the mineral owner's property. If such is the case, the mineral owner would likely prevail on a *per se* takings claim under *Lucas*. On the other hand, if the property owner's mineral holdings are extensive and only a fraction of the mineral interest is affected by the regulatory restriction, as was the case in *Keystone Bituminous*, it is likely a court will apply the *Penn Central* balancing test rather than finding a *per se* taking under *Lucas*. Thus, except in the case where a regulation prevents a mineral owner from exploiting all of his/her mineral holdings, it is highly unlikely that a court would find a regulation restricting a

⁴⁵⁶ See S.B. 498, 61st Leg., Reg. Sess. (Mont. 2009) (codified at MONT. CODE ANN. § 82-11-180 (2009)); H.R. 89, 59th Leg., Budget Sess. (Wyo. 2008) (codified at WYO. STAT. ANN. § 34-1-152 (2009)).

⁴⁵⁷ See S.B. 2319, 61st Leg. Assem., Reg. Sess. (N.D. 2009) (codified at N.D. CENT. CODE § 47-31-01-08 (2006 & Supp. 2009)).

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mineral owner's access to a portion his/her mineral estate for the purpose of protecting the integrity of the CO₂ sequestration reservoir to constitute a *per se* taking.

Unless a court finds there is a deprivation of *all* economic use of a fee simple estate, it is unlikely the court would conclude that regulations restricting the use of some portion of the surface estate or mineral estate constitute a categorical taking under *Lucas*. Although the Court has been less than consistent in its approach to this issue, the trend among courts in recent years appears to steer away from allowing the property owner to define discrete rights in property in either time or space in a way that favors *per se* regulatory takings claims. On the other hand, if CCS regulations deprive a surface owner or mineral owner of some, but not all, economically beneficial use of the surface estate or mineral estate, courts should consider the totality of the circumstances and conduct a *Penn Central* balancing analysis to determine whether a regulatory taking has occurred.⁴⁵⁸ With regard to the first factor in *Penn Central* test, the character of the government action, the purpose of any regulation meant to protect the integrity of the CO₂ sequestration reservoir would be to facilitate the deployment of a technology to mitigate the effects of climate change. The regulation would also be intended to promote public health and safety by ensuring that sequestered does not cause harm to groundwater or escape into the atmosphere. As to the severity of the economic impact, the second factor in the *Penn Central* test, it is uncertain precisely how the use of pore space and the surrounding area will be allocated and regulated. It is likely, however, that surface owners and mineral owners may be limited or prohibited from drilling through a geologic formation in a way that perforates the sequestration reservoir or compromises it in any other

⁴⁵⁸ *Penn Central Transportation Co.*, 438 U.S. at 124.

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way.⁴⁵⁹ For some property owners, these restrictions may have only a minimal economic effect on their current or imminent use of the subsurface, while for others the restrictions may result in substantial economic loss.

Lastly, the third *Penn Central* factor—interference with reasonable, investment-backed expectations—will depend in large part on the extent to which the surface owner or mineral owner currently makes use of the subsurface, or could reasonably expect to do so in the future.⁴⁶⁰ Those owners currently using pore space for natural gas storage, enhanced oil recovery, or underground injection of fluid wastes arguably have a cognizable investment-backed expectation that should be left unencumbered by regulations related to CCS, whereas the vast majority of surface owners will have a difficult time establishing any plausible use for the pore space nearly a mile underground that would be adversely affected by CCS regulations. Ultimately, this issue comes down to not only the property owner’s existing or foreseeable use of the pore space, but also the owner’s expectations at the time an investment is made with respect to using that pore space free of any regulatory encumbrances. Like the other two factors considered under the *Penn Central* balancing test, this will be a factually intensive inquiry, taking into account the timing of investment, the expectations and that time, and whether those expectations were reasonable. In any particular case, there exists the possibility that if regulatory restrictions interfere substantially with the existing use of, or an expectation to use, a property interest, a court may find that the extent of deprivation is so

⁴⁵⁹ See, e.g., Kan. Admin. Regs. §§ 82-3-1100-82-3-311a (proposed Jan. 2009) (regulations for the underground storage of CO₂ that include provisions on permitting, monitoring, and leakage reporting, as well as requirements for drilling through a CO₂ storage facility).

⁴⁶⁰ *Penn Central Transportation Co.*, 438 U.S. at 130.

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great as to constitute a taking on the grounds that the regulation has gone “too far” and the government must therefore pay.⁴⁶¹

2.7 Just Compensation: What is the Value of Pore Space in the Eyes of the Law

Even if the a court finds that the government has taken, or authorized a third party to take, private property, there is no violation of the Fifth Amendment unless the taking is without payment of just compensation. The Supreme Court held that “just compensation required by the Fifth Amendment is measured by the property owner’s loss rather than the government’s gain.”⁴⁶² As Justice Holmes stated, “[T]he question is what has the owner lost, not what the taker gained.”⁴⁶³ Thus, as noted earlier, if a court determines that the economic loss to the owner is zero, the compensation is also zero, and there is no taking in violation of the Fifth Amendment.⁴⁶⁴ Determining the value of any specific item of property, however, can be a very difficult exercise. As a result, the Supreme Court generally has used what it considers to be a practical, if somewhat ambiguous, measure in the form of the concept of “fair market value,” or “what a willing buyer would pay in cash to a willing seller,” even though this measure “does not necessarily compensate for all values an owner may derive from his property.”⁴⁶⁵ In other words, if there is a prevailing market price at the time of the taking,⁴⁶⁶

⁴⁶¹ *Lucas*, 505 U.S. at 1014 (“[W]hile property may be regulated to a certain extent, if any regulation goes too far it will be recognized as a taking.”) (quoting *Mahon*, 260 U.S. at 415).

⁴⁶² *Brown*, 538 U.S. at 235-36 (internal quotations omitted); see also *United States v. Toronto, Hamilton Buffalo Navigation Co.*, 388 U.S. 396, 404 (1949) (“We take it that in the valuation of readily salable articles, price at the market nearest the taking is, at least in the usual case, a practical rule of thumb, and one that is most likely to place the claimant in the pecuniary position he occupied before the taking.”).

⁴⁶³ *Boston Chamber of Commerce v. City of Boston*, 217 U.S. 189, 195 (1910).

⁴⁶⁴ See *Brown*, 538 U.S. at 237.

⁴⁶⁵ *United States v. 564.54 Acres of Land*, 441 U.S. 506, 511 (1979) (internal quotations omitted).

⁴⁶⁶ *Olson v. United States*, 292 U.S. 246, 255 (1934) (“That equivalent is the market value of the property at the time of the taking contemporaneously paid in money.”); see also *Yancey v. United States*, 915 F.2d 1534, 1543 (Fed. Cir. 1990) (“Fair market value under the Fifth Amendment is normally ascertained at the date of the governmental restrictions are imposed, which is the date of the taking.”)

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that price is just compensation.⁴⁶⁷ Fair market value is also recognized as a way to strike a fair “balance between the public’s need and the claimant’s loss” in takings cases.⁴⁶⁸

The Court, however, “has refused to designate market value as the sole measure of just compensation”⁴⁶⁹ because, even in cases where there is an established market, there is not necessarily a fixed algorithm or method for determining the market value.⁴⁷⁰ Although the best index for market value may be recent sales, courts have found that any “fair and non-discriminatory” method of determining a “fair and realistic value” is acceptable.⁴⁷¹ While the fair market value measure becomes somewhat difficult to calculate when there is no willing seller in a takings case, appraisal is even more vexing when there is no established market at all.⁴⁷² As such, the Supreme Court has recognized that, in some circumstances, it simply may be impossible to determine a market value, particularly in cases where there have been too few sales to credibly estimate a future price.⁴⁷³

Turning once again to eminent domain actions brought under the Natural Gas Act in order to develop underground gas storage facilities, determining just compensation in those cases is often difficult because gas storage rights are not commonly traded on the public market the

⁴⁶⁷ *Unites States v. New River Collieries Co.*, 262 U.S. 341, 344 (1923).

⁴⁶⁸ *564.54 Acres of Land*, 441 U.S. at 512 (internal quotations omitted).

⁴⁶⁹ *Id.*

⁴⁷⁰ *Allied Corp. v. Town of Camillus*, 604 N.E.2d 1348, 1350 (N.Y. 1992).

⁴⁷¹ *Id.* (“The ultimate purpose of valuation, whether in eminent domain or tax certiorari proceedings, is to arrive at a fair and realistic value of the property involved so that all property owners contribute equitably to the public fisc. Any fair and nondiscriminating method that will achieve that result is acceptable.” (citations omitted)).

⁴⁷² *United States v. Toronto, Hamilton Buffalo Navigation Co.*, 388 U.S. 396, 407 (1949) (Frankfurter, J., concurring) (“Resort to the conventional formulas for ascertaining just compensation for the taking of property rarely bought and sold, and having therefore no recognized market value, does not yield fruitful results. The variables are too many to permit of anything except an informed judgment.”)

⁴⁷³ *Id.* at 402 (1949) (majority opinion).

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same way as surface rights.⁴⁷⁴ As a result, comparative sales and other valuation methods are difficult to determine. In one Ohio case, *Columbia Gas Transmission Corp. v. Exclusive Natural Gas Storage Easement*,⁴⁷⁵ the United States Court of Appeals for the Sixth Circuit held that state law governing just compensation should apply to federal condemnation of natural gas storage easements.⁴⁷⁶ In so ruling, the court paid particular attention to the express language in the Natural Gas Act⁴⁷⁷ that directs federal courts to look to the practice and procedure of the state in which the property is located.⁴⁷⁸ More generally, the court also asserted that the presumption that state law should be incorporated into federal law is heightened when parties “have entered legal relationships with the expectation that their rights and obligations would be governed by state law standards.”⁴⁷⁹

When the issue of just compensation was certified by the Supreme Court of Ohio, the state court adopted the federal district court’s instructions to the condemnation commission regarding the factors to be taken into account when setting just compensation.⁴⁸⁰ These factors were: 1) comparable sales (if available);⁴⁸¹ 2) any probable revenues to the landowner associated with commercially recoverable natural gas under the property; 3) the fair market

⁴⁷⁴ McGrew, *supra* note 99, at 154.

⁴⁷⁵ *Columbia Gas Transmission Corp. v. Exclusive Natural Gas Storage Easement*, 962 F.2d 1192 (6th Cir. 1992).

⁴⁷⁶ *Id.* at 1199 (6th Cir. 1992).

⁴⁷⁷ 15 U.S.C § 717f(h) (2006) (“The practice and procedure in any action or proceeding for that purpose in the district court of the United States shall conform as nearly as may be with the practice and procedure in similar action or proceeding in the courts of the State where the property is situated...”).

⁴⁷⁸ *Columbia Gas*, 962 F.2d at 1197.

⁴⁷⁹ *Id.* at 1196.

⁴⁸⁰ *Columbia Gas*, 620 N.E.2d at 49-50.

⁴⁸¹ It was reported that in 1993, “Columbia routinely paid four dollars per acre per year for the right to store gas beneath a property” while the East Ohio Gas Company paid “five dollars per acre per year.” McGrew, *supra* note 99, at 153. These transactions are rentals and thus must be converted and reduced to present value in cases where the gas company wishes to obtain a permanent easement. Moreover, because there is no real market for this property other than gas storage, the gas company essentially has a monopoly, which casts doubt on these amounts as fair market value. *Id.*

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value of the storage easement based upon a capitalization of retail income from the right to store gas; 4) depreciation in the fair market value of the condemned tract as a whole by reason of the taking of the gas storage easement; 5) the existence of any mineral leases on the property; and 6) the value of the property from the landowner's perspective (not the value of the storage easement to the natural gas company).⁴⁸²

The judicial principles and industry customs governing just compensation for subsurface natural gas storage could guide the valuation of pore space for CO₂ sequestration in either voluntary transactions or eminent domain actions (provided state or federal eminent domain authority for CCS exists) for owners with established property interest in the subsurface. If evidence of comparable sales or rental payments are not easy to identify or non-existent, as is currently the case for CO₂ sequestration rights, parties will turn to other factors to establish market value. For instance, a landowner who can establish the existence of commercially recoverable amounts of resources may attempt to calculate the probable revenues and costs of extracting the resource to determine just compensation.⁴⁸³ This approach is somewhat controversial, however, because future revenues often are thought to be too speculative.⁴⁸⁴ More specifically, the Court has held that elements affecting value that depend on events or occurrences which, "while within the realm of possibility, are not fairly shown to be reasonably probable, should be excluded from consideration, for that would be to allow mere speculation and conjecture to become a guide for the ascertainment of value."⁴⁸⁵ Avoiding

⁴⁸² *Columbia Gas*, 620 N.E.2d at 49-50.

⁴⁸³ *Id.* at 49 (noting that the full amount must also be reduced by the interest enjoyed by a one time payment).

⁴⁸⁴ *See McGrew*, *supra* note 99, at 156.

⁴⁸⁵ *See Olson*, 292 U.S. at 257.

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such speculation and conjecture in just compensation appraisals has since come to be known as the “reasonable possibility” or “reasonable probability” standard.⁴⁸⁶

Parties also may show a depreciation or loss in the overall property value due to the taking at issue, a measure commonly used in partial takings cases.⁴⁸⁷ For instance, “[i]n general, the ultimate measure of the permanent damages sustained by an owner from the establishment of a pipeline easement across his premises is the difference between the fair market value thereof immediately afterward.”⁴⁸⁸ One complication with this method for both partial and complete takings situations is that the mere announcement of government intent to regulate or condemn can affect the property value before the taking.⁴⁸⁹ In some cases, this can lead to “condemnation blight,” which often occurs when a governmental entity announces its intent to condemn property for a park, a road, or other development, resulting in a dramatic reduction of the property’s marketability.⁴⁹⁰ By the time the government condemns the project years later, “its fair market value will be significantly less than if the government had never [undertaken] the project in the first place.”⁴⁹¹ In other cases, however, the government’s announcement of its intent to condemn can result in an increase in property values, such as when the construction of a new road will increase property values in the area.⁴⁹² The question then becomes whether the government must pay for that increase in value at the time of the actual condemnation. At least twenty-nine states have enacted

⁴⁸⁶ See, e.g., *St. Genevieve Gas Co. v. Tenn. Valley Auth.*, 747 F.2d 1411, 1413 (11th Cir. 1984).

⁴⁸⁷ See McGrew, *supra* note 99, at 158-59.

⁴⁸⁸ *Am. La. Pipe Line Co. v. Kennerk*, 144 N.E.2d 660, 665 (Ohio Ct. App. 1957) (recognizing that in Ohio there is a distinction between damages and compensation).

⁴⁸⁹ See Christopher Serkin, *The Meaning of Value: Assessing Just Compensation for Regulatory Takings*, 99 Nw. U.L. Rev. 677, 696-99 (2005) (discussing how the prospect of an imminent government eminent domain action can have either a positive or a negative effect on the value of the property subject to condemnation).

⁴⁹⁰ *Id.* at 696-97.

⁴⁹¹ *Id.* at 697.

⁴⁹² *Id.* at 698.

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valuation laws that outline how to calculate the time of the taking and the property value before and after the taking.⁴⁹³ Notably, some of the laws are written to require an adjustment in valuation recognizing the effect of the government announcement to condemn or regulate.⁴⁹⁴

In the context of an eminent domain action to acquire subsurface pore space for CO₂ sequestration, the “timing of condemnation” issue could potentially increase or decrease the value of the property. With regard to subsurface pore space already in use for oil and gas production, natural gas storage, or other economic uses, a GCS project announcement could reduce the market value of the subsurface property for these existing economic uses. On the other hand, with regard to subsurface pore space not already in economic use (or reasonably foreseeable economic use), a project announcement could increase the value of that subsurface property because the announcement would create an economic use for that property and other subsurface pore space in the area. This would be particularly true if project development took place over a number of years and during the time created a market value for subsurface pore space for CO₂ sequestration that did not previously exist.

2.8 Discussion

The case law arising from industrial and commercial underground fluid injection operations is instructive of how subsurface property rights might be effectively dealt with in the context of geologic CO₂ sequestration. This body of case law shows that courts have consistently held certain underground fluid injection activities—i.e., enhanced hydrocarbon recovery,

⁴⁹³ Christopher A. Bauer, Note, *Government Takings and Constitutional Guarantees: When Date of Valuation Statutes Deny Just Compensation*, 2003 BYU L. Rev. 265, 278 (2003).

⁴⁹⁴ *Id.*

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underground waste disposal, and freshwater storage and recharge—to be in the public interest and are thus protected from claims of subsurface trespass when 1) the activity is licensed under a state or federal regulatory program, and 2) the property owner could not demonstrate actual harm to, or interference with use and enjoyment of, the land occurred as a result of injection operations.

Thus, while courts have rejected any absolute protection rights in the subsurface on the part of landowners, they have preserved limited landowner rights to use and exploit the subsurface and recover money damages for actual harm caused by subsurface invasions. Similarly, courts have been quite willing to allow landowners to sue for trespass and nuisance when airborne particles and pollution invade the landowner's airspace and cause harm.⁴⁹⁵ In these airspace pollution cases, courts looked to whether the invasion actually interfered with the plaintiff's use and enjoyment of the property or caused actual harm.⁴⁹⁶ In subsurface invasion cases, courts have looked at almost precisely the same factors and reached similar conclusions. In both these lines of cases, courts can be seen as having creating a “liability rule”—which permits the violation of an entitlement without permission from the property owner so long as the violator pays damages for any harm caused—as opposed to a “property rule”— which permits the encumbrance of an entitlement only with permission of the property owner.⁴⁹⁷

⁴⁹⁵ See, e.g., *Davis v. Georgia-Pacific Corp.*, 445 P.2d 481, 483 (Or. 1968) (holding that intrusion of fumes, gases, and microscopic particles on the property of another can constitute a trespass in addition to nuisance); James A. Henderson, Jr. et al., *THE TORT'S PROCESS* 402-03 (7th ed. 2007) (discussing how some courts have allowed claims for trespass, in addition to nuisance, for claims based on the intrusion of smoke, gases, or odors).

⁴⁹⁶ Henderson et al., *supra* note 376, at 400-01.

⁴⁹⁷ See Guido Calabresi & A. Douglas Melamed, *Property Rules, Liability Rules, and Inalienability: One View from the Cathedral*, 85 Harv. L. Rev. 1089, 1092 (1975) (reasoning that some entitlements are protected by a “property rule” (i.e., an injunction) which permits violation of the entitlement only with permission of the

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Ultimately, the extent to which CO₂ sequestration is sought to be developed in areas where the subsurface is already being used commercially for natural gas storage, oil and gas production, or other uses, the cost of obtaining the rights to use subsurface pore space may be significant. In these scenarios, the value of compensation will be derived from the value of those rights as a function of the existing or future, investment-backed uses of the subsurface that would be precluded by GCS. In other cases though, where the geologic formation is appropriate for CO₂ sequestration but not for other commercial uses, the costs associated with acquiring pore space rights might be nominal or perhaps even zero because no economic use is precluded or impaired.⁴⁹⁸ As a result, there may well be a sliding scale of compensation for subsurface pore space based not on the existence of a property right, but on the value of that right based on the existing or reasonably foreseeable uses of the pore space.

One option is for Congress or state legislatures to create a presumption that the regulatory grant of the right to access and use pore space for geologic CO₂ sequestration does not amount to a compensable taking because it 1) does not effect a confiscation of property, and 2) is not the first step in a regulatory taking since pore space owners will unlikely suffer either an actual loss or an interference with any investment-backed expectation. However, this legislation should provide surface owners and mineral owners with an opportunity to rebut this presumption by presenting evidence in an administrative proceeding which demonstrates that CO₂ sequestration will result in a material impairment to a current or non-speculative, investment-backed future use of the subsurface, and that the property owner will

property owner, while other entitlements are protected by a “liability rule” (i.e., damages) which permits violation of the entitlement without permission of the owner so long as the violator pays damages).

⁴⁹⁸ See *Brown*, 538 U.S. at 240 (holding that the state’s taking of private property did not violate the Fifth Amendment because the value of the property, measured by the owner’s pecuniary loss, was zero).

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suffer a consequent economic loss requiring just compensation. This idea is laid out in detail in Chapter 5. The next chapter examines the cost of acquiring subsurface property rights under the assumption compensation might be required to use pore space for CO₂ sequestration.

Chapter 3: Implications of Compensating Property-Owners for Geologic CO₂ Sequestration

Geologic sequestration of CO₂ from power plants and direct air capture has the potential to significantly reduce CO₂ emissions to the atmosphere. However, CO₂ sequestered in deep geologic pore space could migrate laterally over a very sizeable area (1,2). Moreover, large CO₂ footprints increase the probability that geologic CO₂ sequestration fields will overlap and interfere with competing uses of the subsurface. Before a sequestration reservoir can be developed, the project developer will have to acquire the legal right to access and use pore space to avoid liability for subsurface trespass. (3-5) Under current law, if a GCS project developer negotiates an agreement with landowners to use the pore space in exchange for monetary compensation then risks to the developer for liability in trespass would be effectively eliminated.

However, it remains unclear whether, or how widely, compensation for the use of pore space will be legally required. For example, U.S. courts have consistently ruled that, due to the overarching public benefit of disposing fluid waste underground, technical trespass claims against waste injection operators properly licensed under the U.S. Environmental Protection Agency's Underground Injection Control program—the same regulatory program that will very likely license and oversee the injection of CO₂ for geologic sequestration (6)—are generally compensable only when a material impairment with use of the subsurface or the surface can be demonstrated by the aggrieved property owner (4,7-9). This same rationale has been applied to state-authorized enhanced oil and natural gas recovery operations and field unitization—that is, claims for subsurface trespass must yield to the public interest of efficiently producing natural resources (4,7-9). In these cases, finding that a trespass occurred

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depends both on the degree of financial importance as well as the feasibility of future utilization of the resource (4).

It appears that none of the hundreds of operations currently injecting fluid wastes under the EPA UIC program compensate landowners for the use of pore space for long-term disposal (10). However, absent specific new legislation limiting trespass liability, it is not safe to assume that the same will be the case for sequestration of CO₂. For one, GCS facility operators will likely be perceived to have “deep pockets,” so there is a high probability the issue will be litigated. Secondly, some legal commentators posit that the body of case law controlling property disputes arising from the underground storage of natural gas might be invoked by landowners when sequestered CO₂ migrates under their property, providing them with a legally cognizable expectation of compensation (4,8,11). This notion has credence in large part because it is common practice for a natural gas storage company to compensate all property owners potentially affected by a storage project outright in exchange for control of the entire storage field (4,8,12).

In the future, new law might assure access to pore space and expressly limit trespass liability for GCS (9). In fact, there exists a clear trend in U.S. case law to modify subsurface trespass law to require a showing of actual harm to the property-owner (13). Absent prevailing common law or a federally coordinated regulatory regime to this effect, however, one issue that could affect the viability of GCS in the United States is the cost of compensating landowners for the use of pore space. No existing literature examines the degree to which compensating landowners for the use of pore space will affect the economics of GCS.

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Moreover, only analogues, rather than CCS-specific precedents, exist which can provide a guide to calculating the potential cost of compensating pore space owners. Should it be necessary, the cost of acquiring pore space rights will depend on the requirements of the regulations, common law, and business practices to which a GCS project is subject. Here the economic implications of GCS project developers leasing or purchasing the rights to sequester CO₂ in the subsurface under arrangements similar to those now used for natural gas storage were assessed.

The primary predictor of cost will be the land surface footprint under which the injected CO₂ is likely to migrate over a fixed time interval. A probabilistic model was developed to: 1) simulate the temporal and spatial evolution of a subsurface CO₂ plume using geologic data available for deep saline-filled sandstones considered to be suitable GCS targets in Pennsylvania, Ohio, Illinois and the Texas Gulf Coast; and 2) calculate the cost to lease and purchase pore space rights as a function of CO₂ plume size. This analysis ignores the potential effects of pressure perturbations that can extend far beyond the footprint of the injected CO₂ (14,15). Because, as expected (16), geologic properties of the reservoirs examined in this analysis vary substantially, CO₂ plume footprints and the cost of acquiring pore space rights could span several orders of magnitude. Thus, the cost of acquiring pore space rights could be high enough for a GCS project developer to consider transporting CO₂ to a location where pore space acquisition costs are lower. This analysis concludes by assessing the cost of transporting CO₂ via pipeline from the Ohio and Pennsylvania area, where the potential for very large CO₂ plume footprints may not be conducive to large-scale GCS (17), to the lower-cost reservoirs in Illinois and on the Texas Gulf Coast.

3.1 Analytical Model: Estimating CO₂ Plume Size and the Cost of Acquiring Pore Space Property Rights

3.1.1 CO₂ Plume Migration Model

Injection of CO₂ into saline formations and depleted or producing oil and gas reservoirs results in the flow of multiple fluid phases through the porous medium (18). Multiphase flow models that account for differing fluid and rock properties enable fluid flow processes, such as those occurring in GCS, to be simulated. A probabilistic model was developed using the analytical multiphase solution for estimating the spatial distribution of injected CO₂ in deep saline formation presented by Nordbotten et al. (18). Although simplified analytical methods are not sufficient to predict the movement of injected CO₂ in heterogeneous and anisotropic formations with high degrees of accuracy, typically not enough geological data are available during the early phases of any site selection process to allow for the use of more complex numerical models. The Nordbotten et al. solution provides the means for calculating a useful bounding estimate for the extent of migration of a CO₂ plume given the constraints of the geological data currently available for deep saline-filled formations.

Nordbotten et al. (18) showed that, under typical sequestration conditions, the velocity of the CO₂ front is higher near the top of the reservoir than at the bottom. Thus, the general shape of the CO₂-brine interface has a progressively increasing (upward) vertical location with increasing radial distance from the injection well (Figure 3.1). This result minimizes the work required to inject CO₂ into a homogeneous, isotropic geological formation. Nordbotten et al. use the general shape of the invading front, coupled with an assumption of a sharp interface between the fluids, to develop their simple analytical solution (18).

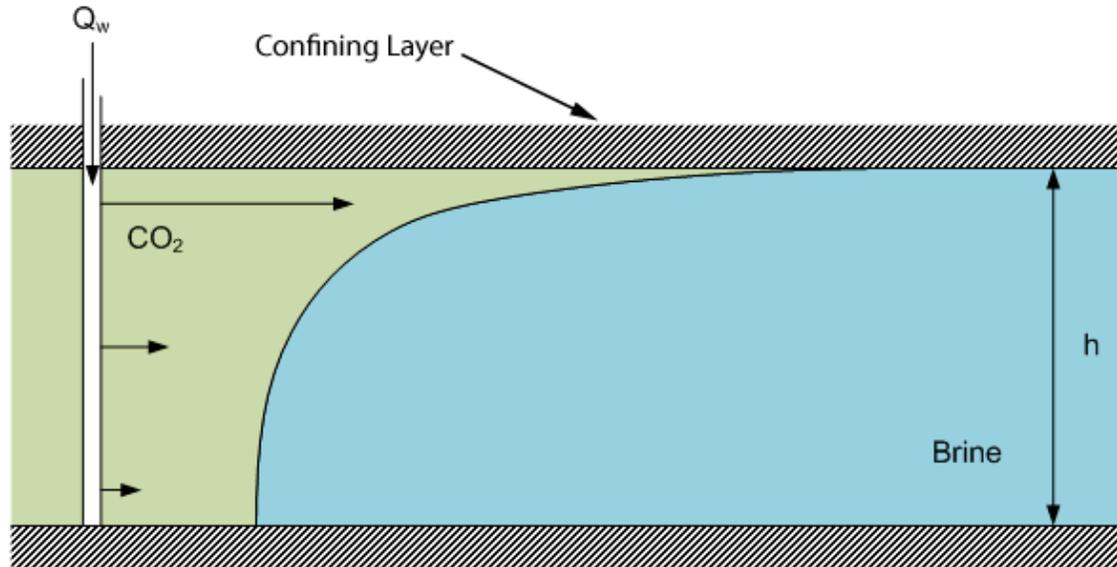


Figure 3.1: Geometry of a system where CO₂ is displacing brine under the Nordbotten et al. solution (18).

CO₂ is typically sequestered as a supercritical fluid to maximize sequestration efficiency (19). For temperatures greater than $T_c=31.1$ °C and pressures greater than $P_c=7.38$ MPa, CO₂ is in a supercritical state (19). Above this pressure and temperature, CO₂ has a low, "gas-like" viscosity, but a "liquid-like" density between 150 to >800 kg/m³ (19). The higher the density of CO₂, the more efficiently the pore space can be used to sequester it as a separate phase because buoyant force, which drives CO₂ upwards and laterally under the confining layer, decreases as the density of the CO₂ phase approaches that of the brine. To maximize the efficiency of geological sequestration, CO₂ injection is typically limited to depths greater than 800 meters, where supercritical conditions are met assuming a hydrostatic pressure gradient 1 MPa per 100 m and geothermal gradient of 25 °C per km (20).

Thus, models of CO₂ distribution in the subsurface must account for: gravity override caused by buoyancy of the CO₂ phase; the greater lateral mobility of CO₂ compared to brine (that

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results from the lower viscosity of CO₂); and the injection work-minimizing distribution of CO₂ in the formation (18). The importance of buoyant force in sequestration relative to the viscosity and pressure forces is related by the dimensionless quantity, Γ , given by:

$$\Gamma = \frac{2\pi g \lambda_w k \Delta \rho h^2}{Q_w} \quad (\text{Eq. 3.1})$$

where g [m/s^2] is acceleration due to gravity, λ_w [$1/Pa \cdot s$] is the phase mobility of brine, k [m^2] is permeability of the rock matrix, $\Delta \rho$ [kg/m^3] is the density difference between the brine and CO₂ phases, h [m] is the net thickness of the formation, and Q_w [m^3/s] is the volumetric injection rate of CO₂ at reservoir conditions.

When buoyancy is insignificant relative to viscous effects (i.e. the value of Γ is small), the full solution for calculating plume size reduces to the radial Buckley-Leverett equation (Equation A8, Supporting Information), a transport equation used to model two-phase flow in porous media (18). This equation has been the basis of a number of analytical models of deep well fluid injection (21-23). Using this simplification, the equation for the maximum radial extent of the CO₂ plume, r_{\max} , which for a constant volumetric injection rate of Q_w given by (18):

$$r_{\max} [km] = \sqrt{\frac{\lambda_c V}{\pi h \varphi \lambda_w (1 - S_{ir})}} \times \frac{1km}{10^3 m} \quad (\text{Eq. 3.2})$$

where λ_c [$1/Pa \cdot s$] is the phase mobility of CO₂, V [m^3] is the volume of injected CO₂, φ [%] is formation porosity, and S_{ir} [%] is the irreducible brine saturation in formation.

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When the value of Γ is large—in this case, greater than 0.5—buoyant force cannot be neglected and the more complex solution incorporating buoyant effects developed by Nordbotten et al. (18) is used to estimate r_{\max} (Equation A12, Supporting Information).

Physical properties of CO₂ at reservoir conditions were estimated using the Peng-Robinson equation of state (24) and the transport properties using the method of Chung et al. (25), and modified for high pressure application by Reid et al. (26). Physical and transport properties of brine were estimated using the correlation of Batzle and Wang (27).

The model assumes a homogeneous, isotropic reservoir, and calculates CO₂ plume footprints that result from a single vertical injection well, completed through the total thickness of the formation. Modeling injection into a single formation layer yields an upper bound on the size of the CO₂ plume, since injection into multiple stacked formations would yield a smaller footprint. Of course, due to the heterogeneous and anisotropic nature of rock properties and structural and stratigraphic features, CO₂ plumes are unlikely to migrate uniformly. This behavior could reduce or enlarge the CO₂ plume footprint. In addition, the host rock, brine and CO₂ are compressible, which would tend to reduce the plume footprint. Finally, because of pressure constraints in the subsurface due to the need to avoid fracturing the geological containing unit, multiple injection points would likely be required to carry out a GCS project of this size (~15,000 metric tons per day injected) (28-30). Further details on the model and the underlying assumptions can be found in Nordbotten et al. (18) and in the Supporting Information.

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3.1.2 Cost of Acquiring Pore Space Rights

The cost to lease pore space on an annual and long-term basis was estimated. The cost to purchase pore space rights up-front was also calculated. In theory, pore space leases could contractually require the project developer to compensate the pore space owner in perpetuity because injection of CO₂ might preclude alternative uses of the pore space for hundreds to thousands of years. Therefore, the cost of leasing pore space annually was examined over a 100-year time horizon, beyond which the present value of additional costs becomes insignificant due to discounting. For the 100-year lease, it is assumed the injected CO₂ ceases to migrate beyond the 30-year plume size calculated by the model.

The annual lease rate (\$/acre/year) for pore space is based on the going rates for natural gas storage on both privately owned lands and state-owned forestlands in Pennsylvania (31). At \$45-65 per acre-per year, Pennsylvania exacts a premium from natural gas storage companies for use of its pore space compared to what private landowners receive, typically \$2-10/acre/year. It was assumed that natural gas storage lease rates are uniform throughout the United States. All cost estimates are calculated with a 15% discount rate and 4% inflation rate. For the long-term lease, the per acre cost was extrapolated from the annual lease rates. The long-term lease bears a higher per acre price tag (\$20 to \$600/acre) than the annual lease because all compensation for use of the pore space is redeemed up-front. These rates represent the present value of the aggregate payment streams generated over 100 years across the range of annual lease rates applied to the model. The per acre cost of purchasing pore space was calculated by taking the product of the maximum CO₂ plume size estimate and the present value of the aggregate payment streams generated over 30-years across the range of

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annual lease rates applied to the model. Due to discounting, the per acre purchase cost is nearly identical to the long-term lease rate.

Application of the annual lease scenario supposes regulations will require that the legal rights to all pore space lying under the footprint predicted using a CO₂ plume distribution model must be acquired by the GCS project developer as a precondition to commencing any injection activities. The long-term lease scenario examined here would not require project developers to acquire all pore space rights up front, but would allow developers to acquire them as they become determined through subsurface monitoring. While not analyzed here, a similar approach could also be applied to the outright purchase of pore space. Monitoring costs are not considered in this calculation because prudent sequestration operators will conduct periodic monitoring to track the evolution of the CO₂ plume regardless of whether the use of pore space requires compensation. For example, Benson et al. developed scenarios in which seismic surveys are performed in the each of the first two years, the fifth year, and every fifth year thereafter for 80 years for the purposes of monitoring (32).

3.1.3 Pipeline Transport Model

Transport of CO₂ to a sequestration site by pipeline is simulated using an engineering economic model developed by McCoy and Rubin (33). CO₂ is piped in a supercritical state to maximize transport efficiency. Capital costs used in the model are based on a regression analysis of natural gas pipeline project costs available in Federal Energy Regulatory Commission (FERC) filings from interstate gas transmission companies (33-35). Capital costs for pipeline include costs for materials, labor, rights-of-way, and miscellaneous charges

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(such as taxes, project management, administration and overheads, regulatory fees, and contingencies allowances) (33,34,36). The required pipeline diameter depends on the CO₂ mass flow rate and the acceptable pressure drop over the pipeline length (33,34). Pipeline costs therefore vary with pipeline length and the CO₂ flow rate. Depending on the pipeline length, additional pumping stations are required to boost the pressure along the pipeline to compensate for pressure losses. The model assumes that an additional booster station is needed every 402 km (205 miles). Specific pipeline costs also vary by geographic region and terrain (33,34). Regional cost differences are captured in the model, though the effect of terrain along a specific pipeline route is not captured by the model. The project regions are the same as those used by the Energy Information Agency (EIA) (33,37). Capital costs were annualized using a fixed charge factor of 15%, which corresponds to a project with a 30-year life and a 14.8% real discount rate.

3.2 Model Application

The total mass of CO₂ injected was fixed at 160 million metric tons (Mt), the amount of CO₂ captured from an 800 megawatt (MW) coal plant operating with a 60% capacity factor and at 90% capture for 30 years (10,38). Pennsylvania and Ohio were chosen for analysis because they are major coal-burning states that are also thought to contain geology suitable for large-scale sequestration of CO₂. In 2007, 70% of the electricity generated in Pennsylvania and Ohio was generated using coal as a fuel source (39). Pennsylvania and Ohio alone combine to make up roughly 13% of America's coal-fired electricity generation, and nearly 10% of all electricity generation in the United States is generated by burning coal in these two states (39).

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The Midwest Regional Carbon Sequestration Partnership (MRCSP) estimated that Pennsylvania and Ohio have potential GCS capacities of around 90 gigatonnes and 46 gigatonnes, respectively (40). The saline formations estimated to have the largest theoretical capacity in the MRCSP region are the Mt. Simon, St. Peter, and Medina/Tuscarora Sandstones (41). Others are the Oriskany Sandstone, Rose Run, and the Sylvania Sandstones (41). Sufficient geologic core data from numerous oil and natural gas fields in the MRCSP region are available to support analysis of the Clinton (OH), Medina (PA), Oriskany (PA), and Rose Run Sandstones (OH). These data were obtained from the Ohio Department of Natural Resources Division of Geological Survey (42). Observations for which the average formation depth is shallower than 800 meters were removed from the dataset. Only observations with a net thickness of at least 10 meters were included in the analysis because portions of these reservoirs where net sand is less than 10 meters may be too thin for sequestration to be feasible (30). The point estimates for the average formation depth, net thickness, porosity and salinity for each oil and gas field in the Clinton, Medina, Oriskany and Rose Run Sandstones that met these cut-off criteria were then aggregated and converted into triangular distributions (Table A1, Appendix A). Stochastic simulations were run using the parameterized geological data as inputs into the CO₂ plume distribution model.

Simulations were also run using deterministic input values based on geologic data from three oil and gas fields (the Volant, East Canton Consolidated-S, and Baltic fields) located in the Medina, Clinton, and Rose Run Sandstones and believed to have large CO₂ sequestration capacities (Table A1, Appendix A). Maximum CO₂ plume footprints were predicted using deterministic input values for two case comparisons: the Frio Sandstone in the Texas Gulf

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Coast, and the Mt. Simon Sandstone at the Mattoon, IL site originally selected for the FutureGen™ project. The Frio dataset is a compilation of core analysis data, geophysical logs, and data extrapolated from available literature (16). The geologic inputs for the Frio Sandstone represent the mean value for each parameter (Table A1, Appendix A). The Mt. Simon data come from the site selection proposal submitted by the Illinois State Geological Survey to the FutureGen™ Alliance (Table A1, Appendix A) and are based on geophysical log data and limited core analysis data (43,44). Only point estimates for the Mt. Simon Sandstone were available for each geologic parameter.

The CO₂ pipeline model was applied to determine the cost of constructing and operating the necessary infrastructure to transport CO₂ captured from a hypothetical 800 MW coal-fired power plant operating for 30 years near the middle of the Pennsylvania/Ohio border to either the Mt. Simon Sandstone in Mattoon, IL (710 km) or a non-specific location in the Frio Sandstone along the North Texas Gulf Coast (1,860 km). A new, stand-alone pipeline would be required for the Mattoon site, whereas a new pipeline originating near the middle Pennsylvania/Ohio border carrying CO₂ to Texas could tie into existing CO₂ pipeline infrastructure in Jackson, MS (Figure 3.2). Because capital and operating costs for CO₂ pipelines vary by region, as noted above, annualized costs were weighted based on the proportion of the pipeline that traverses each region.

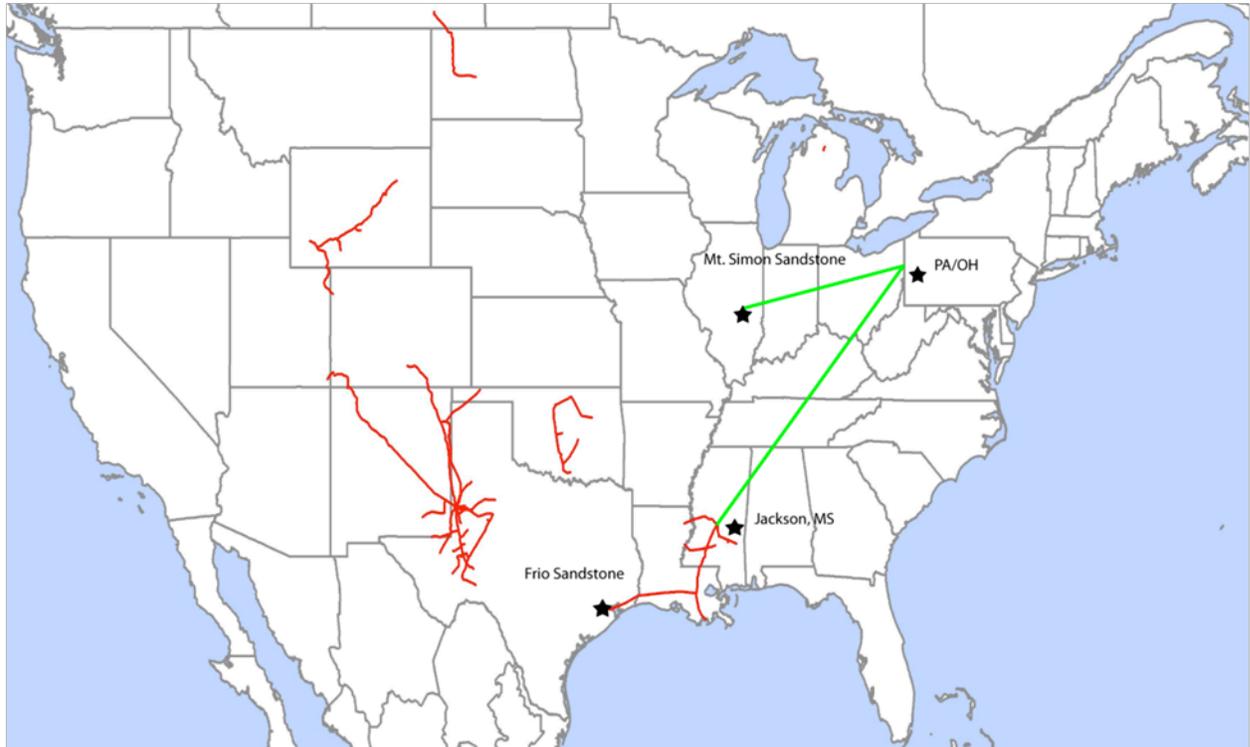


Figure 3.2: Pipeline from PA/OH to the Mt. Simon and Frio Sandstones (45). Red lines represent existing CO₂ pipeline infrastructure; the green lines represent the hypothetical pipeline scenarios assessed in this thesis.

3.3 Results

3.3.1 CO₂ Plume Size

Probabilistic simulations for the Medina, Oriskany, Clinton, and Rose Run Sandstones predict median CO₂ plumes footprints ranging from 4,500 km² to 11,000 km² in areal extent. The distribution of predicted plume footprints at the 5th, 50th, and 95th percentile statistical levels for each reservoir are presented in Table 1.1. The deterministic estimates for the Volant, East Canton, and Baltic oil and gas fields are 1,100 km², 5,200 km², and 4,200 km², respectively. The deterministic simulations predict much smaller plumes for the Frio and Mt. Simon Sandstones: 320 km² and 300 km², respectively. Given that the Mt. Simon and Frio Sandstones have a greater net thickness than sandstones in the MRCSP region examined in

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this chapter, the model was expected to predict smaller CO₂ plume distributions for each of these cases.

Cumulative distribution curves comparing the results obtained for the Medina, Oriskany, Clinton, and Rose Run Sandstones from implementation of the plume-distribution model are provided in the Supporting Information. The sensitivity of CO₂ plume size for each Pennsylvania and Ohio sandstone formation to uncertainty and variability in depth, net thickness, porosity, salinity, irreducible brine saturation, and temperature gradient was examined probabilistically (Figures A5-A8, Appendix A). Formation thickness, porosity, and irreducible brine saturation had the greatest effects on predicted CO₂ plume size for the Medina and Oriskany Sandstones. Plume size is negatively correlated with thickness and porosity, but positively correlated with irreducible brine saturation. CO₂ plume footprint estimates for the Clinton and Rose Run Sandstones were most heavily influenced by formation depth, irreducible brine saturation, and temperature gradient, with plume footprints being smaller at greater depths.

Table 3.1: Extent of CO₂ Plume Size at 30-years for a Total of 160 Mt CO₂ Injected

Formations and Oil & Gas Fields	Plume Size Estimates (km²)
Frio Sandstone (TX)	320
Mt. Simon Sandstone (IL)	300
Medina Sandstone (PA)	
5 th Percentile	1,600
Median	4,500
95 th Percentile	14,000
Volant Field	1,100
Oriskany Sandstone (PA)	
5 th Percentile	2,800
Median	6,500
95 th Percentile	19,000
Clinton Sandstone (OH)	
5 th Percentile	5,800
Median	11,000
95 th Percentile	25,000
E. Canton Consolidated-S Field	5,200
Rose Run Sandstone (OH)	
5 th Percentile	6,500
Median	11,000
95 th Percentile	27,000
Baltic Field	4,200

3.3.2 Pore Space Acquisition Cost

Results suggest that if developers and operators must pay for rights to use pore space for GCS under the assumptions outlined above, the median cost in Pennsylvania and Ohio could range from \$21 million to \$290 million for privately owned land and \$500 million to \$1.7 billion for state-owned land if pore space is either leased annually or purchased outright; and between \$6.8 million and \$84 million for privately owned land and \$140 million to \$500 million for state-owned land if pore space is leased up-front (Table 1.2). This is roughly the equivalent of \$0.04 to \$11 per metric ton of CO₂ (\$/tCO₂) injected. This means the cost of acquiring the legal right to sequester CO₂ could be comparable to, or even exceed, the operational cost of GCS, which the Intergovernmental Panel on Climate Change (IPCC)

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estimated to be between \$0.5 to \$8/tCO₂ (36). Figure 3.3 presents a comparison of the costs for each individual activity in the sequestration chain. Because GCS developers will only acquire a servitude (i.e., the “right to use”) under a lease instrument instead of a fee title (i.e., the full possessory right) if sequestration rights are purchased, it makes sense that, on balance, less compensation will be paid for a sequestration lease than a full fee interest in the pore space.

Table 3.2: Present Value 100-year Lease Cost vs. Purchase Cost (millions 2009\$)¹

	Annual Lease ^a		Long-Term Lease ^b		Purchase Cost ^b	
	Private	State	Private	State	Private	State
Medina (PA)						
<i>5th Percentile</i>	\$7.6-41	\$180-270	\$2.5-13	\$50-79	\$8.3-45	\$170-270
<i>Median</i>	\$21-110	\$500-700	\$6.8-35	\$140-200	\$23-120	\$490-690
<i>95th Percentile</i>	\$62-350	\$1,500-2,200	\$20-110	\$440-640	\$67-380	\$1,500-2,200
Oriskany (PA)						
<i>5th Percentile</i>	\$13-61	\$280-400	\$4.2-20	\$80-120	\$14-66	\$270-400
<i>Median</i>	\$33-150	\$700-1,000	\$11-49	\$200-300	\$36-170	\$680-1,000
<i>95th Percentile</i>	\$91-420	\$1,900-2,800	\$29-130	\$540-830	\$98-460	\$1,800-2,800
Clinton (OH)						
<i>5th Percentile</i>	\$27-130	\$610-860	\$8.7-42	\$170-250	\$29-140	\$590-860
<i>Median</i>	\$49-260	\$1,100-1,600	\$16-82	\$320-490	\$54-280	\$1,100-1,700
<i>95th Percentile</i>	\$120-620	\$2,900-3,700	\$38-200	\$820-1,200	\$130-670	\$2,800-3,700
Rose Run (OH)						
<i>5th Percentile</i>	\$28-140	\$640-930	\$9.1-46	\$180-270	\$31-160	\$620-940
<i>Median</i>	\$52-260	\$1,200-1,700	\$17-84	\$330-500	\$57-290	\$1,100-1,700
<i>95th Percentile</i>	\$120-590	\$2,700-3,900	\$40-190	\$760-1,100	\$140-640	\$2,600-3,900

¹Assumes 15% discount rate and 4% inflation rate.

^aAnnual lease rate range \$2-10 per acre per year for private land, and \$45-65 per acre per year for private land.

^bLong-term lease rate and purchase cost range \$20-100 per acre for private land, and \$400-600 per acre for state-owned land.

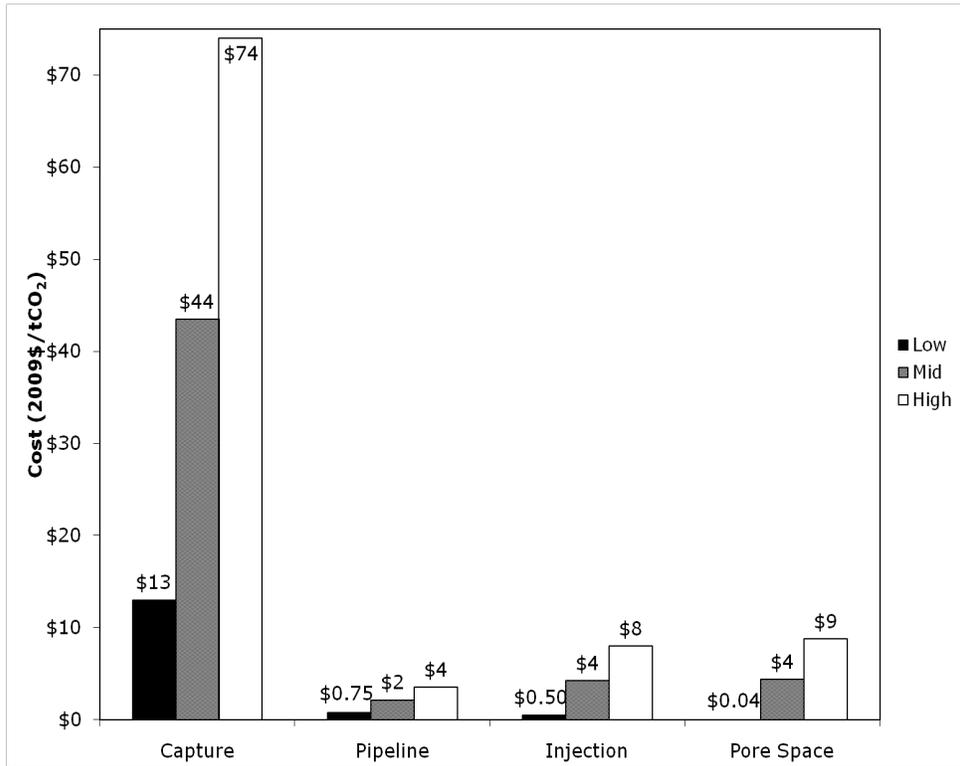


Figure 3.3: Comparison of CCS activity costs on the basis of dollar per metric ton of CO₂ captured, transported, and injected: Capture (46), Pipeline (33), Injection (36) & Pore Space Acquisition. For capture costs, Low = Integrated Gasification Combined Cycle (IGCC), Mid = Pulverized Coal (PC), and High = Natural Gas Combined Cycle (NCGG) (all with installed capture systems).

If compensation is required to use pore space for GCS, the long-term lease approach is consistently the most favorable from an economic standpoint compared to both the annual lease and purchase options by a factor of 3. It should be noted that if pore space is leased annually under a mechanism applied to the long-term lease scenario – that is, annual lease payments are a function of incremental plume growth rather than the maximum predicted plume footprint – the costs under the two lease scenarios are nearly equal, despite the lower per acre annual lease rates.

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The need for long-term stewardship of sequestration sites may make pore space leases impractical. Some very small risk of leakage and other adverse consequences will persist beyond the lifetimes of the private firms operating sequestration facilities. Thus, there is wide agreement that the government, or other specially designed institutions, will have to assume long-term responsibility for closed sites (47,48). It is unlikely these institutions would also take on the economic burden of making lease payments to private landowners, especially in perpetuity. The up-front acquisition of a fee title (i.e., the full possessory right) or servitude (i.e., easement) to the pore space by the GCS developer would avoid this problem and be a relatively straightforward contractual matter.

3.3.3 Pipeline Construction and 30-year Operation Cost

The annualized cost (capital and operational) of transporting approximately 5 million tonnes/year of CO₂ from a large coal-fired power plant near the Pennsylvania-Ohio border (such as the Bruce Mansfield plant (38)) to the Mt. Simon Sandstone in Mattoon, IL is \$41 million (\$8/tCO₂), and \$75 million (\$14/tCO₂) if the CO₂ is piped to the Frio Sandstone in the North Texas Gulf Coast region. Thus, for an operational lifetime of 30 years, the present value cost to transport CO₂ to the Mattoon site and acquire the necessary pore space rights would be \$380 million (\$2/tCO₂), and \$680 million (\$5/tCO₂) for the Frio site (see Table 1.3). This suggests that using thin local formations for sequestration may be more expensive than piping CO₂ to thicker formations at distant sites (Figures 3.4 and 3.5).

Table 3.3: Pipeline Operation & Pore Space Acquisition Cost (millions 2009\$) – PA/OH to Mattoon, IL and Texas Gulf Coast

	Pipeline Cost			Pore Space Acquisition Cost			
	Pipeline Length (km)	Annualized Cost (\$/yr)	Cost of 30-yr Operation (\$)	Plume Size (km ²)	100-yr Annual Lease ^a (\$)	100-yr Long-Term Lease ^b (\$)	Purchase Cost (\$)
Frio (TX)	1,860	\$75	\$680	320	\$1.4-46	\$0.5-12	\$1.6-47
Mt. Simon (IL)	710	\$41	\$380	300	\$1.4-46	\$0.5-13	\$1.5-44

^aAnnual lease rate range \$2-10 per acre per year for private land, and \$45-65 per acre per year for state-owned land.

^bLong-term lease rate and purchase cost range is \$20-100 per acre for private land, and \$400-600 per acre for state-owned land.

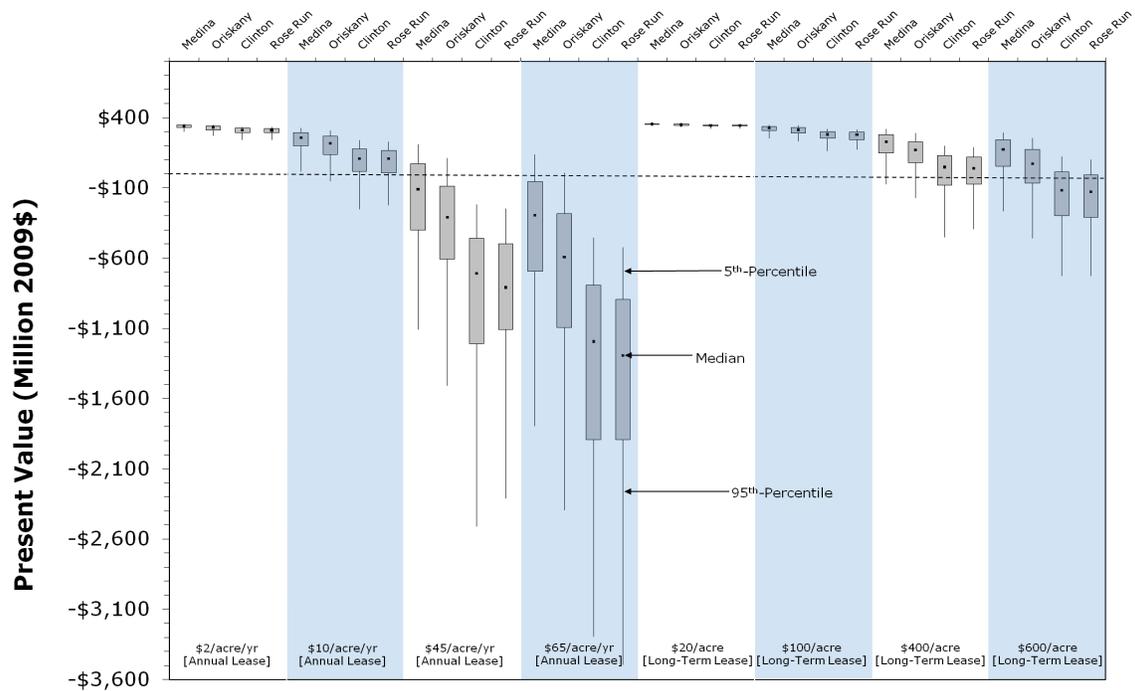


Figure 3.4: Difference between the sum of the Mattoon 30-year pipeline operation cost & 100-year pore space lease cost and the MRCSP sandstone pore space lease costs.

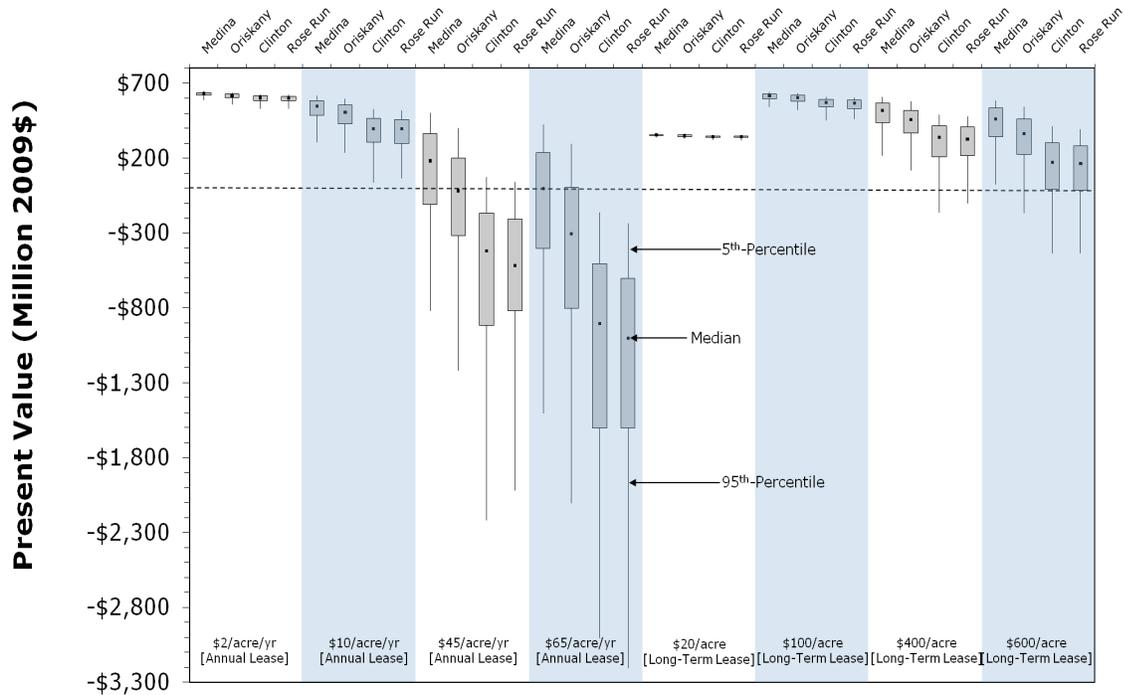


Figure 3.5: Difference between the sum of the Frio 30-year pipeline operation cost & 100-year pore space lease cost and the MRCSP sandstone pore space lease costs.

3.4 Discussion

The results indicate the potential for CO₂ plumes to be very large in size, increasing the degree of legal complexity and the cost associated with acquiring pore space rights, should that be necessary. The results of this analysis are predicated upon the assumption that the examined rock formations exhibit homogenous and uniform geologic properties, so one should not consider the CO₂ plume simulation estimates to be generalizable to all sequestration targets and CO₂ injection scenarios. Nevertheless, the results suggest strongly that the practical sequestration capacity for Pennsylvania and Ohio might be much smaller than theoretical estimates due to the difficulties of dealing with such large plume extents (both from the standpoint of pore space acquisition and site characterization and monitoring). The MRCSP estimates that the theoretical sequestration capacity of the Volant, East Canton,

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and Baltic oil and gas fields each exceed 160 Mt (Table A2, Appendix A) (40,49). Figure 3.6 shows that, were the assumptions of the model fully applicable to these reservoirs, the CO₂ plume footprints would extend beyond the field boundaries by at least a factor of 8 in each case. While the model does not consider pressure perturbations, the relatively thin formations in these two states may also impose non-financial limits due to pressure fronts from interacting injections.

Results from analytical models, numerical simulations, and pilot projects agree that a relatively small fraction of the available pore space will be occupied by injected CO₂, resulting in the CO₂ migrating over large areas (50). Should the use of a marginally suitable reservoir for GCS result in a CO₂ plume that is within the same order of magnitude in size as the very large plumes predicted in this analysis, the cost of acquiring pore space rights could significantly limit economically available sequestration capacity, even if the physical capacity is available. Geologic sequestration of CO₂ should be carried out in the best reservoirs first, where the physical capacity is available and the geologic characteristics are optimal for limiting plume migration. This recommendation may, in some cases, be at odds with injection into an open formation where pressure build-up can be minimized, thus maximizing the capacity and injection rate (29,51). Thus, in some cases there is likely a trade-off between the cost of acquiring pore space and the capacity of sequestration targets.

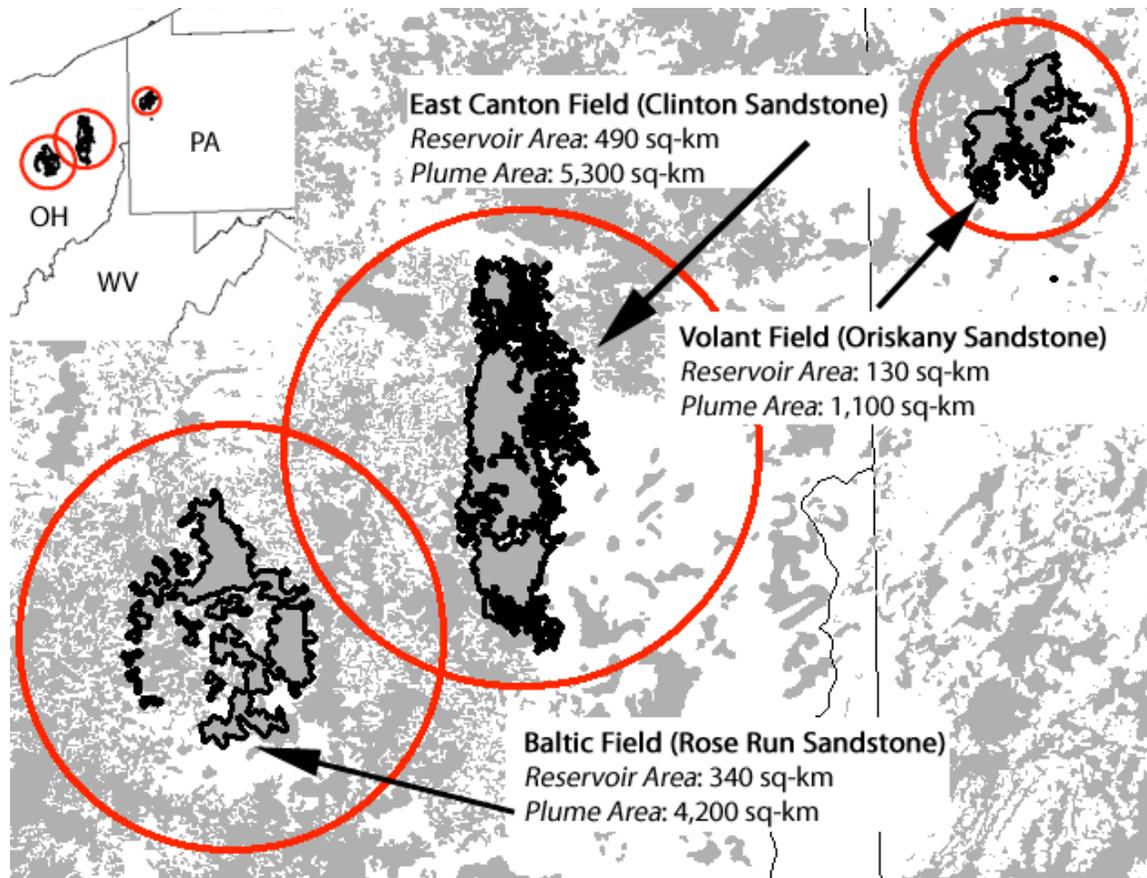


Figure 3.6: Estimated CO₂ plume footprints for oil and gas fields in the MRCSP region. The areas outlined in bold-black represent the oil and gas fields (42), and the areas outlined in bold-red represent the estimated CO₂ plume footprints resulting from sequestration of 160 Mt CO₂ in each field over 30 years.

While very large plume footprints in the relatively thin formations of Pennsylvania and Ohio are likely, pipelines could be constructed and used at a reasonable cost to transport captured CO₂ to the most suitable reservoirs from regions of the United States where coal-fired electricity generation is abundant but sequestration opportunities are limited. Previous work has demonstrated that it is less expensive to build a coal plant with CCS near load than near a suitable reservoir (34). If reservoir resources are limited, however, competition for the available pore space could drive up the cost of acquiring subsurface property rights for sequestration. If circumstances eventually require the use of reservoirs with a low mass-to-

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volume storage capacity, the cost of acquiring pore space rights could increase overall sequestration costs significantly, but even such costs are likely to be smaller than the costs of capture.

If compensation for the use of pore space *is* required, the cost of acquiring pore space for even large plumes may be reduced if serious efforts are focused on examining alternative models for standardizing the procedures for acquiring and transferring pore space rights that limit administrative and transaction costs. Even though the economic cost of acquiring the right to use pore space under the Frio and Mt. Simon Sandstone injection cases examined in this paper would not hinder development of the reservoirs for GCS, the task of negotiating with all relevant landowners within even their relatively small 320 km² (Frio Sandstone) to 300 km² (Mt. Simon Sandstone) area could prove to be difficult. Furthermore, “hold-out” landowners could prevent the development of a GCS reservoir.

Federal legislation could resolve this issue by assuring that GCS operators would have access to pore space and protection against subsurface trespass similar to that enjoyed in practice by other operators of programs that inject waste fluids underground (9). In this case, GCS operators would have to acquire and pay compensation for surface and subsurface rights *only* at the location of the injection well, but not for the entire subsurface sequestration reservoir—like fluid waste and municipal wastewater disposal, enhanced hydrocarbon recovery, and groundwater storage and recharge. Under such a construction, compensation to property-owners neighboring the injection well for the use of pore space would be required *only* when the migration of CO₂ actually and substantially interferes with a demonstrated

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preexisting or imminent use of the subsurface (9). This approach is optimal both because there is an overriding national interest to limit emissions of CO₂ to the atmosphere, and because if the issue of access to pore space gets resolved by state courts and legislation, the U.S. could end up with a patch-work of rules and legal precedents that could further impede the already slow adoption of carbon capture with GCS.

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Chapter 4: Economic Effects of CCS on the Levelized Cost of Electricity, Power Plant Profitability, and Subsurface Property Rights Valuation

Site-specific geology will play a determinant role in the project economics of CO₂ capture and geologic sequestration. For instance, as shown in the previous chapter, carbon dioxide injected and sequestered in deep geologic pore space could migrate laterally over a very sizeable area depending on the structural and geologic characteristics of the sequestration formation. This potentially could lead to very high costs associated with acquiring subsurface property rights for geologic CO₂ sequestration.⁴⁹⁹ Expanding upon the analysis presented in Chapter 3, a model was developed to examine how the economics of an electric generation facility are affected by variations in the geologic characteristics of saline aquifers targeted for CO₂ sequestration.

First, the effects of geology and property rights acquisition costs on the levelized cost of generating electricity were modeled under the assumption that all CO₂ sequestration-related expenses—capture, pipeline transport, injection, and pore space rights acquisition—will be absorbed by the electric generation facility operator. Second, assuming that surface owners and mineral owners must be compensated for the use of pore space, the effects of formation geology and property rights acquisition costs on the profitability of an electric power generation facility with CO₂ capture selling power in the wholesale market were considered. Lastly, the model was used to approximate an economic value for geologic pore space as a function of power plant profitability. It was assumed for each of these three analyses that the owner/operator of the modeled electric generation facility must pay a penalty for each metric

⁴⁹⁹ *Supra* Chapter 3, Section 3.3.2.

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ton of CO₂ emitted into the atmosphere. Simulations were also run where the electric generation facility was credited a monetary benefit for each metric ton of CO₂ captured and subsequently sequestered.

4.1 Methods & Data Sources

An integrated technical and economic CCS model was developed to examine the effects of formation geology on the economics of an electric power generation facility operating with CO₂ capture using power plant performance and economic outputs generated by the Integrated Environmental Control Model (IECM) (1); a project specific cost model for CO₂ transport via pipeline (2); a project-specific cost model for CO₂ injection and sequestration in saline aquifers (3); and a CO₂ plume distribution and property acquisition cost model similar to that presented in Chapter 3.⁵⁰⁰ As noted above, the model was also used to monetize the potential value of pore space to be used for CO₂ sequestration. Figure 4.1 illustrates, at a high level, how the individual model components were integrated.

⁵⁰⁰ *Supra* Chapter 3, Section 3.1.

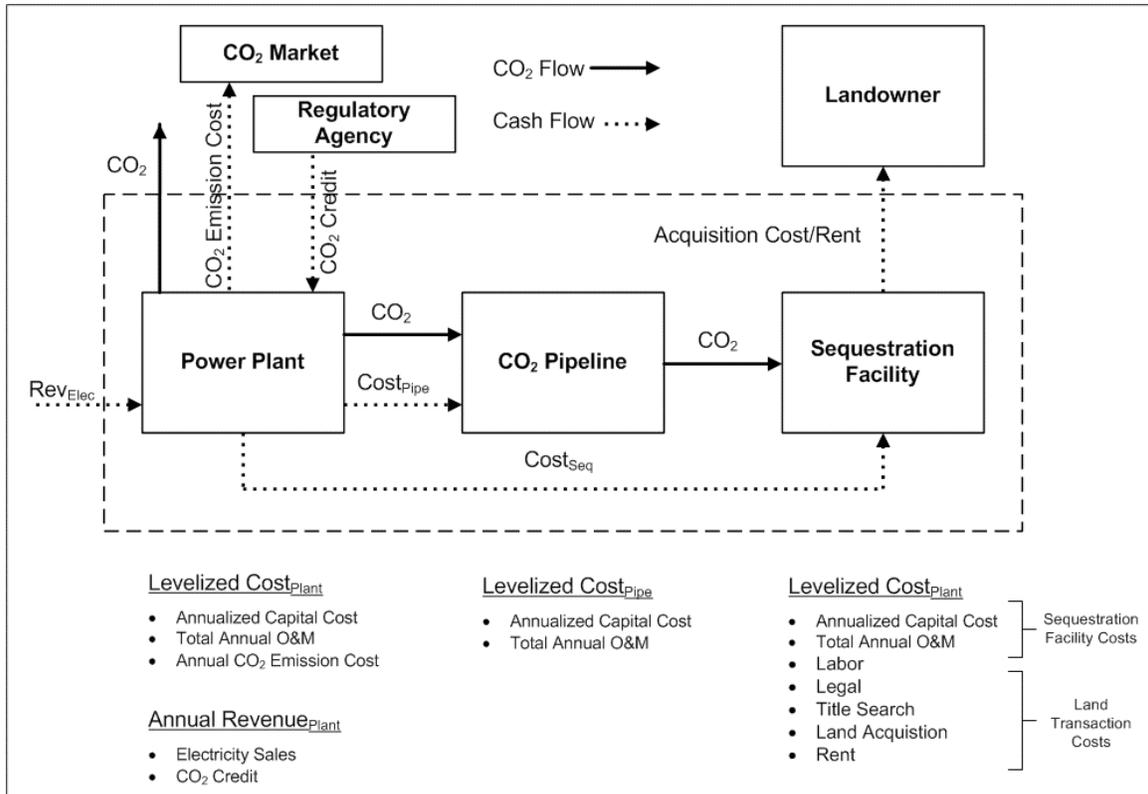


Figure 4.1: Diagram of the integrated CCS model.

The model was first used to investigate how site-specific geology might affect the economics of operating an electric generation facility with CO₂ capture. The engineering and economic details were modeled for a coal-fired, 2-turbine integrated gasification combined cycle (IGCC) facility with CO₂ capture using the IECM Version 6.2.4. (1) The IECM is a publically available and widely-used computer-modeling program developed by Carnegie Mellon for the U.S. Department of Energy’s National Energy Technology laboratory (DOE/NETL) that performs a systematic cost and performance analysis of fossil-fueled electric generation facilities with emission control systems such as CO₂ capture. (1,4) The cost and performance models in the IECM draw upon a variety of detailed engineering-economic studies; results are consistent and generalizable with these other studies for the same set of input assumptions. (1,4) The model employs fundamental mass and energy

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balances, together with empirical data, to quantify overall plant performance, resource requirements, and emissions. (1,4) Plant and process performance models are linked to a companion set of engineering-economic and financial models that calculate the total cost of generating electricity for the entire plant based on the capital cost and annual operating and maintenance (O&M) costs of individual plant components. (1,4)

The IECM model used for the 2-turbine IGCC facility examined herein uses, as a default, the GE gasification process, Appalachian medium sulfur coal, GE combined cycle gas turbines, the sour shift plus Selexol CO₂ capture process, and a net electrical output of roughly 530 MW. The IECM provided the hourly net electricity production, hourly CO₂ emissions, and hourly CO₂ capture rate. The IECM also provided economic outputs for the overall capital required to construct the facility and the annual O&M costs. A capital recovery factor (CRF) of 11.4%—calculated by the IECM and based upon the plant life and model default values for percent of debt and equity, return on debt and equity, the inflation rate, the before tax discount rate, and federal and state tax rates—was used to determine the revenue, reported as 2009 constant dollars, that must be collected annually from electricity customers in order to pay the carrying charges on the capital investment. The facility's annual revenue requirement is the sum of the annualized cost of capital and the total annual O&M costs. Although not treated endogenously in this analysis, power producers will construct a generation facility in a location that will minimize electricity transmission costs. Newcomer and Apt demonstrated that the optimal location for a CCS power facility is nearest the electric load, reducing the losses and costs of bulk electricity transmission. (5)

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For the first analysis, the IGCC facility was treated as a “cost-of-service” electric utility, such that costs associated with electricity generation and CCS would be passed on to electricity customers. The total levelized cost of electricity was calculated as the sum of the facility’s levelized cost of producing electricity and capturing CO₂; the levelized cost of CO₂ pipeline transport, injection and sequestration, and acquisition of subsurface property rights; and the annual cost of paying to emit CO₂ if the emission of GHGs is penalized via a tax, some form of command-and-control regulation such as the tailoring rule proposed by Environmental Protection Agency (6), or a market-based regulatory mechanism such as the cap-and-trade systems proposed in several Senate and House bills (7,8,9). No specific mechanism for penalizing CO₂ emissions was applied in the model, however. Instead, it was assumed that the electric power generator must pay a penalty for each metric ton of CO₂ emitted into the atmosphere (\$/tCO_{2-emit}). The monetized cost of emitting CO₂ was parameterized between \$0/tCO₂ and \$100/tCO₂.

In addition to the annual lease costs such as those considered in Chapter 3, a \$3 per acre transaction cost of securing the rights to lease pore space was applied in the model. This value is the average rate currently being paid by an undisclosed geologic CO₂ sequestration project developer in the United States. Thus, the total annual cost of leasing pore space was calculated as the sum of the annualized up-front transaction cost of securing the rights to lease pore space and the annual lease cost. The annual lease cost was computed as the product of an annual dollar per acre lease rate (\$/acre/yr) and the areal extent of the CO₂ plume. The annual lease rate was parameterized between \$5/acre/yr and \$100/acre/yr.

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First, the proportionate contribution of the cost of emitting CO₂ along with the expenses for electricity generation and CO₂ capture, CO₂ pipeline transport, CO₂ injection and sequestration, and pore space acquisition to the levelized cost of electricity were examined. The cost of injection and sequestration and the cost of acquiring subsurface pore space rights were expected to vary considerably across the saline aquifers considered in this analysis as a function of geology and CO₂ plume size. (3) Injection and CO₂ plume size was modeled using the mean depth, net sand thickness, porosity, and salinity of four of the sandstone formations analyzed in Chapter 3: the Frio, Mt. Simon, Oriskany, and Medina Sandstones (see Table 4.1).⁵⁰¹ The irreducible brine saturation in these formations was assumed to be 30%.

Table 4.1: Formation characteristics

Formation	Depth (m)	Net Sand Thickness (m)	Porosity (%)	Salinity (ppm)
Oriskany Sandstone	2600	19	6	320,000
Medina Sandstone	1500	26	7	180,000
Mount Simon Sandstone	2300	90	13	124,000
Frio Formation	1900	300	30	100,000

A second analysis was performed to determine the effect of geology and the cost of acquiring pore space rights on the profitability of the modeled IGCC facility if it were an independent power producer selling electricity in the wholesale market. Profit was calculated as the difference between the sum of annual electricity sales in the wholesale market and the monetary benefit, if any, received for every metric ton of CO₂ captured and permanently sequestered (\$/tCO₂-seq) and the sum of the levelized cost of the IGCC facility with capture,

⁵⁰¹ See *infra* Appendix A, Model Input Parameters.

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CO₂ transport, CO₂ injection and sequestration, and pore space acquisition, along with the annual cost of emitting CO₂. Thus, profit is the net revenue in excess of the annual revenue requirement. The expected return on the modeled IGCC facilities debt and equity funds is treated endogenously in the revenue requirement/levelized cost of electricity calculation.

The average wholesale price of electricity reported by the Energy Information Agency (EIA) for the North American Reliability Corporation (NERC) region corresponding to the geographic location where each of the sandstone formations assessed in this analysis are situated was applied in the model (see Table 4.2). (10) Specifically, the Frio Sandstone is located in the Texas Regional Entity (TRE) region; the Mt. Simon Sandstone in the SERC Reliability Corporation region; and the Medina Sandstone and Oriskany Sandstone are situated in the Reliability First Corporation (RFC) region. Since it was anticipated that the IGCC facility modeled herein would not be profitable at current wholesale electricity prices, the availability of what shall be termed “sequestration credits” (i.e., a direct monetary benefit received by the facility for each metric ton of CO₂ sequestered) were considered in order to determine the level of subsidy required to create a favorable economic landscape for building commercial CCS facilities. A sequestration credit could take the form of a direct subsidy payment or a tax credit, just to name a couple of examples. Like the cost per metric ton of CO₂ emitted, the monetized value of a sequestration credit was also parameterized \$0/tCO₂ and \$100/tCO₂. CO₂ emission costs did not completely negate the revenue realized from the accrual of sequestration credits since the mass of CO₂ emitted from the modeled facility was a mere a fraction of that captured for sequestration (see Table 4.2).

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Lastly, by running the model “backwards,” the potential economic value of pore space used for geologic CO₂ sequestration from the perspective of the modeled IGCC facility operating as an independent power producer was computed as the difference between the sum of annual electricity sales in the wholesale market and the revenue realized in the form of sequestration credits and the sum of the levelized cost of operating the IGCC facility with capture, CO₂ transport, and CO₂ injection and sequestration, in addition to the annual cost of emitting CO₂, divided by the solution for the annual extent of the CO₂ plume. Because the electric power generator in this model has the opportunity to realize revenue not just from electricity sales but also from sequestration credits for each metric ton of CO₂ sequestered, it is reasonable to consider any revenue realized by the electric power generator in excess of its revenue requirement to be an appropriate index for pore space value. If the modeled IGCC facility was treated as a wholly regulated electric utility in this particular analysis, the economic value of pore space would simply be the equivalent of the quotient of the aggregate monetary value of the CO₂ sequestration credits accrued annually and the areal extent of the CO₂ plume that results from injection and sequestration since all costs associated with CCS and CO₂ emissions penalties would be included in the facility’s rate base and recovered from electricity customers. The question being addressed is whether sequestration credits could generate enough revenue for the electric generation facility to justify a significant flow of cash payments to subsurface property owners, or whether property owners get squeezed.

4.1.1 CO₂ Pipeline Transport Model

Although a CO₂ transport system model interface is available in the IECM, it is not possible to model transport of CO₂ over multiple geographic regions using this particular tool. (1) For this reason, the engineering-economic model for simulating the transport of CO₂ from a

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power plant to a sequestration site developed by McCoy (on which the IECM pipeline tool is based) was used. (2, 3) The CO₂ transport model is composed of two parts: a performance model and a cost model. (2, 3) The performance model takes engineering design parameter inputs, such as pipeline length and design CO₂ mass flow, and calculates the required pipe diameter. (2, 3) The model includes a comprehensive physical properties model for CO₂ and accounts for the compressibility of CO₂ during transport, and allows for the inclusion of booster pumping stations and pipe segment elevation changes. (2, 3) The CO₂ transport cost model combines a user-specified pipeline length and project region with output from the performance model to estimate the annualized capital cost and annual operating cost for the project. (2, 3) Figure 4.2 illustrates the inputs and outputs from the performance and cost models in addition to how the two models interact.

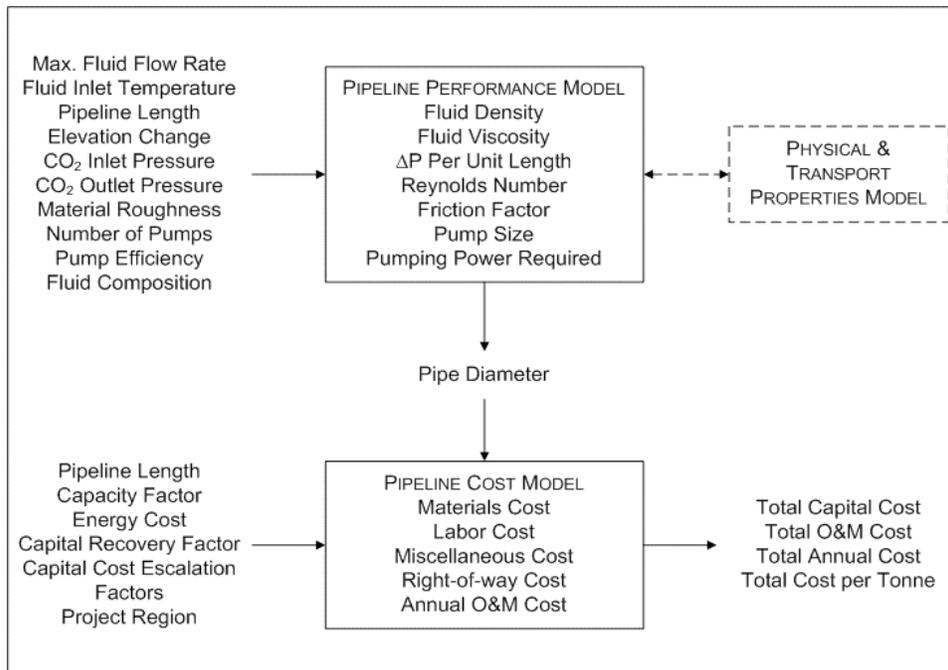


Figure 4.2: Inputs and outputs from for CO₂ transport model (adapted from S.T. McCoy (2, 3)).

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As highlighted in Chapter 3, because there are many similarities between the transport of natural gas and CO₂, McCoy based CO₂ pipeline capital costs on a regression analysis of natural gas pipeline project costs available in Federal Energy Regulatory Commission (FERC) filings from interstate gas transmission companies. (2, 5, 11) Capital costs for pipeline include costs for materials, labor, rights-of-way (ROWs), and miscellaneous charges (such as taxes, project management, administration and overheads, regulatory fillings fees, and contingencies allowances). (2, 5, 12) Because McCoy originally reported materials, ROWs, engineering, overhead, allowance for funds used during construction, and compression capital costs in constant 2004 dollars, a cost escalation factor of 200% was applied to these individual capital costs categories to account for the anticipated increase of individual capital cost components, such as the cost of steel, from 2004 to 2009. All capital costs were annualized using a fixed charge factor of 15%, which corresponds to a project with a 30-year book life and a 14.8% discount rate. (2, 3)

Pipeline costs generally vary based on the length and diameter of the pipeline as well as the quantity of CO₂ transported. Pipeline diameter is a function of CO₂ mass flow rate. (2, 5) Pipeline costs will therefore vary with pipeline length and the CO₂ flow rate. Depending on the pipeline length, additional pumping stations are required to boost the pressure along the pipeline to compensate for pressure losses. (2, 3) Increasing the pipeline length by a factor of two roughly doubles the modeled cost of transporting CO₂. In this analysis, the pipeline length was fixed at 100 km across all simulations, so no booster stations were required. Specific pipeline costs also vary by geographic region and terrain. (2, 5) Regional cost

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differences were captured in the model, though the impact of terrain along a specific route on cost was not considered. The project regions are the same as those used by the EIA. (2, 13)

4.1.2 CO₂ Injection and Sequestration and Property Rights Acquisition Model

A model for geologic sequestration in saline aquifers developed by McCoy (3) was revised to account for the up-front transaction and annual lease costs for pore space associated with developing and operating a geologic sequestration project. As in Chapter 3, Nordbotten et al.'s solution incorporating buoyant force was used to estimate the areal extent of a CO₂ plume resulting from geologic sequestration in a saline aquifer. (3, 14) The sequestration model developed by McCoy, like the pipeline model, is composed of both a performance and cost component. (3) The performance model uses inputs that describe reservoir, CO₂, and brine properties; the development of the sequestration field; the project operation time horizon to estimate the number of wells required to achieve the desired injection over the project life; maximum allowable wellbottom pressure; and the additional compression energy needed to meet the required wellhead pressure. (3) The cost model consists of four principle elements: site characterization costs, project capital costs, O&M costs, and monitoring, verification, and closure costs. (3) For this analysis, the sequestration cost model was adapted to include the up-front transaction and annual rent costs associated with acquiring subsurface property rights for geologic sequestration. The cost model was used to combine results from the performance model with specified cost factors to estimate the total levelized cost of sequestration in a saline aquifer. The inputs and outputs of the sequestration and property rights acquisition model and the interaction between the performance and cost components are shown in Figure 4.3.

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As with pipeline costs, region specific injection costs were captured in the model.

Additionally, a cost escalation factor of 200% was applied to drilling and completion, injection well equipment, injection O&M, and injection compression capital costs to account for the anticipated increase of individual capital cost components between 2004 and 2009.

Capital costs were also annualized using a fixed charge factor of 15%. (3) The up-front transaction cost of securing the right to lease pore space was annualized using a real discount rate of 11%.⁵⁰²

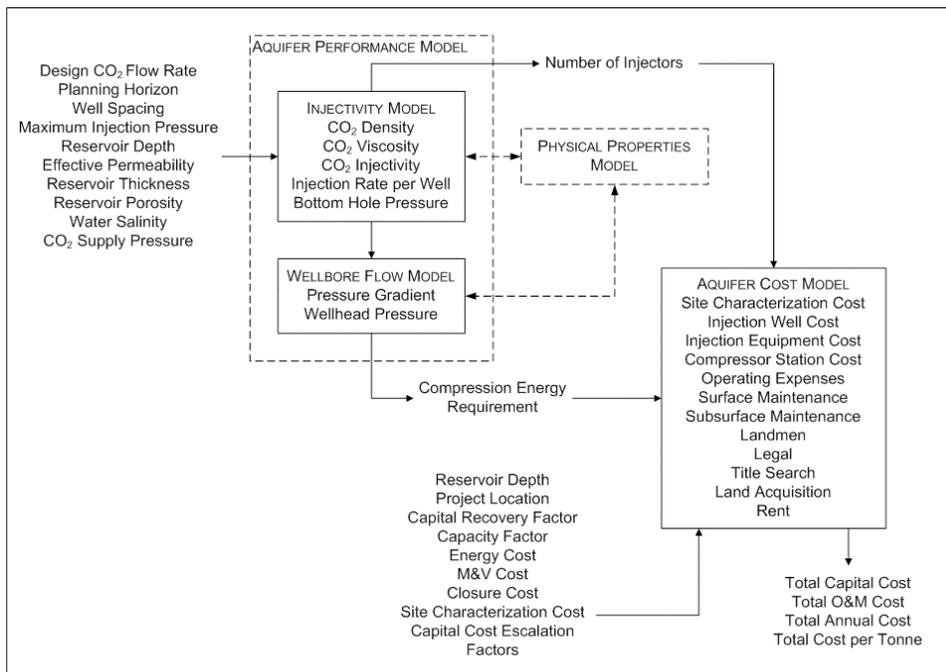


Figure 4.3: Inputs and outputs for the CO₂ sequestration and property rights acquisition model (adapted from S.T. McCoy (2, 3)).

⁵⁰² Assumes a discount rate of 15% and a 4% inflation rate.

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4.1.3 Modeling the Cost of Electricity

The effects of CO₂ emissions penalty costs as well as all costs associated with carbon capture and sequestration—CO₂ capture, CO₂ transport, CO₂ injection and sequestration, and pore space rights acquisition—on the levelized cost of electricity, LCOE [\$/MWh], were analyzed. The cost of emitting CO₂ is the product of the amount of CO₂ emitted annually, $Q_{\text{CO}_2\text{-emit}}$ [tCO₂/yr], and the assumed CO₂ emission price, $P_{\text{CO}_2\text{-emit}}$ [\$/tCO₂]. The annual cost-of-service revenue requirement [\$/yr] for the IGCC facility considered in the model when treated as a wholly regulated electric utility was expressed as:

$$\text{Rev}_{\text{Req}} = \sum_j \text{TLC}_j + Q_{\text{CO}_2\text{-emit}} P_{\text{CO}_2\text{-emit}} ; \quad (\text{Eq. 4.1})$$

$j =$ electricity generation/CO₂ capture, CO₂ pipeline, CO₂ sequestration, property rights

where TLC [\$/yr] is total levelized cost, which is equal to the sum of the annualized capital cost, TAC [\$/yr], and annual operating costs, OC [\$/yr], associated with electricity generation and CO₂ capture, CO₂ pipeline transport, CO₂ injection and sequestration, and the cost of acquiring the rights to use pore space for geologic CO₂ sequestration:

$$\text{TLC}_j = \text{TAC}_j + \text{OC}_j ; \quad (\text{Eq. 4.2})$$

$j =$ electricity generation/CO₂ capture, CO₂ transport, CO₂ sequestration, property rights

The annualized capital cost is the product of the total capital cost, TCC [\$], and the capital recovery levelization factor, CRF:

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$$TAC_j = TCC_j \times CRF; \quad (\text{Eq. 4.3})$$

j = electricity generation/CO₂ capture, CO₂ transport, CO₂ sequestration, property rights

The LCOE [\$/MWh] was calculated by taking the quotient of the annual revenue requirement [\$/yr] and the annual amount of electricity generated [MWh/yr], Q_e :

$$\begin{aligned} \text{LCOE} &= \frac{\text{Rev}_{\text{net}}}{Q_e} && (\text{Eq. 4.4}) \\ &= \frac{\sum_j \text{TL}C_j + Q_{\text{CO}_2\text{-emit}} P_{\text{CO}_2\text{-emit}}}{Q_e} = \frac{\sum_j (\text{TAC}_j + \text{OC}_j) + Q_{\text{CO}_2\text{-emit}} P_{\text{CO}_2\text{-emit}}}{Q_e} \\ &= \frac{\sum_j ((TCC_j \times CRF) + \text{OC}_j) + Q_{\text{CO}_2\text{-emit}} P_{\text{CO}_2\text{-emit}}}{Q_e} \end{aligned}$$

j = electricity generation/CO₂ capture, CO₂ transport, CO₂ sequestration, property rights

Details of the engineering and economic variables in Equations 4.1 through 4.4, including descriptions and values considered in the analysis, are listed in Table 4.2.

4.1.4 Modeling Power Plant Profitability

The effects of the geology of the sequestration sites, parameterized pore space lease rates, and parameterized CO₂ emission prices and monetized sequestration credit values on annual facility profits were analyzed. The annual profit function for the IGCC facility considered in the model was expressed as:

$$\Pi_{\text{Gen}} = \text{annual revenue} - \text{annual expenses}$$

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where annual revenue is the sum of quantity of electricity sold annually [MWh/yr], Q_e , at the average wholesale market price, P_e [\$/MWh], and the annual amount of CO₂ sequestered, $Q_{\text{CO}_2\text{-seq}}$ [tCO₂/yr], at the assumed sequestration credit value, $P_{\text{CO}_2\text{-seq}}$ [\$/tCO₂]:

$$\text{annual revenue} = Q_e P_e + Q_{\text{CO}_2\text{-seq}} P_{\text{CO}_2\text{-seq}} \quad (\text{Eq. 4.5})$$

and where annual expenses is the cost of paying a penalty for annual CO₂ emissions, $Q_{\text{CO}_2\text{-emit}}$ [tCO₂/yr], at the assumed CO₂ emission price, $P_{\text{CO}_2\text{-emit}}$ [\$/tCO₂], in addition to the sum of the annualized capital costs, TAC [\$/yr] and annual O&M costs, OC [\$/yr], for generating electricity and capturing CO₂; CO₂ pipeline transport; CO₂ injection and sequestration; and leasing pore space:

$$\text{annual expenses} = \sum_j (\text{TAC}_j + \text{OC}_j) + Q_{\text{CO}_2\text{-emit}} P_{\text{CO}_2\text{-emit}} ; \quad (\text{Eq. 4.6})$$

$j =$ electricity generation/CO₂ capture, CO₂ transport, CO₂ sequestration, property rights

Details of the engineering and economic variables in Equations 4.5 and 4.6, including descriptions and values considered in the analysis, are listed in Table 4.2.

4.1.5 Modeling Power the Value of Subsurface Property Rights

Pore space value was calculated from the perspective of an independent power producer selling electricity in the wholesale market. The \$/acre value was expressed as the quotient of

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the annual profit—i.e., the revenue exceeding of the annual revenue requirement—and the areal extent of the CO₂ plume, A_{\max} [km²]:

$$\begin{aligned} \text{pore space value} &= \frac{\Pi_{\text{CO}_2}}{A_{\max}} && \text{(Eq. 4.7)} \\ &= \frac{(Q_e P_e + Q_{\text{CO}_2\text{-seq}} P_{\text{CO}_2\text{-seq}}) - (\sum_j (\text{TAC}_j + \text{OC}_j) + Q_{\text{CO}_2\text{-emit}} P_{\text{CO}_2\text{-emit}})}{A_{\max}} \end{aligned}$$

$$A_{\max} = \pi r_{\max}^2 (4.05 \times 10^6) \text{ and } r_{\max} [\text{m}] = \sqrt{\frac{(\lambda-1)V}{2\pi \Delta h \phi (1-S_{wc})}}$$

As discussed in Chapter 3, this solution for CO₂ plume area takes into account buoyant force in sequestration relative to viscosity and pressure forces. For more information on calculating A_{\max} see Chapter 3, Section 3.1.1 and Appendix A. Details of the engineering and economic variables in Equation 4.7, including descriptions and values considered in the analysis, are listed in Tables 4.2 and 4.3.

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Table 4.2: Model performance and economic input parameters.

Variable	Description	Values used in analysis	Source
Electric Generation Facility			
CRF_{Gen}	Capital recovery factor (%)	11.4	CMU CEES (2010)
n	Planning horizon (years)	30	
S_{net}	Facility net electric output (MW)	527.2	CMU CEES (2010)
F_{avail}	Facility capacity factor (%)	75	CMU CEES (2010)
Q_e	Annual electricity generation (MWh)	3.47×10^6	CMU CEES (2010)
Eff_{CO_2}	CO ₂ capture efficiency (%)	95	CMU CEES (2010)
Q_{CO_2-seq}	CO ₂ captured (tCO ₂ /yr) (metric tons)	3.93×10^6	CMU CEES (2010)
Q_{CO_2-emit}	CO ₂ emitted (tCO ₂ /yr) (metric tons)	1.77×10^5	CMU CEES (2010)
TCC_{Plant}	Generation plant capital cost (\$/kW-net)	2,650	CMU CEES (2010)
OC_{Plant}	Generation plant annual O&M cost (\$/yr)	146×10^6	CMU CEES (2010)
P_e	Wholesale electricity price (\$/kWh)	¢5.7 (RFC) ¢6.3 (SERC) ¢7.1 (TRE)	EIA (2008)
P_{CO_2}	CO ₂ value (\$/tCO ₂)	(0-100)	
CO₂ Pipeline			
CRF_{pipe}	Capital recovery factor (%)	15	McCoy & Rubin (2008)
k_{pipe}	Design mass flow (tCO ₂ /yr)	3.93×10^6	
d_{pipe}	Pipeline length (km)	100	
Eff_{pipe}	Pipeline capacity factor (%)	100	McCoy & Rubin (2008)
T_{ground}	Ground temperature (°C)	12	McCoy & Rubin (2008)
P_{inlet}	Inlet pressure (MPa)	13.79	McCoy & Rubin (2008)
P_{outlet}	Maximum outlet pressure (MPa)	10.3	McCoy & Rubin (2008)
Material roughness	Pipe material roughness (mm)	0.0457	McCoy & Rubin (2008)
Injection & Sequestration			
CRF_{inject}	Capital recovery factor (%)	15	McCoy & Rubin (2008)
k_{inject}	Injection rate (tCO ₂ /yr)	3.93×10^6	McCoy & Rubin (2008)
Eff_{inject}	Injection facility capacity factor (%)	100	McCoy & Rubin (2008)
d_{well}	Well spacing (acres)	80	McCoy & Rubin (2008)
$P_{wb, max} (\% p_{frac})$	Well bottom pressure, % of fracture pressure (%)	90	McCoy & Rubin (2008)
Pore Space Acquisition			
$OC_{pore\ space}$	Pore space lease rate (\$/acre/yr)	(5-100)	

4.2 Results

The results suggest that the economics of an electric generation facility operating with CO₂ capture and sequestration will be highly influenced by formation geology and the areal extent of the CO₂ plume. The cost of acquiring the rights to use pore space for geologic CO₂ sequestration could account for between a fraction of a percent to up to two-fifths of the total cost of CCS—that is, capture, CO₂ pipeline transport, injection, and pore space rights acquisition combined—depending on geology and the lease rate applied (see Table 4.2 above

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and Table 4.3 below). Pore space rights acquisition costs account for a much larger proportion of the overall cost of electricity when sequestration was simulated in the Oriskany Sandstone or Medina Sandstone compared to the Frio Sandstone and Mt. Simon Sandstone.

Table 4.3: Electric generation, CO₂ pipeline transport, injection, and pore space acquisition costs (2009\$).

Variable	Description	Frio Sandstone	Mt. Simon Sandstone	Oriskany Sandstone	Medina Sandstone
Electric Generation					
TAC _{Plant}	Generation plant annualized capital cost (\$/yr)	159×10^6	159×10^6	159×10^6	159×10^6
TLC _{Plant}	Generation plant levelized cost (\$/yr)	306×10^6	306×10^6	306×10^6	306×10^6
LCOE	Levelized cost of electricity (\$/MWh)	88.1	88.1	88.1	88.1
CO₂ Pipeline					
TCC _{pipeline}	Pipeline capital cost (\$)	51×10^6	64×10^6	64×10^6	64×10^6
OC _{pipeline}	Pipeline annual O&M cost (\$/yr)	330,000	330,000	330,000	330,000
TAC _{pipeline}	Pipeline annualized capital cost (\$/yr)	7.8×10^6	9.7×10^6	9.7×10^6	9.7×10^6
TLC _{pipeline}	Pipeline levelized cost (\$/yr)	8.2×10^6	10×10^6	10×10^6	10×10^6
Injection & Sequestration					
TCC _{field}	Injection facility field capital cost (\$)	5.3×10^6	6.2×10^6	40×10^6	17×10^6
TCC _{char}	Injection characterization capital cost (\$)	49×10^6	40×10^6	550×10^6	220×10^6
OC _{inject}	Injection facility annual operating cost (\$/yr)	350,000	360,000	400,000	1.4×10^6
TAC _{field}	Field annualized capital cost (\$/yr)	800,000	950,000	6.0×10^6	3.0×10^6
TAC _{char}	Characterization annualized cost (\$/yr)	7.5×10^6	6.0×10^6	83×10^6	40×10^6
TLC _{inject}	Injection facility levelized cost (\$/yr)	8.7×10^6	7.4×10^6	91×10^6	44×10^6
Pore Space Acquisition					
A _{max}	Areal extent of CO ₂ plume (km ²)	440	330	4,900	2,400
TCC _{pore space}	Transactional cost of acquiring right to lease (\$)	320,000	240,000	3.7×10^6	1.7×10^6
TAC _{pore space}	Annualized cost of acquiring lease rights (\$/yr)	590,000 – 11×10^6	440,000 – 8×10^6	3.2×10^6 – 120×10^6	6.7×10^6 – 60×10^6

If all CCS-related expenses are included in the electric generation facility's cost-of-service revenue requirement, the LCOE for the IGCC power plant modeled in this analysis could increase from \$88/MWh to between \$96/MWh and \$152/MWh. As Figures 4.4 to 4.7 illustrate, the potential increase in the cost of electricity attributed to CCS is very sensitive to sequestration field geology, which directly affects the cost of injection and sequestration and the acquisition of pore space rights. The cost of acquiring pore space rights alone could account for between 0.2% and roughly 20% of the total LCOE. However, Figures 4.4 to 4.7

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also suggest that the cost of injection and sequestration will dominate the cost of acquiring pore space rights except at higher lease rates.

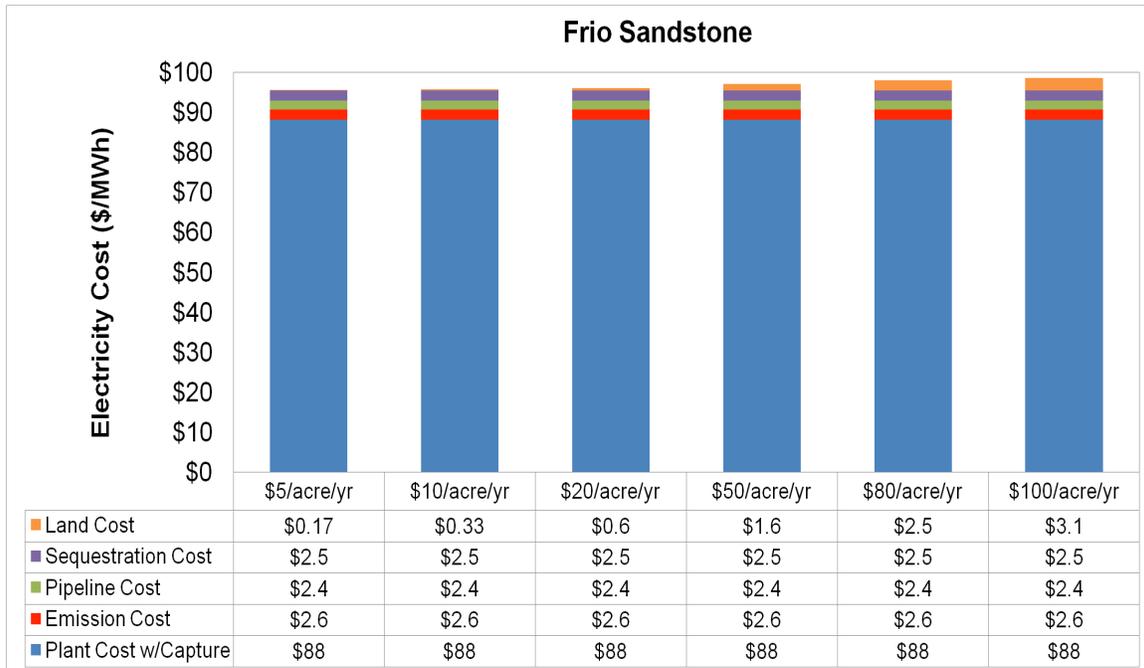


Figure 4.4: Contribution of each CCS-related cost to the LCOE of the modeled IGCC facility resulting from CO₂ sequestration in the Frio Sandstone under the imposition of a \$50/tCO₂ emission cost (2009\$).

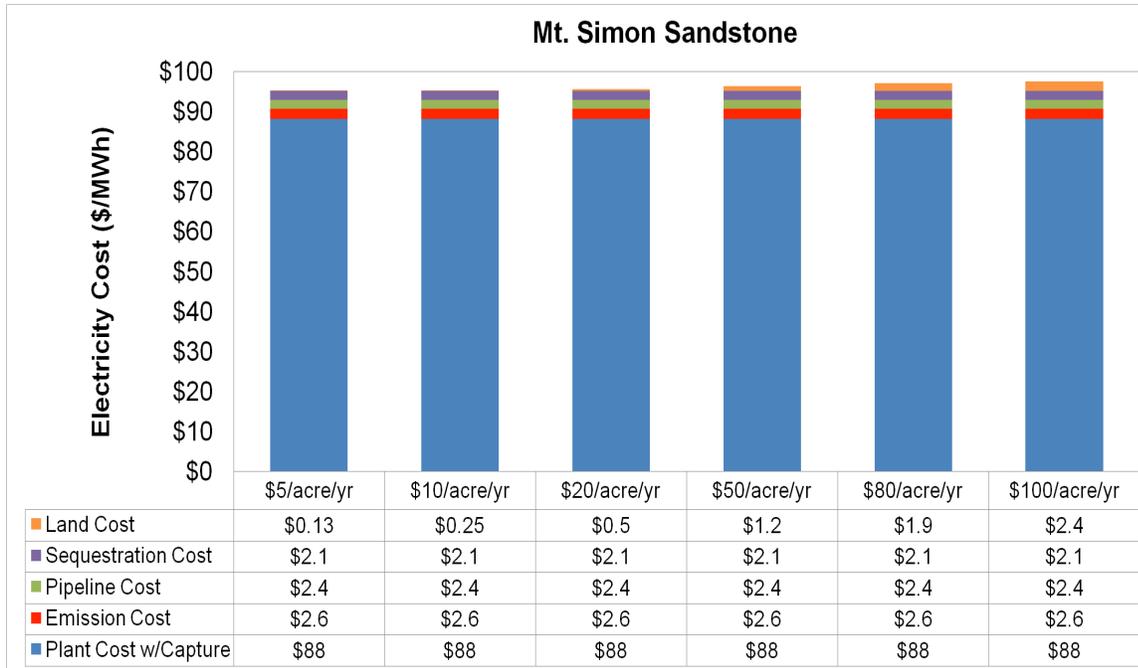


Figure 4.5: Contribution of each CCS-related cost to the LCOE of the modeled IGCC facility resulting from CO₂ sequestration in the Mt. Simon Sandstone under the imposition of a \$50/tCO₂ emission cost (2009\$).

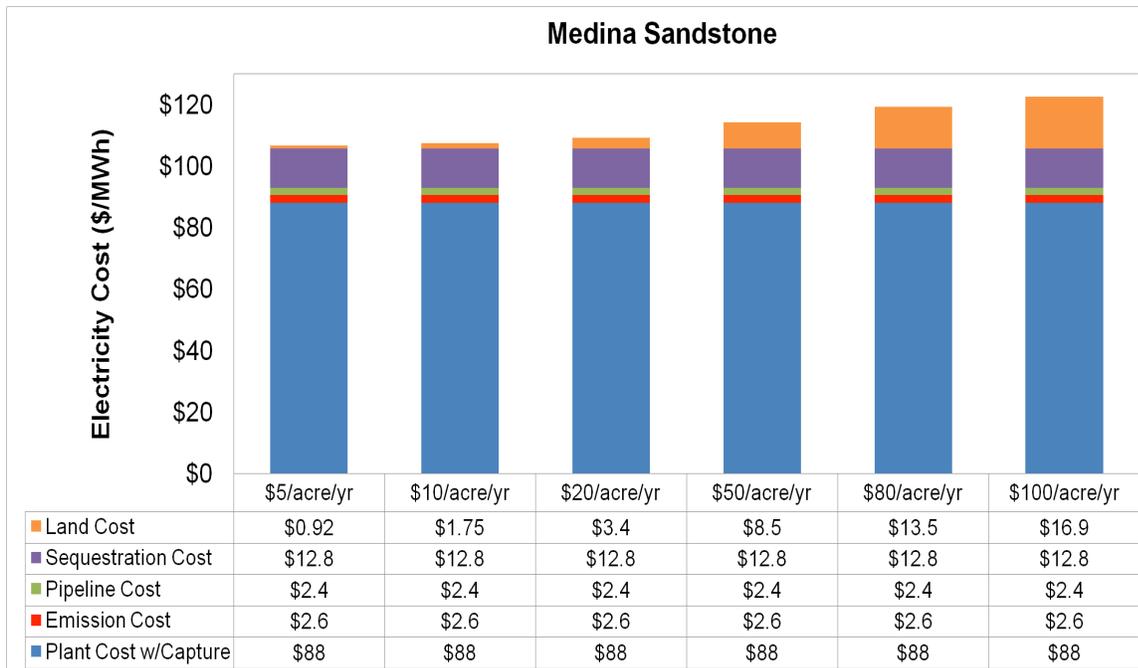


Figure 4.6: Contribution of each CCS-related cost to the LCOE of the modeled IGCC facility resulting from CO₂ sequestration in the Oriskany Sandstone under the imposition of a \$50/tCO₂ emission cost (2009\$).

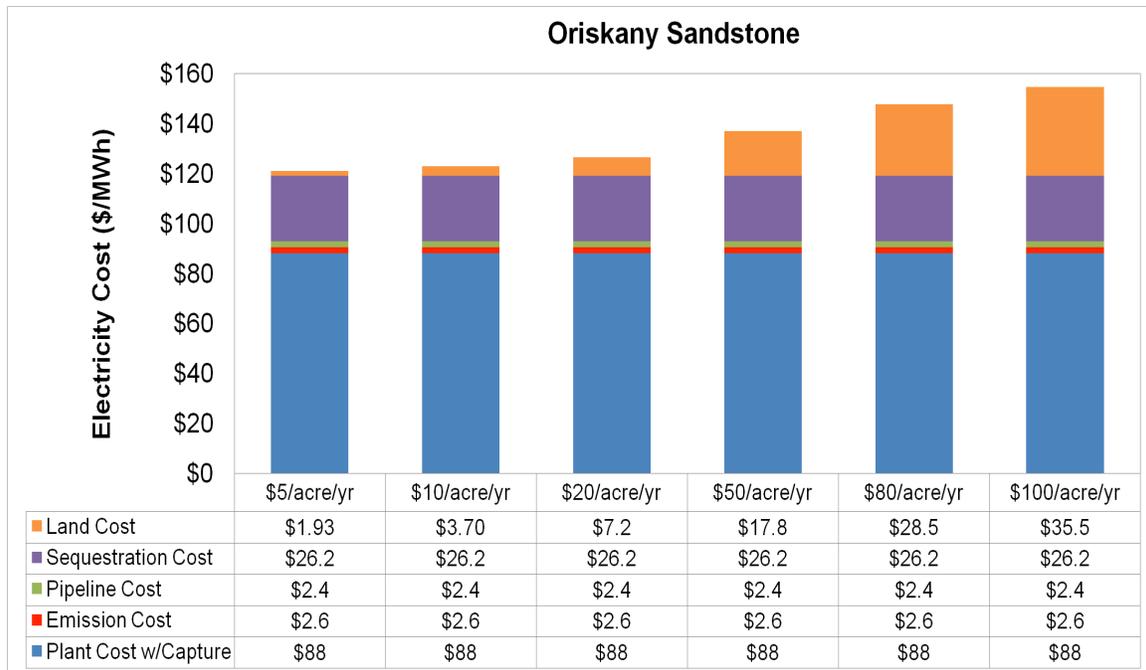


Figure 4.7: Contribution of each CCS-related cost to the LCOE of the modeled IGCC facility resulting from CO₂ sequestration in the Medina Sandstone under the imposition of a \$50/tCO₂ emission cost (2009\$).

Turning to the question of profitability, the IGCC facility, modeled as an independent power producer, was not profitable under any of the sequestration scenarios considered herein given current wholesale electricity prices, even if no penalty is paid for CO₂ emissions (see Figure 4.8). Moreover, the wholesale electricity prices required for the electric generation facility to be profitable—\$10.1/kWh to \$15.6/kWh—were too high to be reasonably expected in the near term (see Figure 4.9). This being the case, some form of subsidy would likely be necessary to incentivize an independent power producer to construct and operate an electric generation facility with CO₂ capture and sequestration in a saline aquifer.

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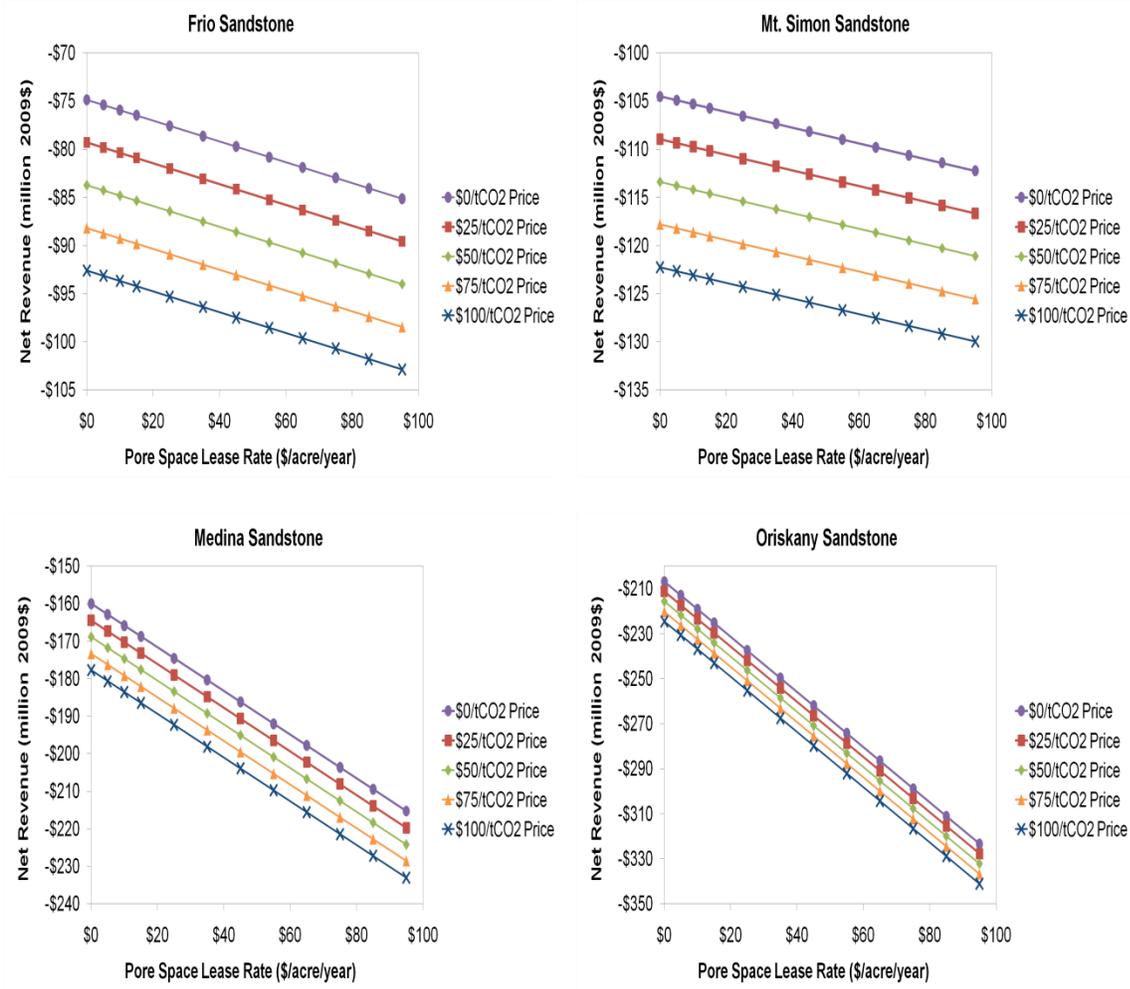


Figure 4.8: Electric generation facility net revenue across \$5-100/acre/year range of lease rates and \$0-100/tCO₂ emission price.

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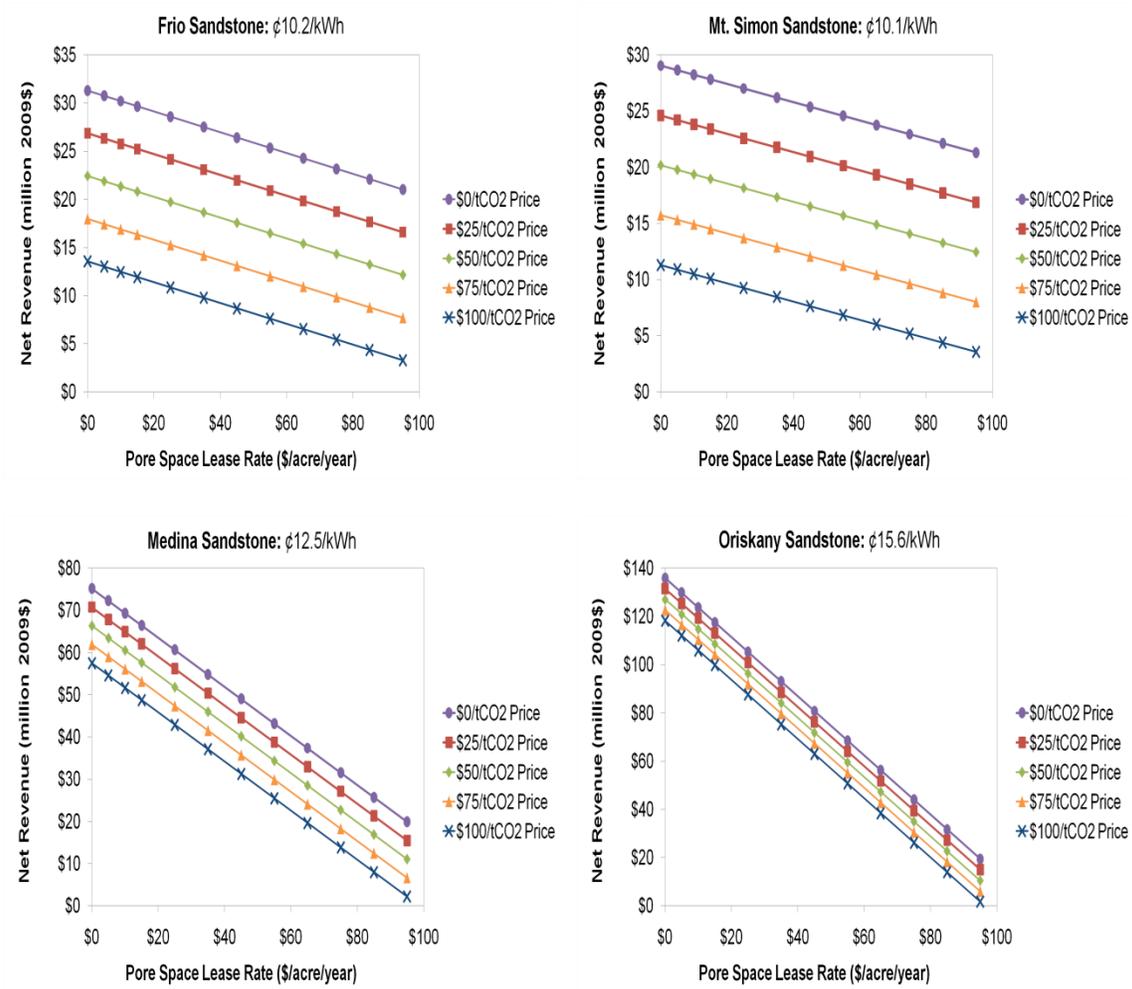


Figure 4.9: Wholesale electricity price necessary for the modeled IGCC facility to be profitable across \$5-100/acre/year range of lease rates and \$0-100/tCO₂ emission price.

Figure 4.10 indicates that under the imposition of \$50/metric ton price on CO₂ emissions, a comparatively modest \$/tCO₂ sequestration credit is required for the modeled IGCC facility to be profitable if sequestration is carried out in the Frio Sandstone or the Mt. Simon Sandstone. By contrast, in order for the electric generation facility to be profitable if CO₂ captured from the facility is injected and sequestered in either the Oriskany Sandstone or Medina Sandstone, the \$/tCO₂ sequestration credit must be considerably higher.

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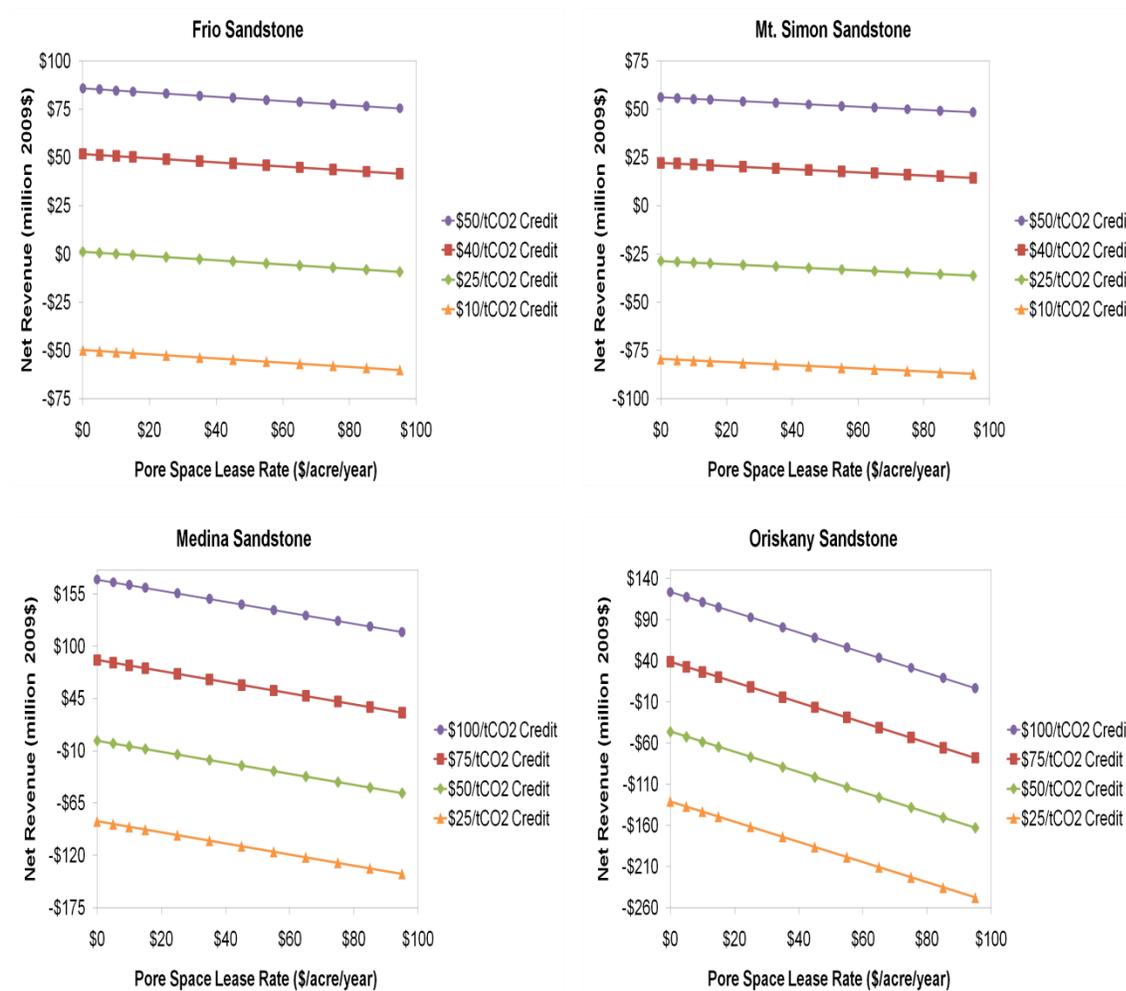


Figure 4.10: Electric generation facility net revenue under a \$50/tCO₂ emission price across \$5-100/acre/yr range of lease rates and \$0-100/tCO₂ sequestration credit value.

Lastly, when the economic value of pore space was modeled as the revenue in excess of the modeled IGCC facility’s annual revenue requirement, the results ranged from less than zero to hundreds of dollars per acre in value (see Figure 4.11). Pore space had no monetary value to the electric generation facility operator in any of the scenarios considered unless revenue from CO₂ sequestration credits was realized. In the Medina Sandstone, pore space only had economic value at all CO₂ emissions prices when the monetary benefit of CO₂ sequestration credits was at least \$50/tCO₂. Pore space in the Oriskany Sandstone was valuable from the perspective of the electric generator when CO₂ sequestration credits had a monetary benefit

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of \$75/tCO₂ and higher. By comparison, pore space in both the Frio Sandstone and Mt. Simon Sandstone began to have positive economic value if the modeled ICGG facility operator received sequestration credits with a monetary benefit of around \$25/tCO₂ and \$40/tCO₂, respectively.

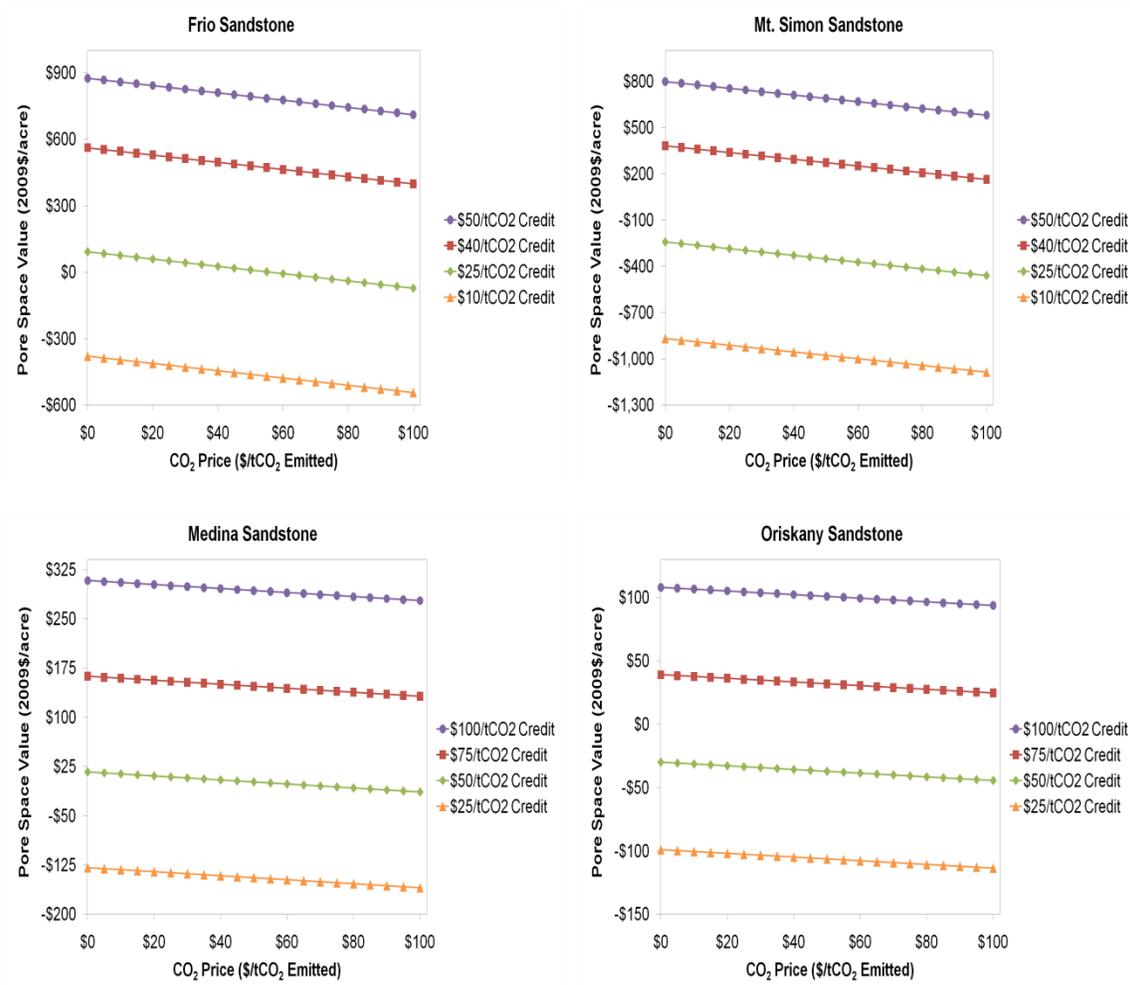


Figure 4.11: Modeled potential value of pore space in each sandstone formation under a parameterized range of CO₂ emission prices and CO₂ sequestration credit values.

4.3 Discussion

The results suggest that geology-dependent CCS costs—i.e., injection, sequestration and property rights acquisition costs—may not be trivial and could greatly increase the overall cost of electricity, perhaps even rendering electric generation facilities capturing CO₂ for the purpose of permanent geologic sequestration in saline aquifers unprofitable. By targeting sequestration formations with geologic characteristics that are favorable for limiting CO₂ plume migration—e.g., thick formations with high porosity— injection, sequestration, and property rights acquisition costs may be considerably constrained. In spite of this, given current wholesale electricity prices, it is unlikely that independent power producers operating with CCS will successfully meet their revenue requirements without some form of subsidy. Of course, this conclusion is inapplicable to wholly regulated public utilities since they, in all likelihood, will be permitted to pass CCS-related expenses along to electricity customers, including those associated with CO₂ pipeline transport, injection, and pore space rights acquisition. Even so, it will be important for regulated utilities to carefully consider sequestration field geology when constructing an electric generation facility with CO₂ capture to ensure that customer electricity prices remain as low as possible. As shown above, thin formations with low porosities will likely lead to high injection costs, large CO₂ plumes, and high property rights acquisition costs, all of which will increase the levelized cost of operating a power plant with CO₂ capture and, in turn, customer electricity prices. In the case of the Medina and Oriskany Sandstones, the combined annualized cost of injection and property rights acquisition alone could increase the LCOE of the electric generation facility by as much as \$15 to \$60 per MWh under these scenarios (see Figures 4.6 and 4.8). What is

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more, the cost of acquiring pore space rights could, under certain leasing assumptions, make up the majority of this increase.

Using the model described in this chapter to monetize the intrinsic geologic value of right to use pore space for geologic CO₂ sequestration from the perspective of the modeled IGCC facility operator, Figure 4.11 above illustrates that the geologic formations with characteristics that will likely constrain CO₂ plume size are more valuable per acre than those formations in which CO₂ will migrate over a very large area. However, the model results also suggests that electric generation facility operators, whether they be independent power producers or wholly regulated utilities, will only be capable of compensating pore space owners if electricity prices are very high (see Figure 4.9), which is unlikely in the short run, or if enough monetary benefit is accrued from the receipt of CO₂ sequestration credits to surpass the revenue requirements for the facilities.

Clearly, if CCS is widely deployed, the cost of electricity and power plant profitability could be adversely affected by a legal requirement that pore space owners must be compensated in all circumstances. Moreover, absent unrealistically high electricity prices or some form of sequestration subsidy, pore space currently has no net-positive, intrinsic economic value which would be passed along to property owners from electric generators. Therefore, while paying property owners to use of pore space for geologic CO₂ sequestration may very well foster public acceptance and appease staunch private property rights advocates, there is no demonstrable legal or economic rationale for compensating property owners who have no current or non-speculative, investment-backed future use of the subsurface where pore space

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targeted for sequestration is located. A pragmatic and equitable solution for constraining the potential negative economic effects associated with acquiring pore space rights would be for state or federal legislatures, or courts, to limit required compensation to only those instances where the injection and migration of CO₂ materially impairs current uses of, or investment-backed interests in, the subsurface. As is thoroughly discussed in Chapter 2, this approach is supported by common law and doctrinal precedent.

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- (6) 40 C.F.R. §§ 51, 52, 70, and 71.
- (7) H.R. 2454, *American Clean Energy and Security Act of 2009* (Waxman-Markey).
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Chapter 5: Pragmatic Approach to Permitting Access and Use of Pore Space for Geologic Sequestration of CO₂

Sequestering CO₂ in deep geologic formations has the potential to mitigate the detrimental effects of climate change on a large scale. However, because CO₂ sequestered in deep geologic pore space could migrate laterally over a potentially very large area (e.g., ~100s to 1,000s of square-kilometers)⁵⁰³ and is intended to remain in the ground permanently, there is a very real possibility that geologic sequestration will overlap and interfere with competing uses of the subsurface that are carried out at depths similar to those at which geologic sequestration has been proposed.⁵⁰⁴ Competing uses include, but are not limited to, groundwater recovery and storage, hydrocarbon production, natural gas storage, fluid waste disposal, and compressed air storage. There is also the potential for one geologic sequestration project to interfere with or prevent the development of competing CO₂ sequestration projects.

Even under the most restrictive approach to property rights, widespread implementation of CCS will likely interfere with at least some recognized and protected property interests in subsurface pore space. To account for these cases, or an even greater number of cases if policymakers or courts opt for a more expansive approach to subsurface property rights, lawmakers should create a framework authorizing the use of pore space for GCS and resolving disputes in a timely and just manner. The circumstances surrounding CCS are not unlike those which existed at the dawn of the oil and gas industry. What is referred to as the

⁵⁰³ See *supra* Chapters 3 & 4.

⁵⁰⁴ See *supra* Chapter 1, Section 1.4.

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Great Era⁵⁰⁵ of oil and gas jurisprudence arose quickly, as sudden supplies and emerging markets for oil and gas cause disputes among property owners. Courts were challenged to provide answers to questions about the relative rights and liabilities incident to the production of coveted resources. The common law provided few direct answers. To fill the void, judges trained in the shadow of Langdell⁵⁰⁶ strictly followed the dictates of legal formalism and invoked the tool of analogy.⁵⁰⁷ By analogizing to the common law rule used to determine rights in wild animals (*ferae naturae*), courts adopted the rule of capture to define a property owner's rights in oil and gas beneath his or her property. Under the rule of capture, an owner of land "acquires title to the oil or gas which he produces from wells drilled thereon."⁵⁰⁸ The rule shields the owner from liability for draining oil from his or her neighbor's tract; the neighbor's remedy is to "go and do likewise."⁵⁰⁹

Yet many courts throughout the Great Era recognized a dissonance between common law doctrines, such as the rule of capture and remedies for trespass, and the prevailing policies

⁵⁰⁵ Maxwell, R.C., *OIL AND GAS LAW IN THE GREAT ERA, NATURAL RESOURCES POLICY AND LAW: TRENDS AND DIRECTIONS* (Island Press, 1 ed. 1993).

⁵⁰⁶ Christopher Columbus Langdell served as the dean of Harvard Law School from 1870 to 1895. Langdell's judicial philosophy was disseminated to his students through the Socratic teaching method and his casebook on contracts. Like the philosophy behind his casebook, "Langdell's aim was to train law students to derive 'the few, ever-present, and ever-evolving and fructifying principles, which constituted the genius of the common law.'" See Presser, S.B. and Zainaldin, J.S., *Cases and Materials on Law and Jurisprudence in American History*. 7 ed. 2009: West. ; Posner, R.A., *Overcoming Law*. 6 ed. 1996: Harvard University Press (stating that under formalistic devices, "law, like mathematics, was understood to be about the relations among concepts rather than about the relations between concepts and reality"). This approach meant lawyers, in the eyes of Langdell and other proponents of formalism, should only act as "professional arbiters of an apolitical and 'scientific' body of rules." Formalists also believed that judges had to restrict themselves to abstract, logical reasoning embodied in *laissez faire* economic principles. See Hall, K.L., *The Magic Mirror: Law in American History*. 8 ed. 2008: Oxford University Press. Thus, the formalist era of decision-making also brought with it the end of the Grand Style of opinion writing, leaving the law "characterized by dry, arid logic, divorced from society and life." See Schwartz, B., *Main Currents in American Legal Thought*. 1 ed. 1993: Carolina Academic Press.

⁵⁰⁷ Rose, C.M., *Possession as the Rule of Property*, 73 U. Chi. L. Rev. 73, 73-88 (1985).

⁵⁰⁸ Hardwicke, R.E., *The Rule of Capture and its Implications as Applied to Oil and Gas*, 8 Tex. L. Rev. 391, 391-422 (1935).

⁵⁰⁹ *Barnard v. Monongahela*, in Pa. 1907 at 362.

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for oil and gas production. For example, in 1900, the United States Supreme Court in *Ohio Oil Co v. Indiana* departed from the wild animal analogy in upholding regulations on production.⁵¹⁰ Instead, Justice White focused on the recognized goals of conserving resources and protecting correlative rights of mineral owners.⁵¹¹ Similarly, in 1962, the Texas Supreme Court promoted the policy of encouraging secondary recovery methods for oil by refusing to enjoin the process even though injected fluids would cross lease lines.⁵¹² In *Railroad Commission v. Manziel*, the court held that the “technical” rules of common law trespass did not apply.⁵¹³

In order to respond effectively and prudently to the property-related questions posed by the deployment of commercial-scale geologic CO₂ sequestration, this chapter argues that legislators and courts adopt the pragmatic, or policy conscious, approach exemplified in opinions such as *Ohio Oil v. Indiana* and *Railroad Commission v. Manziel*. These opinions recognized the need for a special jurisprudence designed to respond to the unique realities of oil and gas production. The approach used in these cases to address new policies and technologies is appropriate for geologic sequestration for two reasons. First, unlike in other areas of the law, a consensus existed about the guiding policies, which included conserving natural resources and encouraging fair and efficient production of oil and gas.⁵¹⁴ The same is true of geologic sequestration, which helps achieve the policy goal of reducing CO₂ emissions to the atmosphere and protecting the public and environment from the deleterious

⁵¹⁰ *Ohio Oil v. Indiana*, 17 U.S. 190 (1900).

⁵¹¹ *Id.*

⁵¹² *Railroad Commission v. Manziel*, 361 S.W.2d 560 (Tex. 1962).

⁵¹³ *Id.*

⁵¹⁴ Summers, W.L., *The Modern Theory and Practical Application of Statutes for the Conservation of Oil and Gas*, 13 Tul. L. Rev. 1-18 (1938).

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effects of climate change. Second, the technology and the markets for oil and gas evolved more rapidly than the courts could produce opinions specifically addressing oil and gas controversies. Today, courts have yet to rule on legal matters associated with CCS since no cases have been ripe for review. Much like oil and gas, CCS technologies and practices are poised to set a faster pace than the courts and lawmakers can keep. In recognizing the conflict between common law doctrines and the prevailing policies underlying oil and gas production, the *Ohio Oil* and *Manziel* courts did little violence to the notions of common law decision-making because of the lack of direct precedents.

Judges and commentators have frequently overworked the traditional tool of analogy in answering questions generated by the birth of an industry unknown at common law.⁵¹⁵ Present commentators who champion oil and gas jurisprudence as an appropriate analogy for geologic sequestration could be putting commercial-scale development of the technology at risk by setting the stage for massive property law conflicts. Such a formalistic approach is myopically focused on creating a common law pedigree,⁵¹⁶ despite potentially more compelling policy reasons to treat use of the subsurface for sequestration differently than oil and gas. By ignoring policy, a formalistic approach could create a high level of uncertainty with regard to subsurface property rights and the use of pore space for geologic sequestration. This uncertainty could lead to costly litigation and create disincentives for investment in CCS. To avoid the counterproductive effects of this approach, lawmakers and judges should apply a pragmatic approach in which competing interests and policies are openly dealt with at the beginning of GCS project development.

⁵¹⁵ Chow, D.C.K., *A Pragmatic Model of Law*, 67 Wash. L. Rev. 755-826 (1992).

⁵¹⁶ Posner, R.A., *OVERCOMING LAW*, at 608 (Harvard University Press 6 ed. 1996).

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At present, there is limited state-level authority and practically no federal-level authority for handling the subsurface property rights issues associated with the use of pore space for CO₂ sequestration as well as other subsurface activities. Moreover, a variety of federal and state agencies currently have authority to regulate existing underground injection operations.

While the Environmental Protection Agency has the authority under the Underground Injection Control program to permit and regulate geologic sequestration of CO₂, the Agency currently does not have the authority to consider the subsurface property issues attendant to the permanent geologic CO₂ sequestration. A legislative framework for GCS is needed that balances the interests of private property owners with the public benefit of sequestration, and reduces possibility of interference with other commercial uses of the subsurface that are also in the public interest. Under this framework, regulators would consider the trade-offs between private interests and the public benefit of a proposed GCS project, determining the most equitable and beneficial use of the pore space. This framework should increase the potential for either avoiding most subsurface property disputes outright, or resolving them at the outset in a stable and predictable environment that is fair and equitable to all affected parties. The remainder of this chapter evaluates a range of common law and statutory approaches to managing the access and use of pore space for geologic sequestration of CO₂ on both private and federal lands, and concludes by proffering a framework for addressing this issue that is fair and equitable to both GCS project operators and private property owners. Model statutory language for this framework is included in Appendix B. It is envisaged that this language would be but one title in a larger CCS bill.⁵¹⁷

⁵¹⁷ The model statutory language in Appendix B for permitting the injection of CO₂ and use of pore space for permanent geologic sequestration was conceived as part of model federal CCS legislation proposed by the CCS Regulatory project entitled “The Carbon Capture and Sequestration Regulatory Act of 2010,” http://www.ccsreg.org/model_legislation.html (accessed August 2, 2010).

5.1 Potential Options for Managing Access and Use of Pore Space: Proper Burials and Recommendations

The decision tree in Figure 5.1 begins with the question of whether anyone enjoys a recognized property right in subsurface pore space. The answer to that question triggers a series of additional policy and legal questions. How they are resolved will determine whether and how geologic CO₂ sequestration will be able to move forward. Consider first the lower branch of Figure 5.1, which assumes that that no vested property rights are currently recognized in subsurface pore space for CO₂ sequestration. In this case, both Congress and the states have the option of fixing legal ownership of this space in some manner.

In the absence of such action, sooner or later the issue will be resolved in the courts on a case-by-case basis. The result could easily be a patchwork of different legal situations in different parts of the country. Legislative action to fix the existence and nature of rights would have the benefit of establishing clear and uniform principles that would yield predictable outcomes, particularly if Congress passed legislation that is applicable throughout the country. Additionally, such efforts at standardization could help to foster coordination when geologic basins underlie several different states. Under the Supremacy Clause of the U.S. Constitution, such Congressional action would likely preempt any state laws that conflict with the federal enactment.

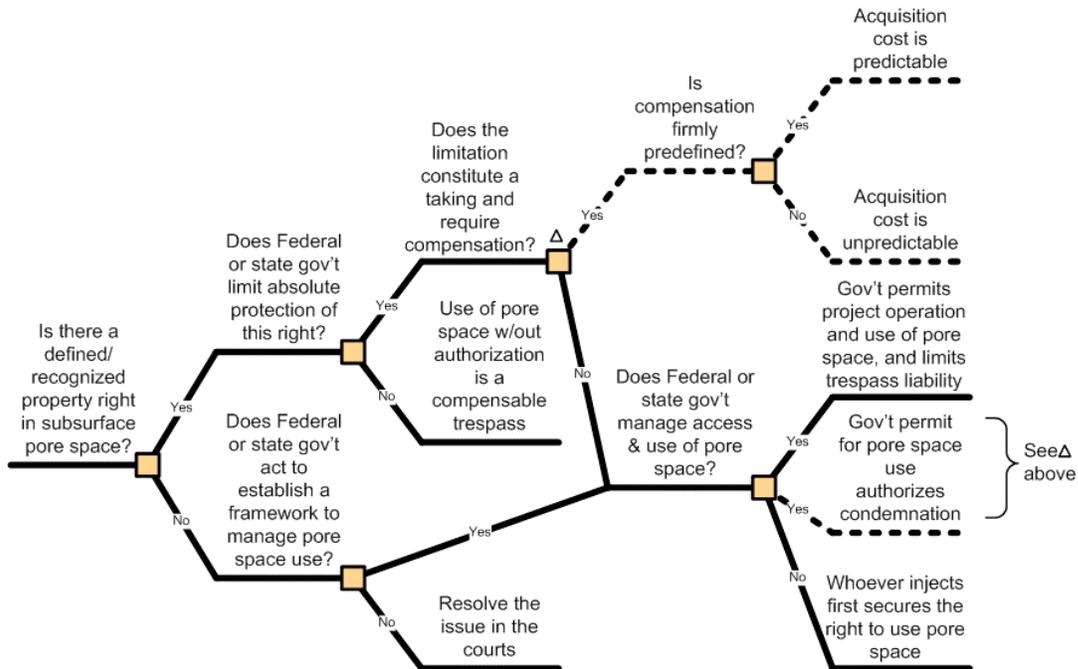


Figure 5.1: Alternative approaches to managing access and use of pore space for geologic CO₂ sequestration. The dashed lines represent approaches utilizing government condemnation of private property.

Turning next to the upper branch of the decision tree in Figure 5.1, if the law is found to already assign ownership of the deep subsurface for use in CO₂ sequestration, then federal and state lawmakers confront the question of whether to intervene to limit that right in some manner. The government routinely limits the rights of property holders, and could do the same in this case. Should lawmakers intervene, the question becomes whether the intervention meets the constitutional standard for a taking of private property within the meaning of the Fifth Amendment to the U.S. Constitution.⁵¹⁸ This is a complex legal question which, if resolved in the negative, would have the simplifying effect of leaving government with the same discretionary choices outlined above (and the same federal supremacy principles) for establishing a framework for use of the deep subsurface. On the

⁵¹⁸ U.S. CONST. amend. V.

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other hand, should the U.S. Supreme Court decide (or let stand a lower court ruling to the same effect) that use or regulation of the deep subsurface constitutes a Fifth Amendment taking, then the government must decide (and courts must ultimately pass on the legality of) whether and how to fix the constitutionally required just compensation for such a taking. If lawmakers were to reach the conclusion that the degree of taking associated with using pore space at depths of a kilometer or more imposes a negligible burden on the use rights of surface property owners, the government could set compensation at a nominal level, or even zero.

A decision not to intervene would not, in itself, preclude sequestration projects; rather, it would consign the developers of such projects to private negotiations with the appropriate owners. In the West, where much of the land is federal and private holdings are large, this might not be terribly difficult. In the East, where small, fractional ownership of real property predominates, acquiring such rights would entail transactions with hundreds or even thousands of individual landowners.

Note that several of the routes through the decision tree (Figure 5.2) result in outcomes that could make it difficult to develop large, commercially viable CCS projects. If the federal or state governments do not intervene to manage or limit the protection of private property rights for the use of pore space for geologic CO₂ sequestration, the development of GCS projects could adversely affect power plant economics and the cost of electricity due to the high cost of acquiring pore space rights, as shown in Chapters 3 & 4.

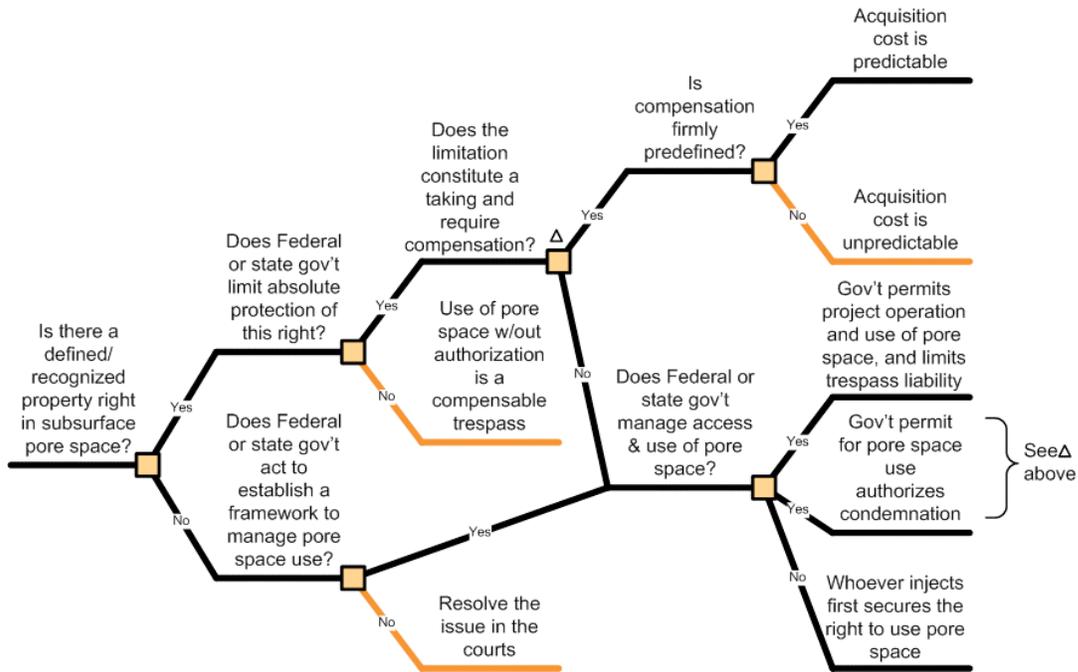


Figure 5.2: Approaches to managing access and use of pore space that could make development geologic CO₂ sequestration costly and difficult.

This result could be the same even if Congress or the states establish a framework for condemnation procedures yet stop short of predefining just compensation rates. Faced with highly variable and unpredictable acquisition costs, would-be GCS developers might be discouraged from moving forward with a project before even attempting negotiations with the appropriate surface owners and mineral owners. If neither Congress nor the states act to establish a framework for access and use of deep pore space for geologic CO₂ sequestration, disputes over ownership and fair compensation will be left to the courts. Relying on the courts to adjudicate disagreements about subsurface property rights and contractual obligations between GCS project developers/operators and private property owners could significantly delay, if not permanently halt, the development of many GCS projects. This discussion of judicial barriers to GCS development assumes, of course, that the appropriate property owners will be amenable to the use of the deep pore space in which they hold a

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vested property interest. “Hold-out” landowners could prevent development of GCS projects, especially in the eastern United States where there are innumerable small private land holdings. Given the urgent need to address climate change, this is clearly an outcome that must be avoided.

5.1.1 Expansive Private Property Rights in the Subsurface

If pore space is determined to be a protected by a “property rule”⁵¹⁹ of the kind that is not limited by the amount of space at issue, whether the owner had used the pore space in the past, or whether there are any non-speculative, investment-backed uses⁵²⁰ for the pore space, the likely judicial consensus would be that all surface owners (and in some cases mineral owners) have the right to exclude others from using pore space for geologic CO₂ sequestration, and are entitled to compensation if the pore space is used.⁵²¹ Figure 5.3 represents this expansive view private property rights in the subsurface in the context of CO₂ sequestration. Under this approach, existing and non-speculative, investment-backed future uses of the pore space would be relevant only in determining the amount of just compensation due.⁵²² As a legislative matter, this is similar to the approach taken by Montana, North Dakota, and Wyoming, all of which declared surface owners hold title to

⁵¹⁹ See Guido Calabresi & A. Douglas Melamed, *Property Rules, Liability Rules, and Inalienability: One View from the Cathedral*, 85 Harv. L. Rev. 1089, 1092 (1975) (reasoning that some entitlements are protected by a “property rule” (i.e., an injunction) which permits violation of the entitlement only with permission of the property owner, while other entitlements are protected by a “liability rule” (i.e., damages) which permits violation of the entitlement without permission of the owner so long as the violator pays damages).

⁵²⁰ For the purpose of this thesis, “non-speculative, investment-backed use” and “non-speculative, investment-backed expectation” mean the ability to recover actual mineral resources or engage in current or imminent subsurface activities that have substantial economic value.

⁵²¹ See *Loretto v. Teleprompter Manhattan CATV Corp.*, 458 U.S. 419, 436-38 (1992); *Tahoe-Sierra Pres. Council, Inc. v. Tahoe Reg'l Planning Agency*, 535 U.S. 302, 322 (2002).

⁵²² For a discussion of approaches to determine value and just compensation, see *supra* Chapter 2, Section 2.7.

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subsurface pore space.⁵²³ If done, this would most likely require compensation the surface landowner for any CO₂ sequestration, either by bilateral agreement or through the exercise of eminent domain or compulsory unitization.⁵²⁴

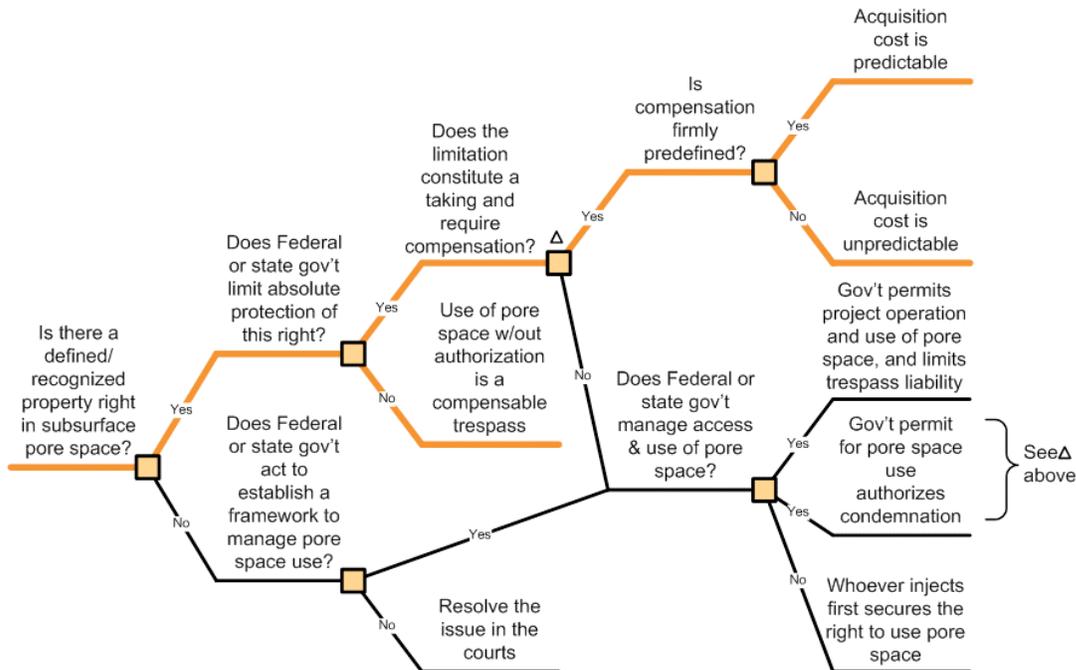


Figure 5.3: Expansive property rights approach to managing access and use of pore space for geologic CO₂ sequestration.

Similarly, the Interstate Oil and Gas Compact Commission issued a model statute for GCS that contemplates the acquisition of property rights in the same manner as for natural gas storage projects: “The Model General Rules and Regulations propose the required acquisition of these storage rights and contemplate the use of state natural gas storage eminent domain

⁵²³ See S.B. 498, 61st Leg., Reg. Sess. (Mont. 2009) (codified at MONT. CODE ANN. § 82-11-180 (2009)); S.B. 2319, 61st Leg. Assem., Reg. Sess. (N.D. 2009) (codified at N.D. CENT. CODE § 47-31-01-08 (2006 & Supp. 2009)); H.B. 89, 59th Leg., Budget Sess. (Wyo. 2008) (codified at WYO. STAT. ANN. § 34-1-152 (2009)).

⁵²⁴ Unitization for GCS, adapted from oil and gas development, is essentially a contractual instrument backed by statutory authority that requires landowners to consent to the use of their pore space for CO₂ sequestration if the majority of the surface acres (based on percentage) within a regulatory-approved project boundary have been voluntarily committed for developed as a single sequestration unit.

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powers or oil and gas unitization processes to gain control of the entire storage reservoir.”⁵²⁵

This is a seemingly logical extension of a known regulatory program. The IOGCC Model Statute has the advantage of working through the well-established mechanisms of state oil and gas agencies that are familiar with drilling and reservoir regulations.

The natural gas model is not without its shortcomings, however. One limitation of the IOGCC’s Model Statute is that it does not authorize CO₂ sequestration to be conducted in formations containing economically-recoverable amounts oil and gas, or other valuable resources.⁵²⁶ Under the IOGCC’s model, a GCS developer could not use (or condemn via eminent domain) a formation that had once produced minerals without first establishing, by agreement or otherwise, that the minerals are exhausted. Over the large areas that could be affected by a CO₂ sequestration operation, this may be difficult to prove. What is more, the question of just how depleted mineral-bearing strata must be before the pore space can be used for CO₂ sequestration may be addressed differently from state to state, and some states view the issue of mineral exhaustion very favorably to the mineral estate owner, taking into account potential new production methods and technologies.⁵²⁷ This means that if a GCS project was developed and it was later discovered that CO₂ was being injected into, or that is migrated into, strata containing recoverable resources, the only option may be to discontinue sequestration operations. Thus, project developers may well be motivated to identify formations, such as saline aquifers, that have never yielded valuable minerals and have little prospect of doing so.

⁵²⁵ IOGCC, *Storage of Carbon Dioxide in Geologic Structures: A Legal and Regulatory Guide for States and Provinces* (2007) (IOGCC Guide) (hereinafter referred to as the IOGCC Model Statute).

⁵²⁶ *Id.* at § 3(a)(3).

⁵²⁷ See *International Salt v. Geostow*, 697 F. Supp. 1258, 1270 (W.D.N.Y. 1988); accord *Dept. Transp. v. Goike*, 560 N.W.2d 365 (Mich. Ct. App. 1996).

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Another important question to consider with regard to the IOGCC Model Statute is whether the proposition of having to acquire property rights in the subsurface from hundreds or thousands of landowners in order to develop a GCS site will make the natural gas storage model administratively unwieldy and economically unattractive. The IOGCC model statute requires a GCS project developer to identify and negotiate in good faith with all property owners “having property interests affected by the storage facility.”⁵²⁸ Consequently, the natural gas model would likely result in higher costs associated with acquiring the pore space right necessary for geologic CO₂ sequestration than would be realized under an approach that limits required compensation to only those instances where the injection and migration of CO₂ materially impairs current or non-speculative, investment-backed future uses of the subsurface. As discussed in Chapter 3, an expansive view of subsurface property rights modeled after the natural gas model could greatly discourage the development of GCS due to the potentially overwhelming cost of having to compensate all property owners overlying the CO₂ sequestration reservoir.⁵²⁹ With CO₂ sequestration, this could be true even if the value of just compensation is clearly defined and constrained, as in *Loretto*,⁵³⁰ because the CO₂ plume could migrate over hundreds to thousands of square-kilometers.⁵³¹ Of course, the nature and extent of the money expended and the infrastructure needed will depend on how widely GCS is deployed, where it is deployed, and how integral a techno-strategy CCS becomes in America’s approach to limiting GHG emissions.

⁵²⁸ IOGCC Model Statute, *supra* note 23, at § 3(a)(2).

⁵²⁹ See *supra* Chapter 3, Section 3.4.2.

⁵³⁰ See *Loretto v. Teleprompter Manhattan CATV Corp.*, 446 N.E.2d 428, 435 (N.Y. 1983) (fixing compensation for the taking at one dollar).

⁵³¹ See *supra* Chapter 3, Section 1.4.1; Chapter 4, Section 4.2.

5.1.2 *Federal or State Ownership of Deep Pore Space*

It is plausible to theorize that just as *Causby*⁵³² confirmed that federal legislation cut off property interests in the higher airspace, legislation authorizing the use of the deep subsurface for CO₂ sequestration could similarly truncate property interests in the deep subsurface, except in connection with those uses that are currently in existence or subject to non-speculative, investment-backed expectations. As shown in Chapter 2, numerous courts have held that a surface owner's interest in the subsurface is "limited" at best, relying on *Causby* and other cases limiting the surface owner's right to control the airspace.⁵³³ Arguably, even if states expressly provide by statute that a surface owner has a property right in the pore space, as Wyoming, North Dakota, and Montana have done, such a state-created property interest may be limited by the judicial application of *Causby* to subsurface rights that places "objective" limits on rights to the subsurface.⁵³⁴ In other words, the argument would be that just as Wyoming could not vest in surface owners the right to the airspace far above their property as a result of the objective, background principles expressed in *Causby*, Wyoming cannot vest in surface owners the right to the deep subsurface as a result of courts' application of *Causby* to the subsurface.⁵³⁵

This argument is consistent with a 2008 article by John Sprankling in the UCLA Law Review entitled *Owning the Center of the Earth*.⁵³⁶ In this article, Sprankling takes the position that private property rights to land should not extend more than 300 meters (1,000

⁵³² *United States v. Causby*, 328 U.S. 256 (1946).

⁵³³ See, e.g., *Chance v. BP Chems. Inc.*, 670 N.E.2d 985, 992 (Ohio 1996); see also *supra* Chapter 2, Section 1.5.2.

⁵³⁴ See *Costal Oil & Gas Corp. v. Garza Energy Trust*, 268 S.W. 3d 1, 11 (Tex. 2008); *Chance* 670 N.E.2d at 992; see also *supra* Chapter 1, Section 1.4, notes 113-119 (and accompanying text).

⁵³⁵ *Id.*

⁵³⁶ See John G. Sprankling, *Owning the Center of the Earth*, 55 UCLA L. Rev. 979, 1022-25 (2008).

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feet) below the surface of the earth, and the subsurface beneath that threshold should belong to the federal government.⁵³⁷ The article did not focus on geologic CO₂ sequestration specifically, but instead focused on the issue of subsurface ownership in connection with today's technological ability to develop various energy and climate change technologies, including CCS and enhanced geothermal systems, that must make use of the subsurface in ways not contemplated in the past.⁵³⁸ Sprankling contends that based on case law involving subsurface water, oil and gas development, and hazardous waste injection, among others, American law has never determined whether a landowner's rights extend more than two miles below the surface and that even case law within two miles of the surface is largely inconsistent.⁵³⁹ He concludes that property owners should have some rights below the surface to accommodate foundations, trees, and other normal surface facilities, but those rights should not extend more than 1,000 feet below the surface.⁵⁴⁰

Following Sprankling's argument, Congress or the states could enact legislation declaring a "public highway" of sorts in the subsurface at a specified depth below the surface of the earth just as has been done with navigable airspace.⁵⁴¹ Such action could establish a system for compensating property owners with existing uses of the subsurface below that depth if they are harmed by CO₂ injection, and truncate the establishment of future private property rights and expectations going forward.⁵⁴² This regime would need to formalize and standardize procedures for authorizing access and use of pore space for CO₂ sequestration. Such a

⁵³⁷ *Id.* at 982.

⁵³⁸ *Id.* at 1029-32.

⁵³⁹ *Id.* at 1020.

⁵⁴⁰ *Id.* at 1026-28, 1031.

⁵⁴¹ See 42 U.S.C. § 171 (2006).

⁵⁴² Sprankling does recognize the potential need to acknowledge and honor "all existing rights to extract specific valuable minerals, at least to the extent appropriate to ensure a reasonable return on prior investments." Sprankling, *supra* note 34, at 1037-38.

5.1.3 Limiting the Protection Property Rights in the Subsurface Based on Existing Uses and Non-Speculative, Investment-Backed Expectations

While vesting deep subsurface property in the federal or state governments has appeal as a means to facilitate new technologies like CCS, such an approach fails to recognize the realities of how the subsurface has historically been used and is used today. As discussed in Chapter 1, in many regions of the country, subsurface property rights below 1,000 feet include coal production, oil and natural gas exploration, production, and storage, freshwater production and storage, fluid waste and wastewater injection, and compressed air energy storage.⁵⁴³ Congress has chosen to implicitly recognize those property rights under some circumstances, such as through the eminent domain provisions of the Natural Gas Act,⁵⁴⁴ and courts have recognized those rights by allowing for claims of trespass and nuisance in cases of actual interference or harm.⁵⁴⁵ Courts also have created mechanisms to compute just compensation when subsurface areas are needed for a public use such as natural gas storage.⁵⁴⁶ Thus, the country's history of the use of the subsurface is in fact different from its use of the airspace.

Even though there may be federal background principles (e.g., *Causby*) that would prevent the vesting of property in airspace other than those used in connection with the surface, the same is far less true with regard to the subsurface.⁵⁴⁷ To date, there has been no federal

⁵⁴³ See *supra* Chapter 1, Section 1.4.

⁵⁴⁴ See 15 U.S.C. § 717f(h).

⁵⁴⁵ See *supra* Chapter 2, Section 2.5.1.

⁵⁴⁶ See *Columbia Gas Transmission Corp. v. Exclusive Natural Gas Storage Easement*, 962 F.2d 1192, 1199 (6th Cir. 1992).

⁵⁴⁷ See *Lucas v. S.C. Coastal Council*, 505 U.S. 1003, 1029 (1992) (looking to “background principles” of the state’s law of property and nuisance as an exception to the per se takings rule for regulations that deprive a landowner of all economic use of property); *Bair v. United States*, 515 F.3d 1323, 1327-28 (Fed. Cir. 2008)

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declaration of a “public highway” in the subsurface in the way there has been with airspace, and any future declaration along those lines would come into conflict with vested economic interests in the subsurface in many areas of the country.⁵⁴⁸ Economic use of the subsurface may end at a certain depth, for instance any deeper than is necessary for existing and future natural gas storage, waste injection, and oil and gas development. But to the extent that CO₂ sequestration will be at depths that are currently subject to existing or non-speculative, investment-backed uses (and it appears that it will be),⁵⁴⁹ there do not appear to be any background principles of common law that would prevent states from vesting those property rights in surface owners or mineral owners if they choose to do so, or preventing courts from recognizing such rights as a matter of common law or constitutional law.⁵⁵⁰

An approach based on existing and non-speculative, investment-backed uses would likely result in the existence of subsurface property rights in some regions of the country but not in others, based on whether the geology is suitable for CO₂ sequestration and whether that might compete with oil and gas development, natural gas storage, and the like. Protecting subsurface property rights based on existing uses and non-speculative, investment-backed expectations would provide a middle ground approach to property rights that makes geologic CO₂ sequestration somewhat more expensive to implement, but would recognize, value, and compensate for competing economic uses that would be impaired by GCS. Moreover, this approach is firmly grounded in common law precedent. In the context of enhanced recovery

(recognizing that “state-created property interests may be limited by federal laws” and that federal law can constitute “background principles” that can prevent a per se takings claim.)

⁵⁴⁸ See *supra* Chapter 2 (discussing the difference in historic use of the airspace and historic use of the subsurface).

⁵⁴⁹ See *supra* Chapter 1, Section 1.4.

⁵⁵⁰ See *Lucas*, 505 U.S. at 1029 (discussing “background principles”).

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of oil and gas, fluid waste injection, and freshwater storage and recovery stated, the courts have refused any absolute protection property rights in the deep subsurface, but have retained limited protection of property rights that would allow property owners to recover monetary compensation for damage to property caused by actual and substantial harm or interference. Allowing recovery for actual damage to property is different from finding that a landowner possesses the type of property right in the subsurface that empowers the him/her to prevent others from injecting fluids into the pore space underlying the landowner's property; it is this type of absolute protection of subsurface property rights the courts seem to have clearly rejected in the context of enhanced hydrocarbon recovery, underground fluid waste injection, and freshwater storage.

Under this approach, CCS-specific legislation could establish the presumption that the regulatory grant of the right to access and use pore space for geologic CO₂ sequestration does not amount to a compensable taking because the issuance of a pore space permit 1) does not effect a confiscation of property, and 2) is not the first step in a regulatory taking since pore space owners will unlikely suffer an actual loss or an interference with any investment-backed expectation. However, this legislation should provide surface owners and mineral owners with an opportunity to rebut this presumption by presenting evidence in an administrative proceeding which demonstrates that CO₂ sequestration will result in a material impairment to a current or non-speculative, investment-backed future use of the subsurface, and that the property owner will suffer a consequent economic loss requiring just compensation.

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One application of this standard, shown in Figure 5.5, is in essence a “first-in-time, first-in-right” approach to the use of pore space for CO₂ sequestration, where neither the government nor its agencies would oversee and manage the right to access and use subsurface pore space for CO₂ sequestration. The “first in time, first in right” theory, also referred to as prior appropriation, has been used in the United States to encourage and give a legal framework for other commercial activities. Prior appropriation water rights, sometimes known as the Colorado Doctrine in reference to the U.S. Supreme Court case *Wyoming v. Colorado*,⁵⁵¹ is a system of allocating water rights based on the general principle that water rights are unconnected to land ownership, and can be sold or mortgaged like other property. The first person to use a quantity of water from a water source for a beneficial use has the right to continue to use that quantity of water for that purpose. Subsequent users can use the remaining water for their own beneficial purposes provided they do not impinge on the rights of previous users. The early prospectors and miners in the California Gold Rush of 1849, and later gold and silver rushes in the western United States, also applied first in time, first in right theory to mineral deposits. The first one to discover and begin mining a deposit was acknowledged to have a legal right to mine. As with water rights, mining rights could be forfeited by nonuse. The miner’s codes were later legalized by the federal government in Mining Act of 1866, and then in the Mining Law of 1872. Similarly, the Homestead Act of 1862 granted legal title to the first farmer to put public land into agricultural production.

⁵⁵¹ *Wyoming v. Colorado*, 259 U.S. 419 (1922).

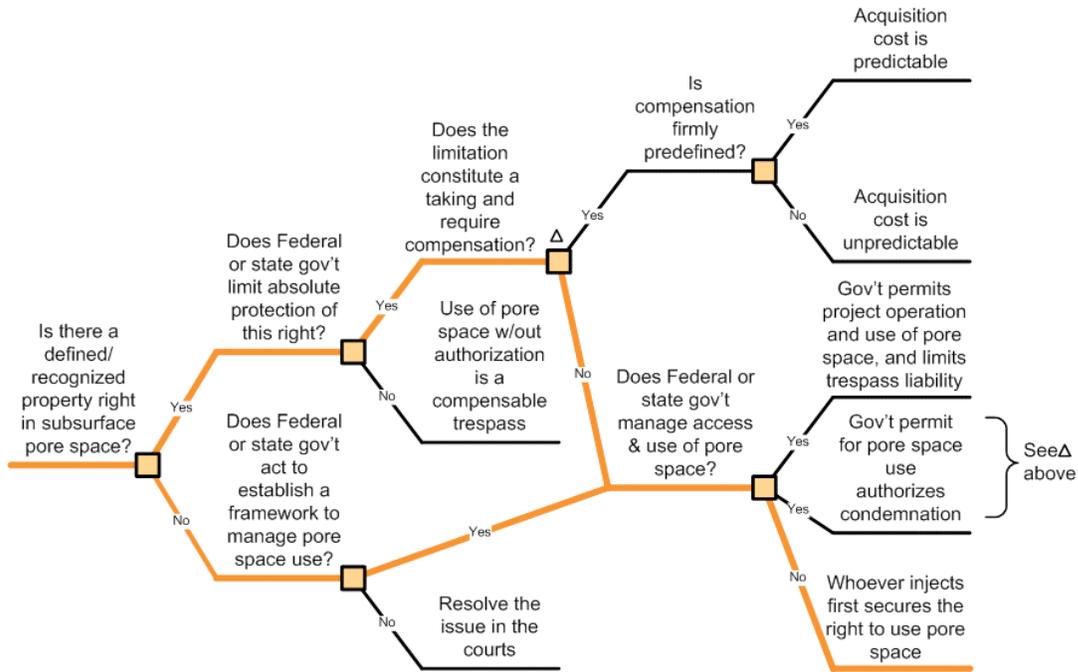


Figure 5.5: “First-in-time, first-in-right” approach to managing access and use of pore space for geologic CO₂ sequestration.

Under this approach, a GCS operator would possess the privilege inject CO₂ into subsurface pore space with the knowledge that it will migrate through the targeted geologic strata provided it is in compliance with regulations covering injection operations. Of course, the uncompensated use of pore space would only be permissible if it does not interfere with a verified existing or non-speculative, investment-backed use of the subsurface that has been asserted by a property owner.

A second application of this standard would be for federal or state governments to codify a formal process for managing the access and use of pore space for geologic CO₂ sequestration, wherein the project developer acquires a permit to use the pore space for GCS and, if necessary, the right to invoke eminent domain authority (see Figure 5.6). Congress or the states could also codify a subsurface trespass liability standard for the use of pore space

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for CO₂ sequestration. This particular approach could facilitate the rapid development of commercial-scale CCS in response to climate change by both standardizing a procedure for acquiring pore space and constraining acquisition costs. The next two sections in this chapter lay out in detail a model framework for managing access to and use of pore space for CO₂ sequestration on private and federal lands based on this approach.

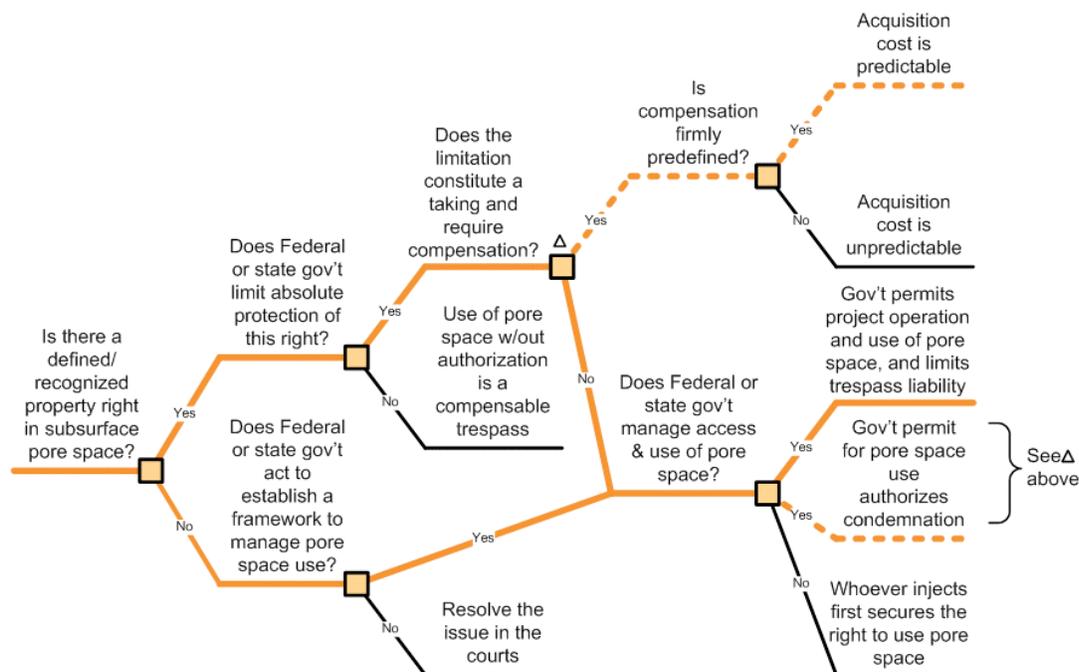


Figure 5.6: Recommended approach to managing access and use of pore space for geologic CO₂ sequestration.

5.2 Model Framework for Permitting Access and Use of Pore Space for Geologic CO₂

Sequestration on Private Lands

If policymakers commit to the widespread deployment of CCS, project developers will need authorization to access and use subsurface pore space to avoid liability for subsurface trespass. This could be accomplished through the creation of a federal framework for managing the access and use of pore space for geologic CO₂ sequestration. A state-based

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framework, while certainly possible, will have difficulty addressing problems related to sequestration under federal lands, sequestration in geologic reservoirs that cross state lines, and other interstate issues related to the transport and injection of CO₂ into the subsurface on the scale required to meaningfully address climate change.

As discussed in Chapter 2, simply because a private party owns the land overlying a sequestration reservoir does not necessarily mean the landowner has the right to prevent parties from injecting CO₂ into the geologic formation or demand compensation for the use of pore space therein.⁵⁵² For instance, courts have consistently held that the use subsurface property in the context of such injection activities as enhanced hydrocarbon recovery, fluid waste injection, and freshwater storage is compensable only when actual harm or interference with an existing use or non-speculative, investment-backed interest in the subsurface results from the underground injection fluids. However, even under the most restrictive approach to subsurface property rights, commercial-scale deployment of GCS has the potential to impair at least some protectable property interests in subsurface pore space. Thus, a federal process is needed to resolve these conflicts. The EPA and states with delegated authority currently regulate and permit injection of substances, including CO₂, pursuant to the UIC Program administered under the Safe Drinking Water Act (SDWA).⁵⁵³ However, in order to implement large-scale sequestration of CO₂ to reduce GHG emissions, federal legislation is required that specifically authorizes the injection of CO₂ for the purpose of permanent

⁵⁵² See *supra* Chapter 2, Section 2.5.

⁵⁵³ 40 C.F.R. §§ 144-146 (2008); see Safe Drinking Water Act, 42 U.S.C. § 300(h)(d) (2006); see also U.S. Environmental Protection Agency, Underground Injection Control Program, http://www.epa.gov/safewater/uic/wells_sequestration.html (accessed July 21, 2020); Federal Requirements Under the Underground Injection Control (UIC) Program for Carbon Dioxide (CO₂) Geologic Sequestration (GS) Wells, 73 Fed. Reg. 43,492 (proposed July 25, 2008).

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sequestration into designated underground geologic reservoirs and declares that geologic CO₂ sequestration for the purpose of mitigating climate change is a “public use” carried out in the “public interest.” Additionally federal legislation governing large-scale CO₂ sequestration must also include provisions authorizing the EPA and state UIC permitting agencies to issue permits (hereinafter referred to as “pore space permits”) granting GCS developers the exclusive right to access and use pore space for the injection and sequestration of CO₂. However, no possessory interest in the pore space should be conveyed through the issuance of a pore space permit, only a perpetual easement to use the pore space for the sole purpose of CO₂ sequestration.

As noted above, federal legislation should also create a presumption that the regulatory grant of the right to access and use pore space for geologic CO₂ sequestration does not amount to a compensable taking unless there is evidence presented that demonstrates CO₂ sequestration will result in a material impairment to a current or non-speculative, investment-backed future use (herein after referred to as a “preexisting interest”) of the subsurface, and that the property owner will suffer a consequent economic loss requiring just compensation. If it is demonstrated that a preexisting interest would be materially impaired by CO₂ injection, the geologic CO₂ sequestration project should be permitted only upon 1) a modification of the project that that avoids the impairment; 2) a contractual agreement between the owner of the preexisting interest and the project developer; 3) or a finding by the permitting agency that the condemnation of the preexisting interest through the exercise of eminent domain authority, with appropriate compensation, is necessary for the proper operation of the GCS

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project. Lastly, a claim of subsurface trespass should not be actionable against a project operator conducting geologic CO₂ sequestration in accordance with a valid permit.

5.2.1 Required Legislative and Administrative Action

Permanent geologic sequestration of CO₂ and access to pore space for GCS should be permitted under a modified version of the EPA's UIC program. Implementing a federal framework for permitting the access to and use of pore space for GCS will require federal legislation specifically aimed at addressing and promoting geologic CO₂ sequestration, as well as amendments to the Safe Drinking Water Act and a modification and expansion of the UIC permitting rules for GCS proposed by the EPA.⁵⁵⁴

5.2.1.1 Statutory Declaration that Geologic CO₂ Sequestration is a Public Use

Federal legislation must declare that permanently sequestering CO₂ in deep geologic formations to combat the detrimental effects of climate change is a public use undertaken in the national interest. While courts may have occasion to find geologic sequestration of CO₂ is a public benefit on a case-by-case basis, courts frequently look to statutory policy statements to determine the public interest. Unequivocal statutory language would provide explicit, persuasive guidance to the courts. As discussed earlier in Chapter 2, under the Fifth Amendment to the U.S. Constitution, the government has the power to appropriate private property by eminent domain so long as it is taken for a “public use” and “just compensation”

⁵⁵⁴ 40 C.F.R. §§ 144-146 (2008); *see* Safe Drinking Water Act, 42 U.S.C. § 300(h)(d) (2006); *see also* U.S. Environmental Protection Agency, Underground Injection Control Program, http://www.epa.gov/safewater/uic/wells_sequestration.html (accessed July 21, 2020); Federal Requirements Under the Underground Injection Control (UIC) Program for Carbon Dioxide (CO₂) Geologic Sequestration (GS) Wells, 73 Fed. Reg. 43,492 (proposed July 25, 2008).

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is paid.⁵⁵⁵ Courts have broadly interpreted “public use” to include not only the use of property for schools, railroads, post offices and the like that will be put into “use by the public,” but also a wide range of more controversial “public purposes” connected to land development, such as the government transfer of property from one private owner to another to develop the property in a way that will eliminate blight or simply increase the tax base for the community.⁵⁵⁶ Moreover, the Supreme Court upheld a very broad interpretation of the public use clause, confirming that it was not limited to “use by the public,” but included any purpose of public benefit, public interest, or value to the community.⁵⁵⁷ As discussed in Chapter 2, time and again courts have upheld the use of eminent domain authority in connection with the creation of subsurface natural gas storage fields. What is more, courts have consistently ruled that enhanced hydrocarbon recovery, field unitization, fluid waste injection, and freshwater storage are all a benefit to the community and in the public interest in order to shield injection operators from trespass liability.⁵⁵⁸ Establishing that the geologic sequestration of CO₂ to reduce GHG emissions is a “public use” is rather straight forward proposition given growing recognition of the dangers of climate change. There is now broad consensus among the scientific community that climate change poses a significant threat to human health and the environment.⁵⁵⁹ At the current time climate change is seen as one of

⁵⁵⁵ U.S. CONST. amend. V; *see supra* Chapter 2, Section 2.6.

⁵⁵⁶ *See Kelo v. City of London*, 545 U.S. 469, 484-86 (2005) (finding that the City of New London’s exercise of eminent domain power to take private residences in connection with the development of a corporate headquarters for the Pfizer Corporation to increase the city’s tax base and spur development in an economically distressed area was a “public purpose” consistent with the Fifth Amendment).

⁵⁵⁷ *Kelo*, 545 U.S. 469.

⁵⁵⁸ *See supra* Chapter 2, Section 2.5.

⁵⁵⁹ *See, e.g.*, Rais Akhtar et al., *Human Health*, in IPCC FOURTH ASSESSMENT REPORT, CLIMATE CHANGE 2007: IMPACTS, ADAPTATIONS, AND VULNERABILITY 393 (Martin Parry et al. eds., 2007), <http://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-chapter8.pdf>; *see also* Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act, 74 Fed. Reg. 66,496 (Dec. 15, 2009) (to be codified at 40 C.F.R. ch. I); U.S. Environmental Protection Agency, Endangerment and Cause or Contribute Findings for Greenhouse Gases Under the Clean Air Act, <http://www.epa.gov/climatechange/endangerment.html> (accessed July 27, 2010).

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the country's most pressing environmental needs, and thus there is a very strong argument in favor of implementing technology to address that need is a public benefit, particularly if such technology is carried out pursuant to federal legislation declaring it a public use and supporting that declaration with the appropriate scientific data and findings.⁵⁶⁰

5.2.1.2 Amendments to the SDWA and UIC Permitting Rules

Because the singular environmental and public health and safety object of the SDWA is to underground sources of drinking water, the UIC program in its current form does not allow UIC regulators⁵⁶¹ to consider multiple environmental objectives when permitting injection projects. Specifically, and in the context of CO₂ sequestration, the UIC regulator currently cannot weigh the environmental and human health benefits of geologic CO₂ sequestration against public benefits derived from protecting underground drinking water sources. For sure, protecting drinking water is an essential environmental and public health goal, but so is curtailing the effects of climate change. At times these goals may be incompatible, yet they may also be complimentary. For instance, the IPCC concluded that climate change presents significant risk to groundwater as rising sea levels extend areas of salinization and increased precipitation variability decreases recharge to groundwater.⁵⁶² Thus, placing a permitting regime for GCS within an existing regulatory program that must follow the strict statutory mandate to protect underground sources of drinking water could prevent important CO₂ sequestration projects from being developed and, consequently, have a detrimental effect on

⁵⁶⁰ See *Kelo*, 545 U.S. at 483-84 (focusing on the comprehensiveness of the city's plan and thoroughness of deliberations in upholding the city's determination of public use); *id.* at 493 (Kennedy, J., concurring) (same).

⁵⁶¹ For the purpose of this thesis, "UIC regulator" means a state that has primary enforcement authority under § 1422 of the Safe Drinking Water Act for the underground injection of CO₂, and the Administrator for the Environmental Protection Agency for any other state.

⁵⁶² See Rais Akhtar et al., *supra* note 57, at 976.

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efforts to combat climate change. Therefore, new federal legislation should grant discretion to UIC regulators to make a determination that one or more provision of the SDWA is applicable in whole or in part to a specific source of underground drinking water if the regulator finds that the public benefit of geologic CO₂ sequestration outweighs the protection of the underground drinking water source at issue. In making such a determination, the UIC regulator must carefully balance the goals of minimizing the present and future threats to human health and the environment imposed by climate change with the protection and safety of underground sources of drinking water. In addition, the UIC regulator must consider the following factors when undergoing this balancing analysis:

- 1) direct and indirect impacts to underground sources of drinking water and human health and the environment resulting from geologic sequestration of CO₂;
- 2) local impacts of potential surface leakage of sequestered CO₂, assessing both the probability and magnitude of potential harm;
- 3) the Nation's need to deploy and use CCS technology to control GHG emissions, and
- 4) any such other factors as the UIC regulator determines to be relevant.

Similarly, the inability of the EPA or its designated state agencies to permit the access and use of pore space for geologic CO₂ sequestration and resolve related property disputes upfront and at the time of permitting could be counterproductive with respect to meaningfully reducing CO₂ emissions. For instance, if CGS project developers are required to contract with and compensate each and every individual property owner overlying the sequestration reservoir—which could be hundreds to thousands of square-kilometers in area—regardless of

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whether injected CO₂ causes actual and substantial harm, the administrative and economic ramifications of such an approach to property rights could immobilize many CO₂ sequestration projects.⁵⁶³ To avoid such a paralytic outcome, federal legislation should establish procedures under which UIC regulators are authorized to issue pore space permits—having the effect of a perpetual easement—granting GCS project operators that have received a CO₂ injection permit under the UIC program the exclusive right to access and use pore space for geologic CO₂ sequestration within the subsurface project boundary⁵⁶⁴ specified by the injection permit. This is not to suggest project developers should be prohibited from acquiring pore space rights through private negotiations. On the contrary, if a project developer acquired consent to use pore space from all property owners overlying the subsurface project boundary defined in the CO₂ injection permit, a pore space permit is not necessary.

5.2.2 Creation of Federal Remedy for Claims of Subsurface Trespass Related to Geologic CO₂ Sequestration

Project operators injecting CO₂ pursuant to a valid CO₂ injection permit and, if necessary, a pore space permit should be protected from trespass liability. Specifically, federal legislation should decree that the use of pore space should not give rise to an actionable trespass claim unless actual and substantial harm is caused to established protectable property interests. A federal standard for subsurface trespass liability would obviate the need to make a federal declaration or modify state common law and statutory determinations regarding pore space

⁵⁶³ See *supra* Chapter 3, Section 3.3.1; Chapter 4, Section 4.2.

⁵⁶⁴ The “subsurface project boundary” is the *ex ante* estimated special extent of free-phase injected CO₂ delineated both by the lateral and vertical boundaries from the time injection commences to the time that free-phase CO₂ ceases flowing, and taking into account a margin of error in predictions.

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ownership. Instead, the role of determining ownership of pore space should remain with the states. A pore space permit should not protect a GCS operator if injection or migration of CO₂ materially impairs preexisting interests that were identified during the UIC permit proceeding, or property interests outside the project boundary specified by the CO₂ injection permit (see Sections 5.2.4 and 5.2.5 below). Federal legislation should specify that the standard for calculating money damages should be the present value of the demonstrated impairment, or the otherwise expected value of the future income stream that would have accrued had the interest not been impaired. Punitive damages should be barred if GCS project operator who caused the material impairment is in compliance with the terms of the CO₂ injection permit, and injunctive relief should not be allowed unless the owner of the impaired property interest demonstrates that the harm to the property owner clearly outweighs the utility of CO₂ sequestration. Finally, the United States district court for the district in which a trespass claim arises should have exclusive jurisdiction over such a claim.

5.2.3 Creation of Eminent Domain Authority for Geologic CO₂ Sequestration

The circumstance may arise where the absolute projection of a preexisting interest in the subsurface would prevent the property operation of a geologic CO₂ sequestration project under application for a pore space permit. If the right to use pore space for CO₂ sequestration can be acquired via voluntary contractual agreement from the owner of the preexisting interest, the issue would be effectively resolved. However, owners of preexisting interests would not be obliged to consent to use of their pore space in such a situation, and could therefore easily stymie the development of a GCS project if they refuse to allow their pore space to be used or demand compensation in excess of what the project developer is willing

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to pay. To ensure geologic CO₂ sequestration projects which are deemed by a UIC regulator to be in the highest public interest are not unreasonably delayed or even thwarted by hold-out property owners, federal legislation authorizing the use of eminent domain for geologic CO₂ sequestration is necessary as a back-stop in situations where the right to use pore space cannot be acquired through voluntary contractual negotiations. Whether a geologic CO₂ sequestration project is of such national importance as to justify the appropriation of a preexisting interest is a determination that should be made by the UIC regulator at the time a project application is under review.

If use of eminent domain is warranted, the holder of a CO₂ injection permit should be granted the right, via the issuance of a pore space permit (see Section 5.2.5 below), to appropriate any subsurface strata required for the project to move forward, but only after all reasonable and good faith attempts to negotiate with the relevant property owner(s) have been exhausted. Eminent domain should be exercised in the district court of the United States for the district in which the pore space is located. Additionally, the practices and procedures in any eminent domain action should conform as nearly as possible to the practices and procedures in for a similar action or proceeding in the courts of the state where the pore space is located. A GSC operator should be allowed to use the pore space at issue once the federal district court has determined the fair value of the property being appropriated and compensation has been paid to the affected property owner(s). A GCS project developer should also have the option to engage in the immediate use of the pore space targeted for appropriation—this is known as a “quick condemnation”—provided the developer deposits funds in escrow with the appropriate federal district court equal to the appraised value of the property and establishes

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sufficient financial viability to pay any additional amount awarded by the court in the eminent domain proceeding. The advantage of a quick condemnation is that it avoids any potential delay in project development that could result from disputes regarding the value of the property that arise during the eminent domain proceeding. The standard for calculating just compensation should be present value of the interest impaired by the condemnation, or the otherwise expected value of the future income stream that would have accrued had the interest not been appropriated. In both a traditional or quick condemnation action, no possessory interest in the pore space would be taken by the federal government and subsequently conveyed to the GCS project developer. Instead, a perpetual easement to use the condemned pore space would be acquired by the developer.

5.2.4 Permitting Structure and Requirements

One distinct advantage of grafting a framework for managing the access and use of pore space for CO₂ sequestration onto a modified version of the UIC program is that such an approach could capitalize on the experience of UIC regulators, their relationship with state environmental and natural resource agencies and geologic surveys, and the knowledge about GCS UIC regulators amassed while preparing the proposed rules for regulating the injection of CO₂ for permanent geologic sequestration. Another advantage to this approach is that UIC regulators—that is the EPA or designated state environmental and natural resource departments or oil and gas commissions⁵⁶⁵—are well positioned to balance the need for permanent geologic sequestration of CO₂ in response to climate change with the need to protect underground sources of drinking water supplies so as to ensure the overall safety and

⁵⁶⁵ Environmental Protection Agency, UNDERGROUND INJECTION CONTROL PROGRAM: UIC PROGRAM PRIMACY, <http://www.epa.gov/safewater/uic/primacy.html#who> (accessed July 29, 2010).

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protection of human health and the environment. Federal and state UIC regulators are also the most qualified to make decisions regarding CGS injection well spacing, density, and the overall number of allowable wells. Lastly, a federal-based approach is most appropriate for regulating CO₂ injection and permitting the use of pore space for interstate GCS projects that cross more than one or more jurisdictional boundary.

Currently, the regulatory context for geologic sequestration is shaped by a strong history of state and local control of land use issues, property rights issues, and significant variation among states in both geology and applicable law. State environmental and natural resource agencies, oil and gas commissions, mining agencies, and geologic surveys, all of which have invaluable local knowledge, should play a significant role in permitting of geologic sequestration projects as either the EPA-designated UIC regulator or consultants to the UIC permitting process for CO₂ sequestration. Collectively, state regulatory agencies are well-positioned to promote the development of GCS, protect underground sources of drinking water as well as human and environmental health, and prevent the degradation of economically recoverable hydrocarbon resources and hard mineral resources. Therefore, as with the existing UIC program, states and tribes should be able to apply for primary enforcement responsibility to implement the UIC program for CO₂ sequestration within their borders. However, states and tribes seeking primary enforcement responsibility under the UIC program for geologic sequestration of CO₂ should be required to develop a framework and enact statutory authority for acquiring the necessary ownership interests, easements, or licenses necessary to occupy subsurface pore space. State UIC programs for GCS should be further required to take into account the effects that permanent geologic sequestration of CO₂

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in the permitting state will have in any other state. In the same vein, federal UIC regulations must ensure that any state with a reasonable prospect of being affected by the issuance of CO₂ injection permit under another state's UIC program has the right to intervene and participate in proceedings conducted by the permitting state. The EPA should have the authority to revoke or override any CO₂ injection permit issued by a state UIC regulator if the state regulator fails to take into account the effects that permanent geologic sequestration of CO₂ in the permitting state will have in any other state. The EPA's authority should also supersede that of the state UIC regulator when the injection of CO₂ as authorized by the state permit is determined to substantially endanger underground sources of drinking water (unless an exception has been granted) and/or poses a threat to human and environmental health and safety.

If a state applies for and is granted primary enforcement authority under the UIC program for permanent geologic sequestration of CO₂, the discretion to adopt stricter permitting and operational standards for GCS than those adopted by the EPA should also be delegated to those states. However, if a GCS project will require the use of pore space located in more than one state (i.e., an interstate project) with primary UIC enforcement authority, the relevant states must enter into a cooperative agreement with respect to permitting and regulating the project. If the states fail to reach an agreement, the EPA should assume primary enforcement authority of the interstate project. This is because the permitting process for GCS projects, especially those that will cross state borders and perhaps require multiple permits as a consequence, could be quite onerous if project developers are subjected to a myriad of state-level standards and requirements. This is especially true in the matter of

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permitting the use of pore space because a high degree of discontinuity, as well as uncertainty, is likely to exist with respect to the risk of exposure to subsurface trespass liability since common law rules and statutory provisions governing subsurface trespass vary from state to state. Without clear and predictable permitting rules and legal standards, project developers might not be willing to invest the time and make the large capital investment required to build CO₂ sequestration projects at the scale necessary to meaningfully reduce emissions of CO₂.

5.2.4.1 Open Application Procedure for a UIC Injection Permit for Geologic CO₂

Sequestration

When a geologic CO₂ sequestration project developer applies for a CO₂ injection permit, the UIC regulator UIC regulator should publish the application in Federal Register and require the applicant to provide any additional public notice the regulator determines to necessary. A period of 90 days should be afforded to other GCS project developers and operators who wish to contend that the issuance of a CO₂ injection permit and, if applicable, an pore space permit will impair their own ability to develop and operate an alternative and potentially competing geologic CO₂ sequestration project to intervene and file a competing application. An intervener should be entitled to equal consideration with the original applicant if they file a competing application within 90 days after public notice of the original application was filed. If a competing application is submitted outside this window and no other competing applications are pending, the original application should be considered and resolved upon its own merits. If competing applications are considered and a losing applicant, prior to filing its application, acquired the ownership interests, easements, or licenses necessary to occupy

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pore space through state statutory authority or voluntary contract, the prevailing applicant should have to compensate the losing applicant for all expenses incurred in securing the rights to occupy the pore space. Upon payment, all rights and interests in the pore space would be transferred to the prevailing applicant.

5.2.4.2 Effect of a CO₂ Injection Permit for Geologic Sequestration of CO₂

If a CO₂ injection permit is issued to a project applicant, no permit should be issued to any other person to inject CO₂ for the purpose of geologic CO₂ sequestration within the subsurface project boundary defined in the existing permit, unless the permit provides otherwise. A CO₂ injection permit should not relieve the GCS project operator of any liability for failing to obtain the ownership interests, easements, or licenses necessary to occupy pore space unless the injection permit incorporates a pore space permit.

5.2.5 Application for a Pore Space Permit

If a CO₂ injection permit applicant seeks to develop a geologic CO₂ sequestration project in a state (or states) that has (or have) not codified statutory authority for accessing and using pore space for CO₂ sequestration and the applicant has not acquired through voluntary contract the ownership interests, easements, or licenses necessary to occupy pore space, the project developer, in connection with its CO₂ injection permit application, should be able to include a request for a pore space permit. As specified earlier in this section, a pore space permit would convey to a project operator the exclusive right to access and use pore space for geologic CO₂ sequestration within the subsurface project boundary defined in the CO₂ injection permit. If a request is made for a pore space permit, the UIC regulator should

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publish the request in Federal Register and require the applicant to provide any additional public notice the regulator determines to be necessary. A period of 60 days for participation in the permit application proceeding should be afforded to all interested parties and owners of preexisting interests that may be materially impaired by the granting of the pore space permit. If an interested party or preexisting interest-holder fails to intervene within 60 days after public notice of the original application was filed, such party should be deemed to have waived any and all rights and property interests that may become impaired by the geologic CO₂ sequestration project should a pore space permit be issued. However, an interested party or the holder of a preexisting interest should be permitted late intervention in the pore space permit proceeding upon a showing of good cause. A competing geologic CO₂ sequestration project applicant who intervenes in the pore space permit proceeding must also indicate their intention to file a competing application for a CO₂ injection permit within 90 days of the original project application.

If it is demonstrated that a preexisting interest would be materially impaired by the issuance of a pore space permit, the geologic CO₂ sequestration project should be permitted only upon 1) a modification of the project avoids the impairment; 2) a contractual agreement between the owner of the preexisting interest and the project applicant; or 3) a finding by the UIC regulator that condemnation of the preexisting interest through the exercise of eminent domain, with appropriate compensation, is necessary to the proper operation of the CO₂ sequestration project under application. In connection with a pending application for geologic CO₂ sequestration, the UIC regulator should be permitted to exclude from the subsurface

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project boundary, or authorize the use of eminent domain, for any portion of a geologic formation where the strata is:

- subject to active and properly licensed exploration or production of hydrocarbon or hard mineral resources;
- actively used for the properly licensed injection of brines or other fluids for the purpose of enhanced recovery of hydrocarbon resources;
- actively used for storage of crude oil;
- actively used for injection of fluid wastes or municipal wastewater for disposal pursuant to a valid UIC permit;
- actively used for certificated natural gas storage;
- actively used for properly licensed groundwater recovery and storage;
- actively used for properly licensed compressed air energy storage;
- actively used for geothermal electric power generation;
- actively being subjected to geophysical and environmental testing for the purpose of developing a geologic sequestration project, provided that the ownership interests, easements, or licenses necessary to occupy the pore space for permanent geologic sequestration of CO₂ have been by the project developer through either state statutory authority or voluntary contract; or
- actively used for other purposes the UIC regulator deems relevant.

In summary, if the pore space permit is issued, preexisting interests not asserted within 60 days after public notice of the pore space application was filed should be subject to GS

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development without compensation. Furthermore, when no preexisting interest in the subsurface is established, the public interest associated with permanently sequestering CO₂ in geologic pore space in response to climate change should prevail over the right of surface owners and mineral owners to prevent GCS project operators who hold both a valid CO₂ injection permit and a pore space permit from using pore space on their property and demand compensation for trespass. If a surface owner or mineral owner believes the issuance and effect of a pore space permit is tantamount to a *per se* physical taking of private property without just compensation, the property owner may, of course, file a takings claim.

5.2.6 Dominance of the Mineral Estate

The permitting requirements for CO₂ injection and pore space should not preempt the mineral rights laws of any state, except to the extent necessary to ensure that mineral exploration and production activities will not cause leakage of sequestered CO₂, or compromise the integrity of the geologic sequestration reservoir in any way. Unless a preexisting interest has been established or a geologic CO₂ sequestration project developer does not have a pore space permit and has not acquired the ownership interests, easements, or licenses necessary to access and use pore space for CO₂ sequestration through either state statutory authority or voluntary contract, the holder of a state-law right to conduct mineral exploration or production activities should not be entitled to compensation as a result of any such activities being precluded or restricted to protect the integrity of the geologic sequestration site. As with all other property interests, mineral rights should be subject to condemnation through the exercise of eminent domain.

5.3 Model Framework for Permitting Access and Use of Pore Space for Geologic CO₂ Sequestration on Federal Lands

The Department of Energy's Carbon Sequestration Atlas estimated that around 5.5 percent of the U.S. onshore geologic CO₂ sequestration capacity lies beneath leasable federal lands.⁵⁶⁶ Sequestering CO₂ on federally-owned lands is touted as having two distinct advantages over sequestering on private land: fee simple ownership of surface, mineral and pore space rights, and large contiguous tracts of land. However, a fair proportion of the roughly 250 million surface acres and 700 million acres of subsurface mineral estates managed by United States Bureau of Land Management (BLM) administrators is intermixed with private land. Therefore, any permitting framework for GS on federal lands must address two confounding property-related issues: 1) the situation where ownership of the surface and mineral estates is split between the federal government and private landowners (i.e., "split estates"), and 2) sequestering CO₂ on marginally-sized tracts of federal land held in fee simple by the Government that are boarded by privately owned lands. Use of federal land will also require compliance with all applicable federal, state and local laws and regulations that protect environmental and human health, including the National Environmental Policy Act⁵⁶⁷ (NEPA), the SDWA and the EPA's UIC regulations, the National Historic Preservation Act⁵⁶⁸ (NHPA) and the Endangered Species Act⁵⁶⁹ (ESA). NEPA will require extensive analysis and documentation of the potential environmental impacts of GCS projects proposed

⁵⁶⁶ See U.S. Dep't of Energy, CARBON SEQUESTRATION ATLAS OF THE UNITED STATES AND CANADA 15 (2007), http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlas/ATLAS.pdf (accessed July 21, 2010).

⁵⁶⁷ 42 U.S.C. §4321.

⁵⁶⁸ 16 U.S.C. §470.

⁵⁶⁹ 16 U.S.C. §1531 *et seq.*

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on federal lands.⁵⁷⁰ Areas of Critical Environmental Concern (ACECs), such as wilderness, areas, national parks and monuments, will not be available for GS development.⁵⁷¹

5.3.1 Authority to Permit Geologic CO₂ Sequestration on Federal Lands

Current federal statutes and regulations do not directly address injection of CO₂ into the subsurface on federal lands for permanent geologic sequestration. The Federal Land Policy and Management Act⁵⁷² (FLPMA) and the Mineral Leasing Act^{573,574} (MLA)—which give the Bureau of Land Management (BLM) the authority to issue rights-of-way (ROWs) for pipelines and other infrastructure, the licensing of oil and gas exploration for production, the injection of CO₂ for enhanced recovery of oil resources, and the injection and underground storage of natural gas (all on federal land)—could easily be modified to specifically authorize the use of federal lands for geologic CO₂ sequestration.⁵⁷⁵ Both Congress and the Department of the Interior (DOI) are currently examining the FLPMA and the MLA to determine to what extent the DOI and the BLM can, and should, exercise authority over GS on federal lands, as well as what changes to public land laws are necessary.

5.3.1.1 Federal Land Policy and Management Act

The FLPMA provides ample legal authority to approve geologic CO₂ sequestration projects on BLM-administered federal land. Title V of the FLPMA authorizes the BLM to issue

⁵⁷⁰ See United States Department of the Interior, FRAMEWORK FOR GEOLOGICAL CARBON SEQUESTRATION ON PUBLIC LAND, Report to Congress, at 10 (June 2009) (in compliance with Section 714 of the Energy Independence and Security Act of 2007 (P.L. 110-140, H.R.6)).

⁵⁷¹ 43 U.S.C. §1701 *et seq.*

⁵⁷² *Id.*

⁵⁷³ 30 U.S.C. §181 *et seq.*

⁵⁷⁴ 30 U.S.C. §351 *et seq.*

⁵⁷⁵ See United States Department of the Interior, FRAMEWORK FOR GEOLOGICAL CARBON SEQUESTRATION ON PUBLIC LAND, Report to Congress (June 2009) (in compliance with Section 714 of the Energy Independence and Security Act of 2007 (P.L. 110-140, H.R.6)).

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rights-of-way over and under federal land for a variety systems, including: 1) systems for the transportation of storage liquids and gases (other than natural gas or synthetic gaseous fuels); 2) systems for the generation, transmission, and distribution of electric energy; and 3) any other systems or facilities that are in the public interest and require rights-of-way.⁵⁷⁶ Title V rights-of-way, which can be easements, are issued for a term that gives the holder the certainty and security needed to obtain adequate financing, even if this means that the term is “very long or even perpetual.”⁵⁷⁷ Congress intended that BLM’s authority under Title V “be all inclusive and provide [the BLM] the requisite authority to grant any right-of-way for any purpose which is in the public interest[.]”⁵⁷⁸ Title V was “intended to include rights-of-way which serve future needs arising out of existing and future technology advances. This clause is broad enough to cover rights-of-way for...any other systems which are not yet in general use.”⁵⁷⁹ Accordingly, there is little question that the BLM’s authority under Title V is broad enough to cover geologic CO₂ sequestration.

Even if the BLM’s authority under Title V is determined not to cover geologic CO₂ sequestration, Section 302(b) of the FLPMA grants the BLM the authority to permit CO₂ sequestration on federal lands. This provision authorizes the BLM to issue easements, permits, and leases for industrial and commercial uses that cannot be authorized under other laws.⁵⁸⁰ In fact, last year the DOI submitted a report to Congress that recognized Section

⁵⁷⁶ 42 U.S.C. § 1761(a)(2), (4),(7).

⁵⁷⁷ Senate Report No. 94-583 at 71.

⁵⁷⁸ *Id.* at 66.

⁵⁷⁹ *Id.* at 67.

⁵⁸⁰ 3 U.S.C. § 1732(b); 43 C.F.R. § 2920.1-1.

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302(b) could be used for geologic CO₂ sequestration.⁵⁸¹ The report stated that the BLM has the statutory authority to allow federal land under its jurisdiction to be used for geologic CO₂ sequestration under either Title V or Section 302(b) of the FLPMA. Even so, the FLPMA should be amended in a manner so as to expressly convey to the BLM the authority to issue rights of ways and licenses for construction and use of pipelines and other systems required for the transportation, distribution, and permanent geologic sequestration CO₂ on federal lands.

5.3.1.2 *Mineral Leasing Act*

The MLA authorizes the Secretary of the Interior to approve the subsurface storage of natural gas “in [federal] lands leased or subject to lease” to “avoid waste and promote conservation of natural resources”, regardless of whether the gas is produced on federal lands.⁵⁸² In *Exxon Corp. v. Lujan*,⁵⁸³ the United States Court of Appeals for the 10th Circuit affirmed a BLM decision to issue a right-of-way for a CO₂ under the MLA rather than the FLPMA.⁵⁸⁴ While the case is not entirely on point because it dealt with the issue of CO₂ pipelines and not natural gas storage, it provides some meaningful precedent. The MLA right-of-way provisions govern oil and natural gas pipelines, while the FLPMA provisions govern pipelines other than oil and natural gas pipelines. The court reviewed Exxon’s appeal of the BLM permit issuance, specifically whether a CO₂ pipeline could be characterized as a natural gas pipeline under the MLA. The *Exxon* court upheld an earlier ruling by the Federal District

⁵⁸¹ See United States Department of the Interior, FRAMEWORK FOR GEOLOGICAL CARBON SEQUESTRATION ON PUBLIC LAND, Report to Congress at 9 (June 2009) (in compliance with Section 714 of the Energy Independence and Security Act of 2007 (P.L. 110-140, H.R.6)).

⁵⁸² 30 U.S.C. § 226(m)

⁵⁸³ See *Exxon Corp. v. Lujan*, 970 F.2d 757 (10th Cir. 1992).

⁵⁸⁴ *Id.* at 763.

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Court of Wyoming, which found that the MLA never defined the word “gas” and that the plain meaning of “natural gas” was ambiguous with regard to whether it encompassed CO₂. Because of the statutory ambiguity, the district court looked to the legislative history of the MLA.

After analyzing the Congressional debate of the precursor to the MLA, the court found that if one were to categorize gases in the broadest possible manner at the time the MLA was enacted, “they would fall into two categories—natural gas; that is, gases that occur naturally, or artificial gas; namely, gases manufactured in the laboratory.”⁵⁸⁵ The district court further found that if Congress had wanted to define natural gas restrictively in the MLA, Congress knew of the term “hydrocarbon” and could have defined “natural gas” to mean “gaseous hydrocarbons,” excluded smaller components of the natural gas such as CO₂, or simply used the term “hydrocarbon.”⁵⁸⁶ The court also referred to a legal opinion from the Department of the Interior’s Office of the Solicitor, which argued that the MLA refers only to “gas” or “natural gas” without any qualifying adjectives, and that a nonrestrictive reading of the terms would be supported under the oil and gas leasing provision of the MLA.⁵⁸⁷ The Exxon court then held that the term “natural gas” had a “technical meaning thus precluding reliance on its ordinary definition.”⁵⁸⁸ Any use of the word “natural” was meant to distinguish the gas from that which was “artificially produced.”⁵⁸⁹ Extending the Exxon courts analysis of the MLA’s right-of-way provisions to subsurface storage provisions, it would appear that CO₂ falls

⁵⁸⁵ *Exxon Corp. v. Lujan*, 730 F.Supp. 1535, 1543 (D. Wyo. 1990).

⁵⁸⁶ *Id.*

⁵⁸⁷ U.S. Department of the Interior, OWNERSHIP OF AND RIGHT TO EXTRACT COALBED METHANE GAS IN FEDERAL COAL DEPOSITS, 88 Interior Dec. 538 (1981).

⁵⁸⁸ *Lujan*, 730 F.Supp. at 1544.

⁵⁸⁹ *Id.* at 1545.

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within the MLA's definition of "gas," and that geologic CO₂ sequestration would be governed by the MLA's provisions on the "subsurface storage of natural gas."

5.3.2 Permitting Structure and Requirements

The BLM and EPA should jointly license geologic CO₂ sequestration projects on federal lands and split estates pursuant to the UIC permitting procedures laid out in Sections 5.2.4 and 5.2.5 above. Under this framework, property rights conflicts arising from the encroachment of pore space on private lands can be effectively avoided because the framework, by design, is blind with respect to ownership. Application of this framework would enable a GCS project to be permitted on federal and private lands simultaneously. So even if CO₂ injection is carried-out on federal land, a GCS project developer can acquire any necessary pore space rights on private through voluntary contract, the issuance of a pore space permit, or, if applicable, eminent domain during the joint BLM/UIC permit process. Under this approach, GCS projects that are properly licensed by both the EPA and BLM would be authorized to inject CO₂ and allow it to migrate across both federal and private lands without being exposed to trespass liability so long as the relevant subsurface rights have been acquired pursuant to the requirements specified in Section 5.2.5, CO₂ migration does not materially impair preexisting interests, and CO₂ does not migrate beyond the subsurface project boundaries specified in the CO₂ injection permit.

5.3.2.1 Two-Phase Licensing Procedure

The BLM should issue perpetual easements under Title V of the FLPMA for geologic CO₂ sequestration exploration and development projects on federal lands through a two-phase

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licensing procedure: one license would be issued to study and characterize the proposed CO₂ sequestration site, the other to develop the site and conduct CO₂ injection. The BLM should be authorized to charge administrative fees and collect a nominal annual rent from license-holders for the administration and management of geologic CO₂ sequestration licenses.

Phase I: Project Area License: Geologic CO₂ sequestration project developers should have to apply for a project area license, which would grant the applicant the exclusive right to conduct environmental and geological testing and monitoring within the proposed subsurface project boundary. Priority of application should be given to the first complete application the BLM receives. The project area license term should be for a period of five years, during which time the pore space within the proposed project boundary should not be available to other potential applicants. This is necessary because issuing multiple project area licenses for the same geologic strata could create a competitive and economic disadvantage. Specifically, it is possible that project developers would be dissuaded from sinking large sums of money into the characterization and testing of potential geologic CO₂ sequestration sites if that investment could evaporate when the BLM issues a development license to a competing project area license holder. During this first phase, the holder of a project area license must formulate a Plan of Development (POD) for the proposed geologic CO₂ sequestration project to be submitted during second phase of the application process. A plan of development would be a detailed design of the geologic sequestration project and CO₂ transportation, distribution, and injection facilities. The plan of development helps the BLM assess the public safety and environmental effects of the proposed CO₂ sequestration project and its facilities.

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Phase II: Project Development License: To qualify to apply for a project development license for CO₂ sequestration on federal land, the holder of a project area license must submit a plan of development to the BLM no later than five years from the time the project area license was issued. A project developer must simultaneously apply for a CO₂ injection permit for geologic sequestration at the time it files for a project development license with the BLM. A project development license should be awarded based on the merits of the applicant's plan of development as well as be contingent on the applicant securing a CO₂ injection permit for geologic CO₂ sequestration. A project development license, in combination with a CO₂ injection permit and, if necessary, a pore space permit, would grant the applicant the right to construct, operate, and maintain underground wells and necessary surface and subsurface facilities for the permanent geologic sequestration of CO₂ within the project boundary specified in the UIC permit. If the applicant is successful in securing the project development license, no CO₂ injection permit may be issued to any other person to inject CO₂ within the subsurface project boundary defined in the existing CO₂ injection permit. As discussed above, project development license proceedings and CO₂ injection permit proceedings for projects that will be carried-out on split estates will be subject to the requirements outlined in Section 1.2.5 if the project applicant has not acquired the ownership interests, easements, or licenses necessary to occupy pore space on private lands through voluntary contract or state statutory authority.

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5.3.2.2 Environmental Review of Federal Actions Authorizing Geologic Sequestration of CO₂ on Federal Lands and Split Estates

The BLM should be the lead agency for the purpose of federal environmental review pursuant to the National Environmental Policy Act and, in consultation with all relevant agencies, should prepare a single environmental review document for each license application phase to be used as the basis for decisions under federal law related to each project phase. The environmental review for the project area license should only assess the likely environmental effects of the testing facilities to be constructed and operated under the terms of the license. The environmental effects of permanent geologic sequestration of CO₂ should not be considered for environmental review of the project area license. Instead, the environmental review for the project development license should assess the likely environmental effects of geologic CO₂ sequestration and the facilities and wells constructed for that purpose.

Chapter 6: Conclusions

If policymakers commit to the widespread deployment of CCS, project developers will need authorization to access and use subsurface pore space to avoid liability for subsurface trespass. This could involve protracted negotiations with hundreds, if not thousands, of individual property owners for each CCS project sought to be developed; it could also be as straight forward as receiving the appropriate regulatory approval to inject CO₂ for the purpose of permanent geologic CO₂ sequestration. The case law arising from industrial and commercial underground fluid injection operations is instructive of how subsurface property rights might be effectively dealt with in the context of geologic CO₂ sequestration. As is thoroughly discussed in Chapter 2, this body of case law shows that courts have consistently held certain underground fluid injection activities—i.e., enhanced hydrocarbon recovery, underground waste disposal, and freshwater storage and recharge—to be in the public interest and are thus protected from claims of subsurface trespass when 1) the activity is licensed under a state or federal regulatory program, and 2) the property owner could not demonstrate actual harm to, or interference with use and enjoyment of, the land occurred as a result of injection operations. So while courts have rejected any absolute protection of rights in the subsurface on the part of landowners, they have preserved limited landowner rights to use and exploit the subsurface and recover for actual harm or material impairments caused by subsurface invasions. Similarly, courts have been quite willing to allow landowners to sue for trespass and nuisance when airborne particles and pollution invade the landowner's airspace and cause harm. In these airspace pollution cases, courts looked to whether the invasion actually interfered with the plaintiff's use and enjoyment of the property or caused actual harm. In subsurface invasion cases, courts have looked at almost precisely the same factors

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and reached similar conclusions. In both these lines of cases, courts can be seen as having created a “liability rule”—which permits the violation of an entitlement without permission from the property owner so long as the violator pays damages for any harm caused—as opposed to a “property rule”—which permits the encumbrance of an entitlement only with permission of the property owner. Whether legislatures or the courts will apply a liability rule to geologic CO₂ sequestration remains an open and oft-debated question.

The legal complexity associated with acquiring pore space rights for GCS may be further exacerbated by the fact that subsurface CO₂ plumes to be very large in size, on the order of hundreds to thousands of square-kilometers in areal extent. Should the use of relatively thin sandstones with low mass-to-volume storage capacities—such as the Medina and Oriskany Sandstones—for GCS result in CO₂ plumes that are within the same order of magnitude in size as the very large plumes computed in this thesis (see Table 3.1 and accompanying text in Chapter 3), the cost of acquiring pore space rights, should compensation be required, could increase the overall cost of sequestration substantially (see Table 3.2 and Figure 3.3 and accompanying text in Chapter 3). An evaluation of pore space acquisition costs in complete isolation is only marginally informative, however; these expenses should be considered in the context of overall electric generation facility economics. The reality is that all geology-dependent CCS expenses—i.e., injection, sequestration, and pore space acquisition—may not be trivial and could greatly increase the overall cost of electricity, perhaps even rendering electric generation facilities capturing CO₂ for the purpose of permanent geologic sequestration in saline aquifers unprofitable.

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By targeting sequestration formations with geologic characteristics that are favorable for limiting CO₂ plume migration—e.g., thick formations with high porosity—injection, sequestration, and property rights acquisition costs may be considerably constrained. In spite of this, given current wholesale electricity prices, it is unlikely that independent power producers operating with CCS will successfully meet their revenue requirements without some form of subsidy. Of course, this conclusion is inapplicable to wholly regulated public utilities since they, in all likelihood, will be permitted to pass CCS-related expenses along to electricity customers, including those associated with CO₂ pipeline transport, injection, and pore space rights acquisition. Even so, it will be important for regulated utilities to carefully consider sequestration field geology when constructing an electric generation facility with CO₂ capture to ensure that customer electricity prices remain as low as possible. Thin formations with low porosities will likely lead to high injection costs, large CO₂ plumes, and high property rights acquisition costs, all of which will increase the levelized cost of operating a power plant with CO₂ capture and, in turn, customer electricity prices. In the case of the Medina and Oriskany Sandstones, the combined annualized cost of sequestration and property rights acquisition alone could increase the levelized cost of electricity for an electric generation facility by as much as \$15 to \$60 per MWh under the scenarios assessed in this thesis (see Table 4.3 and Figures 4.4 to 4.7 and accompanying text in Chapter 4). What is more, the cost of acquiring pore space rights could, under certain leasing scenarios, make up the majority of this increase.

Ultimately, the extent to which CO₂ sequestration is sought to be developed in areas where the subsurface is already being used commercially for natural gas storage, oil and gas

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production, or other uses, the cost of obtaining the rights to use subsurface pore space may be significant. In these scenarios, the value of compensation will be derived from the value of those rights as a function of the existing or future, investment-backed uses of the subsurface that would be precluded by GCS. In other cases though, where the geologic formation is appropriate for CO₂ sequestration but not for other commercial uses, the costs associated with acquiring pore space rights might be nominal or perhaps even zero because no economic use is precluded or impaired. A proxy for the intrinsic, monetized value of the right to use pore space not currently used for any economic purpose was derived as a function of the profitability of the IGCC facility with CO₂ capture modeled in this thesis. By so doing, it was shown that geo-sequestration targets with characteristics that will likely constrain CO₂ plume size could be more valuable per acre than those formations in which CO₂ will migrate over a very large area. However, electric generation facility owners/operators, whether they be independent power producers or wholly regulated utilities, will only be capable of compensating pore space owners if electricity prices are very high, which is unlikely in the short run, or if enough monetary benefit is accrued from the receipt of CO₂ sequestration credits to surpass the revenue requirements for the facilities (see Figures 4.9 to 4.11 and accompanying text in Chapter 4).

Clearly, if CCS is widely deployed, the cost of electricity and power plant profitability could be adversely affected by a legal requirement that pore space owners must be compensated in all circumstances. Moreover, absent unrealistically high electricity prices or some form of sequestration subsidy, pore space currently has no net-positive, intrinsic economic value which would be passed along to property owners from electric generators. Therefore, while

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paying property owners to use of pore space for geologic CO₂ sequestration may very well foster public acceptance and appease staunch private property rights advocates, there is no demonstrable legal or economic rationale for expansive protection of pore space rights for GCS and requiring compensation to property owners who have no current or non-speculative, investment-backed future use of the subsurface where pore space targeted for sequestration is located.

A pragmatic solution for constraining the potential logistical hurdles and negative economic effects associated with acquiring pore space rights for geologic CO₂ sequestration would be to restrict required compensation to only those instances where the injection and migration of CO₂ materially impairs current or non-speculative, investment-backed future uses of the subsurface. This could be accomplished through the creation of a federal framework for managing the access and use of pore space for geologic CO₂ sequestration. A state-based framework, while certainly possible, will have difficulty addressing problems related to sequestration under federal lands, sequestration in geologic reservoirs that cross state lines, and other interstate issues related to the transport and injection of CO₂ into the subsurface on the massive scale required to meaningfully address climate change. Foremost, federal legislation must specifically authorize the injection of CO₂ for the purpose of permanent sequestration into designated underground geologic reservoirs and declare that geologic CO₂ sequestration for the purpose of mitigating climate change is a “public use” carried out in the “public interest.” Additionally federal legislation governing large-scale CO₂ sequestration must also include provisions authorizing the Environmental Protection Agency and state Underground Injection Control permitting agencies to issue permits granting GCS developers

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the exclusive right to access and use pore space for the injection and sequestration of CO₂. No possessory interest in the pore space should be conveyed through the issuance of a pore space permit, only a perpetual easement to use the pore space for the sole purpose of CO₂ sequestration.

Such federal legislation should also create a presumption that the regulatory grant of the right to access and use pore space for geologic CO₂ sequestration does not amount to a compensable taking because the issuance of a pore space permit 1) does not effect a confiscation of property, and 2) is not the first step in a regulatory taking since pore space owners will unlikely suffer either an actual loss or an interference with any investment-backed expectation. However, this legislation should provide surface owners and mineral owners with an opportunity to rebut this presumption by presenting evidence in an administrative proceeding which demonstrates that CO₂ sequestration will result in a material impairment to a current or non-speculative, investment-backed future use of the subsurface, and that the property owner will suffer a consequent economic loss requiring just compensation. If it is demonstrated that a preexisting interest would be materially impaired by CO₂ injection, the geologic CO₂ sequestration project should be permitted only upon 1) a modification of the project that that avoids the impairment; 2) a contractual agreement between the owner of the preexisting interest and the project developer; 3) or a finding by the permitting agency that the condemnation of the preexisting interest through the exercise of eminent domain authority, with appropriate compensation, is necessary for the proper operation of the GCS project. Lastly, a claim of subsurface trespass should not be actionable against a project operator conducting geologic CO₂ sequestration in accordance with a valid

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permit. This approach, while perhaps contentious, is efficient as well as fair and equitable to both GCS project developers and private property owners and doctrinally sound.

The findings and conclusions drawn in this thesis are intended to help guide discussion, research, and decision-making processes undertaken by policymakers and industry leaders with respect to the commercial-scale deployment of CCS. A detailed analysis of takings and the anticipated long-term constitutional and economic implications of different approaches to pore space property rights governance is required before new laws, if any, are enacted at the federal or state levels. In addition, further work examining electric generation facility economics is necessary to understand how facility profitability and the cost of electricity might be affected if CCS is implemented under the specific and various climate and energy bills proposed in the House and Senate. In this vein, the short run and long run effects of CO₂ prices on the deployment of CCS as a function of the cost of electricity, existing generation facility dispatch order, fuel switching, and future technology changes in the generation fleet should be estimated. A detailed techno-economic analysis of the effects of GCS carried out in conjunction with enhanced hydrocarbon recovery on power plant economics is also needed. It is plausible to think that under current wholesale electricity prices the economics of GCS with EOR might be more favorable compared to GCS in saline aquifers. However, since CO₂ sequestration has traditionally been a secondary effect of oil recovery, a straight forward levelized cost analysis is not appropriate and is outside the scope of the work presented in this thesis. The models presented in this thesis should also be applied to additional site-specific geologic data for saline aquifer sequestration targets. It is the intention of this author to address these issues in future work.

Appendix A: CO₂ Plume Distribution Model—Input Parameters, Analytical Solution Derivation, and Model Sensitivity

Model Input Parameters

The model requires eight input parameters: formation depth, net thickness, porosity, permeability, salinity, temperature and pressure. Formation thickness, porosity, permeability, and depth can vary by several orders of magnitude among and within reservoirs and have large effects on injections rates. The parameterized and deterministic inputs to the model are show in Table A1.

Formation Depth, Net Thickness, Porosity and Salinity. Formation depth is the depth of the geological formation below the surface (meters). Formation thickness is the net thickness of the permeable zones of the geological formation (meters). Net thickness is used because formations typically have zones of high permeability inter-layered with low-permeability zones. Effective porosity is the percentage of the volume of connected pores in a unit volume of the formation. Porosity generally decreases with depth (*l*), but in this case, no statistically significant correlation between porosity and depth exists in the data for the four Pennsylvania and Ohio sandstones analyzed in this paper. Since the net thickness of high-permeability zones is used in this model, the effective porosity of high permeability zones is also used here. Salinity is the amount of dissolved NaCl in the interstitial pore water in the target formation, expressed as part per million by weight (ppm).

Formation Pressure. The relationship between pressure and depth is modeled as linear under hydrostatic conditions. At hydrostatic conditions, pressure typically increases at

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approximately 10 MPa/km. The relationship is expressed as:

$$P_d = G_p d + P_a \quad [MPa]$$

where P_d is pressure as a function of depth, G_p is the hydrostatic pressure gradient, 10 MPa/km, d is formation depth, and P_a is atmospheric pressure.

Formation Temperature. The relationship between temperature and depth is also modeled using a linear approximation. The average geothermal gradient is assumed to be approximately 25°C/km, but because actual temperature gradients vary somewhat from one region to another, a triangular distribution is assigned to the geothermal gradient for Monte Carlo simulations carried out in this analysis (see Table A1). The relationship between temperature and depth is expressed as:

$$T_d = G_T d + T_s \quad [K]$$

where T_d is temperature as a function of depth, G_T is the geothermal gradient, d is formation depth, and T_s is the surface temperature.

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Table A1: Model Input Parameters

	Depth (m)	Net Thickness (m)	Porosity (%)	Salinity (ppm)	Irreducible Brine Saturation (%)	CO ₂ Saturation ² (%)	Temperature Gradient (°C/km)
Frio Sandstone (TX)							
<i>Deterministic</i>	1,900	300	30	100,000	30%	70%	25
Mt. Simon Sandstone (IL)							
<i>Deterministic</i>	2,300	90 ¹	13	125,000	30%	70%	25
Medina Sandstone (PA)							
<i>Triangular: Min</i>	810	10	3%	100,000	30%	70%	20
<i>Max</i>	2,000	57	18%	250,000	90%	10%	50
<i>Mode</i>	1,500	20	8%	190,000	60%	40%	30
Volant Field							
<i>Deterministic</i>	1,800	26	18%	230,000	30%	70%	25
Oriskany Sandstone (PA)							
<i>Triangular: Min</i>	2,000	10	2%	250,000	30%	70%	20
<i>Max</i>	2,800	41	10%	350,000	90%	10%	50
<i>Mode</i>	2,700	13	5%	340,000	60%	40%	30
Clinton Sandstone (OH)							
<i>Triangular: Min</i>	830	11	7%	100,000	30%	70%	20
<i>Max</i>	1,700	20	10%	210,000	90%	10%	50
<i>Mode</i>	1,100	11	8%	130,000	60%	40%	30
E. Canton Consol.-S Field							
<i>Deterministic</i>	1,600	13	8%	200,000	30%	70%	25
Rose Run Sandstone (OH)							
<i>Triangular: Min</i>	830	10	8%	100,000	30%	70%	20
<i>Max</i>	2,300	12	10%	280,000	90%	10%	50
<i>Mode</i>	1,600	11	8%	200,000	60%	40%	30
Baltic Field							
<i>Deterministic</i>	1,900	12	10%	240,000	30%	70%	25

¹To provide a conservative estimate that accounts for uncertainty with respect to permeability and porosity in the Mt. Simon Sandstone at the Mattoon site, half the value of the gross thickness reported by the Illinois Geological Survey was used in this analysis (2,3).

²CO₂ saturation is not actually an input parameter to the plume distribution model, but rather the outcome resulting from the assumed parameterized irreducible brine saturation.

Irreducible Brine Saturation

Brennan and Burruss note that as the interstitial pore water that is not displaced by injected CO₂ (i.e., irreducible brine) in the sequestration reservoir increases, storage capacity (in mass per unit volume) decreases, and the areal extent of the CO₂ plume becomes larger (4).

Brennan and Burruss performed their storage capacity analysis applying irreducible water

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saturations at 5%, 50%, 75%, and 100% (4). Numerical simulations of CO₂ plume migration in the Frio injection project best match the observed behavior at irreducible brine saturations of between 15% and 30% (5). Therefore, values for irreducible brine saturation were parameterized [Triangular (90,30,60)] and input into the model.

CO₂ Plume Distribution Model: Analytical Solution Derivation (6)

Model predictions depend largely on the values of key parameters, which describe the properties of the formation and native fluids. Multiphase models solve a series of governing equations to predict the composition and volumetric fraction (i.e., the fraction of the formation pore space taken up by fluid) of each phase state (e.g., liquid, gas, supercritical fluid), as well as fluid pressures, as a function of location and time for a particular set of conditions.

The results obtained by Nordbotten et al. (2) agree broadly with Buckley-Leverett theory for small values of the dimensionless gravity factor, Γ . For convenience, their result is derived here using the similar assumptions—namely, effects of capillary pressure are negligible, fluids are incompressible, and the reservoir petrophysical properties are homogeneous—using arguments analogous to those used by Dake (7) for an unstable, horizontal displacement.

For a differential cylindrical volume of the system shown in Figure 3.1 of the paper, the volumetric balance on the CO₂ phase can be written:

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$$\varphi \frac{\partial \bar{S}_c(r,t)}{\partial t} + \nabla \cdot q_c(r,t) = 0 \quad (\text{Eq. A1})$$

where: \bar{S}_c is the vertically averaged saturation of CO₂, φ is the reservoir porosity, q_c is the flux of CO₂, r represents radial distance from the injection well, and t is time. Assuming drainage (i.e., CO₂ is displacing brine in a brine-wet reservoir), the vertically averaged saturation of CO₂, \bar{S}_c , is defined as:

$$\bar{S}_c = \beta(1 - S_{wc}) \quad (\text{Eq. A2})$$

Darcy's law for the brine and CO₂ phases can be written as:

$$q_c = -K\beta\lambda_c \nabla p_c \quad (\text{Eq. A3})$$

$$q_w = -K(1 - \beta)\lambda_w \nabla p_c \quad (\text{Eq. A4})$$

In Equations A3 and A4, K is the intrinsic permeability of the reservoir, β is the fraction of the reservoir thickness invaded by the CO₂ plume, λ_n is the mobility (k_r/u) for the CO₂ phase (c) or the brine phase (w), and ∇p is the pressure gradient.

Since the fluids are incompressible ($\nabla \cdot q = 0$), the flux into the system equals the flux out of the system and the total apparent flux, q_t , is:

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$$q_t = \frac{Q_{well}}{A} = q_c + q_w$$

where Q_{well} is the injection rate of CO₂ into the system and A is the area across which the flux

occurs. Assuming capillary pressure is negligible and, therefore $\nabla p_c = \nabla p_w = \nabla p$,

substituting Equations A3 and A4 yields:

$$\frac{Q_{well}}{A} = -K[\beta\lambda_c + (1-\beta)\lambda_w]\nabla p \quad (\text{Eq. A5})$$

Solving Equation A5 for pressure gradient results in:

$$\nabla p = -\frac{Q_{well}}{KA[\beta\lambda_c + (1-\beta)\lambda_w]}$$

which can then be substituted into Equation A3 to arrive at the flux of the CO₂ phase as a function of the injection rate.

$$\nabla p = \frac{\beta\lambda_c}{\beta\lambda_c + (1-\beta)\lambda_w} \left(\frac{Q_{well}}{A} \right) = f_c \frac{Q_{well}}{A} \quad (\text{Eq. A6})$$

In Equation A6, the term referred to as f_c is the fractional flow of the carbon dioxide phase in the system. Substituting this equation into the volumetric balance, Equation A1 yields:

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$$\varphi \frac{\partial \bar{S}_c}{\partial t} + \nabla \cdot \left(f_c \frac{Q_{well}}{A} \right) = 0$$

Writing the divergence operator for a cylindrical coordinate system gives:

$$\varphi \frac{\partial \bar{S}_c}{\partial t} + \frac{1}{r} \frac{\partial}{\partial r} \left(r f_c \frac{Q_{well}}{2\pi r h} \right) = 0$$

Simplifying results in:

$$\varphi \frac{\partial \bar{S}_c}{\partial t} + \frac{Q_{well}}{2\pi r h} \frac{\partial f_c}{\partial r} = 0 \quad (\text{Eq. A7})$$

Applying the chain rule to the fractional flow equation, the $\partial f_c / \partial r$ can be rewritten:

$$\frac{\partial f_c}{\partial r} = \frac{\partial f_c}{\partial \bar{S}_c} \times \frac{\partial \bar{S}_c}{\partial r} = f'_c \frac{\partial \bar{S}_c}{\partial r}$$

Upon substitution into Equation A7, a statement of the Buckley-Leverett equation for a radial system is reached:

$$\frac{\partial \bar{S}_c}{\partial t} + \frac{Q_{well} f'_c}{2\pi r h \varphi} \frac{\partial \bar{S}_c}{\partial r} = 0 \quad (\text{Eq. A8})$$

This equation was solved by Woods and Comer (8) for the boundary conditions $r = r_w$ at $t = 0$, resulting in:

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$$r(\bar{S}_c) = \sqrt{\frac{f'_c Q_{well} t}{\pi h \varphi} + r_w^2} \quad (\text{Eq. A9})$$

If vertically averaged saturation of the CO₂ phase was not assumed (i.e., Eq. A4), determination of f'_c would require an assumption of the shape of the relative permeability curves for the CO₂-brine system and particular reservoir rock. However, operating under the assumption saturation is a linear average of phase saturations (i.e., Eq. A2), f'_c can be expressed via the chain rule as:

$$f'_c = \frac{df'_c}{d\beta} \times \frac{\partial \beta}{d\bar{S}_c} = \frac{\lambda_w \lambda_c}{[\lambda_w + \beta(\lambda_c - \lambda_w)]^2} \left(\frac{1}{1 - S_{wc}} \right)$$

Substituting this into the above equation, an expression for the radial distance as a function of the fraction of the formation height invaded by the CO₂ plume is reached:

$$r(\beta) = \sqrt{\frac{\lambda_w \lambda_c Q_{well} t}{\pi h \varphi (1 - S_{wc}) [\lambda_w + \beta(\lambda_c - \lambda_w)]^2} + r_w^2} \quad (\text{Eq. A10})$$

Assuming the injection well radius is much smaller than the radius of the CO₂ plume, the maximum extent of the CO₂ plume occurs at $\beta = 0$:

$$r_{\max} = \sqrt{\frac{\lambda_c V}{\pi h \varphi \lambda_w (1 - S_{wc})}} \quad [m] \quad (\text{Eq. S11})$$

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In the situation where the dimensionless gravity factor, Γ , is large, the solution presented in Equation A11 under predicts the extent of migration of the CO₂-brine interface. However, after incorporating the effects of buoyancy into the derivation (and making the same assumptions as above) Nordbotten et al. arrived at:

$$r_{\max} = \sqrt{\frac{(\lambda - 1)V}{2\pi\Lambda h\phi(1 - S_{wc})}} \quad [m] \quad (\text{Eq. A12})$$

where λ is the mobility ratio for the displacement (λ_c/λ_w), and Λ is the Lagrangian multiplier. The Lagrangian multiplier, Λ , comes from the numerical solution of:

$$\Lambda(\lambda - 1)^2 - \Gamma(\lambda - 1) + \Gamma\lambda \ln\left(\frac{\Gamma + \Lambda}{\Lambda\lambda}\right) = \frac{2\lambda[\Lambda(\lambda - 1) - \Gamma]}{\lambda - 1} \quad (\text{Eq. A13})$$

Estimated Oil & Gas Field CO₂ Sequestration Capacities in the MRCSP

Region

Table A2: Oil & Gas Field CO ₂ Sequestration Capacities in the MRCSP Region (9,10)				
Producing Formation	Field Name	State	Field Size (km ²)	GS Potential (million tonnes)
Medina	Volant	PA	130	310
Clinton	E. Canton Consolidated-S	OH	490	250
Rose Run	Baltic	OH	340	230

CO₂ Plume Size Results

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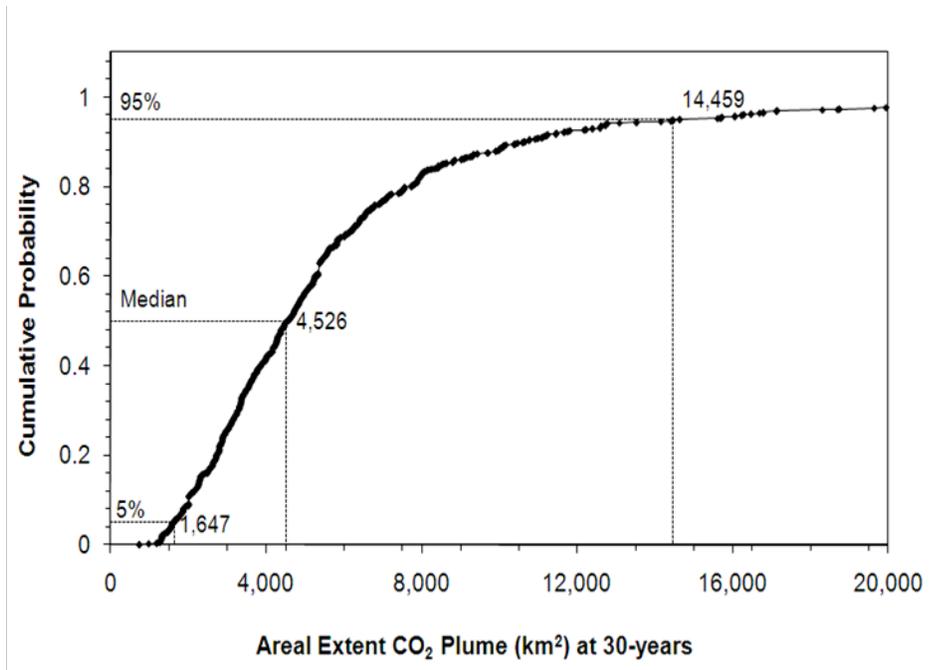


Figure A1: Medina Sandstone estimated CO₂ plume footprint using the Nordbotten et al. solution.

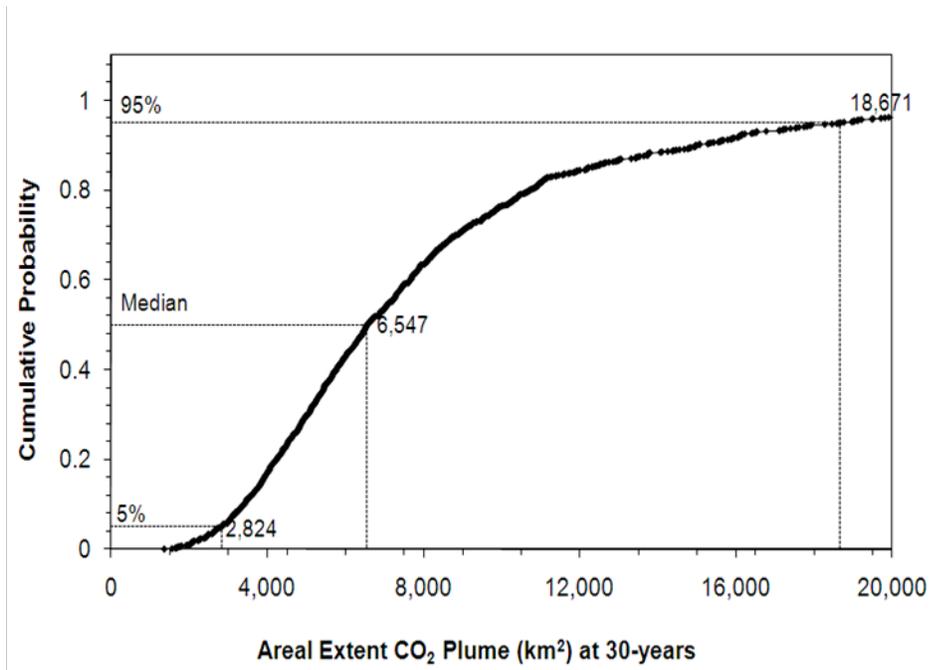


Figure A2: Oriskany Sandstone estimated CO₂ plume footprint using the Nordbotten et al. solution.

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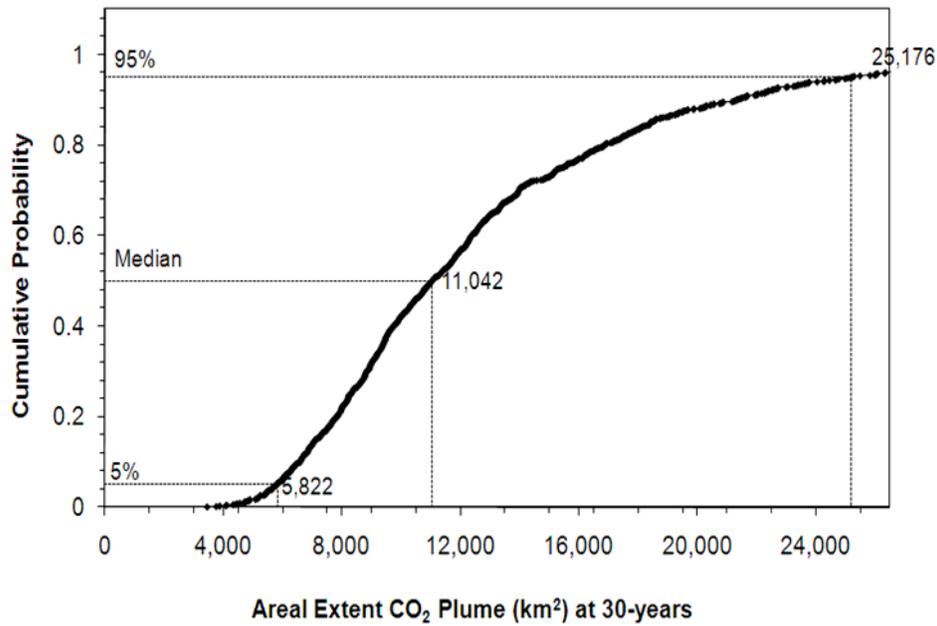


Figure A3: Clinton Sandstone estimated CO₂ plume footprint using the Nordbotten et al. solution.

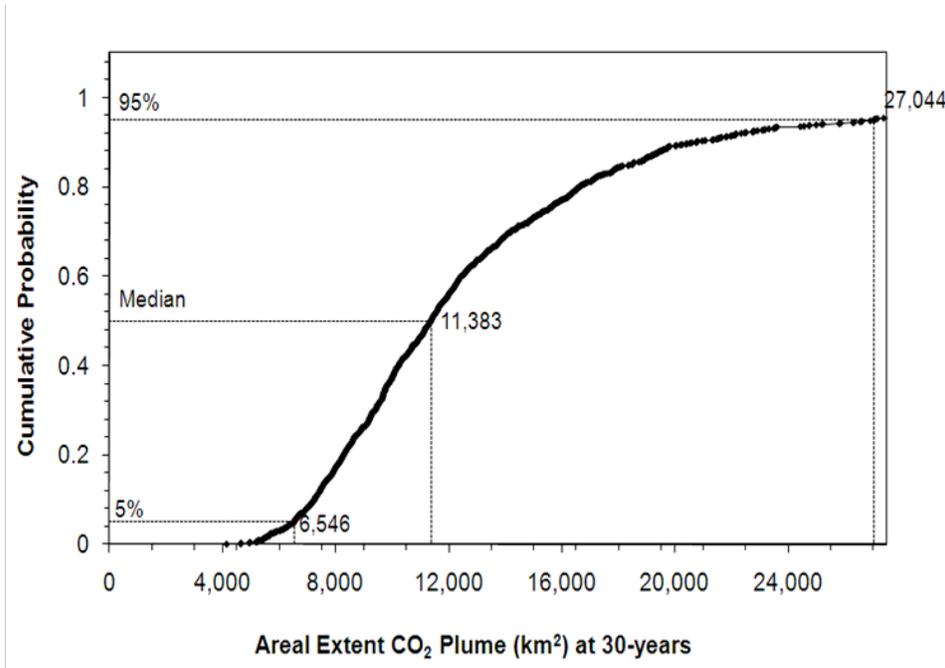


Figure A4: Rose Run Sandstone estimated CO₂ plume footprint using the Nordbotten et al. solution.

CO₂ Plume Model Sensitivity

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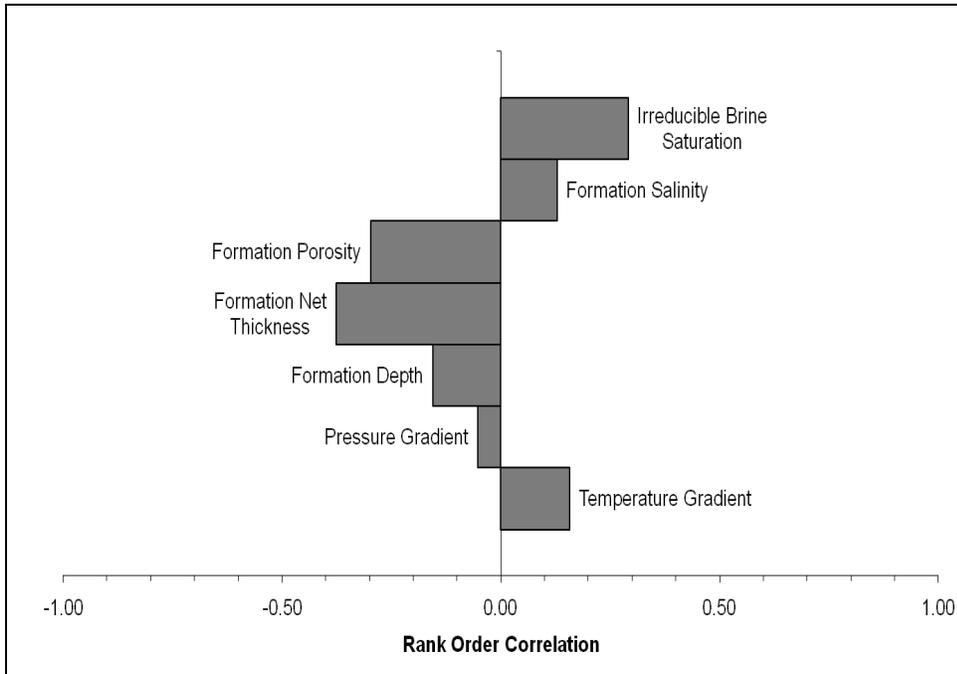


Figure A5: Medina Sandstone rank order correlation between the results of the Monte Carlo sensitivity analysis and the parameters assigned triangular distributions.

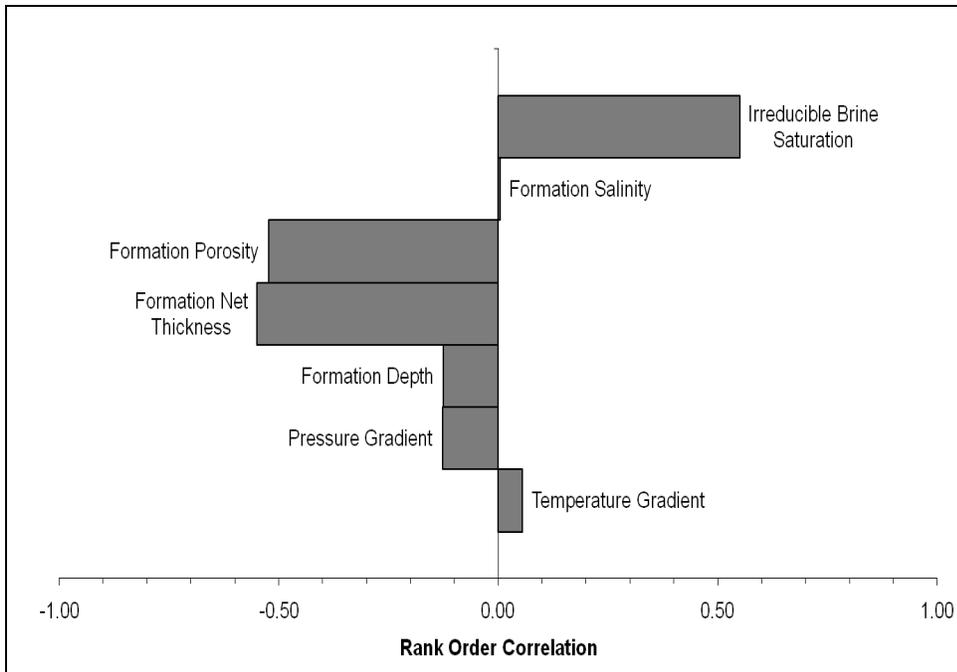


Figure A6: Oriskany Sandstone rank order correlation between the results of the Monte Carlo sensitivity analysis and the parameters assigned triangular distributions.

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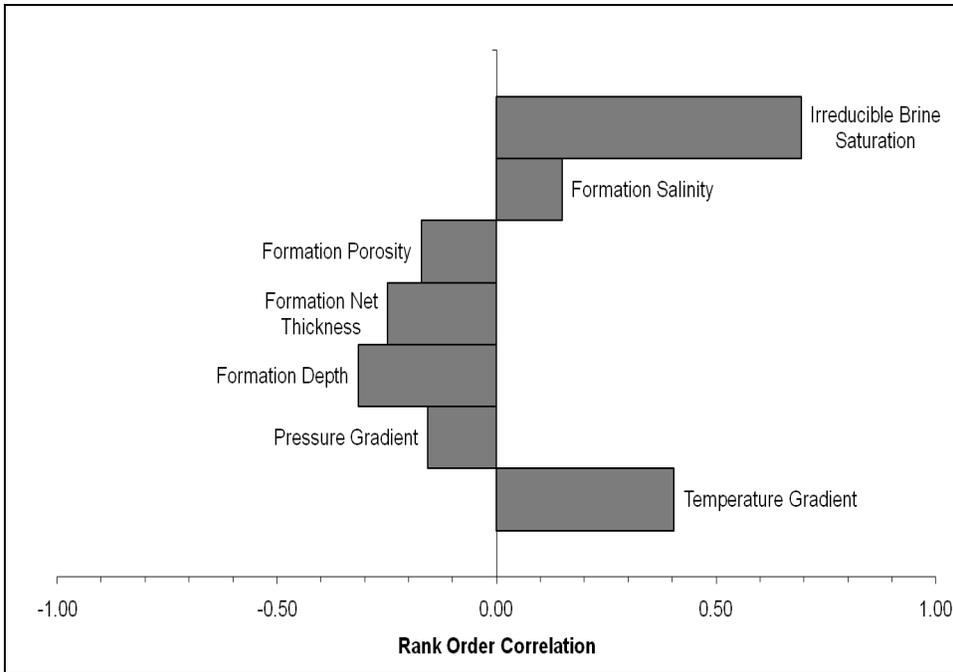


Figure A7: Clinton Sandstone rank order correlation between the results of the Monte Carlo sensitivity analysis and the parameters assigned triangular distributions.

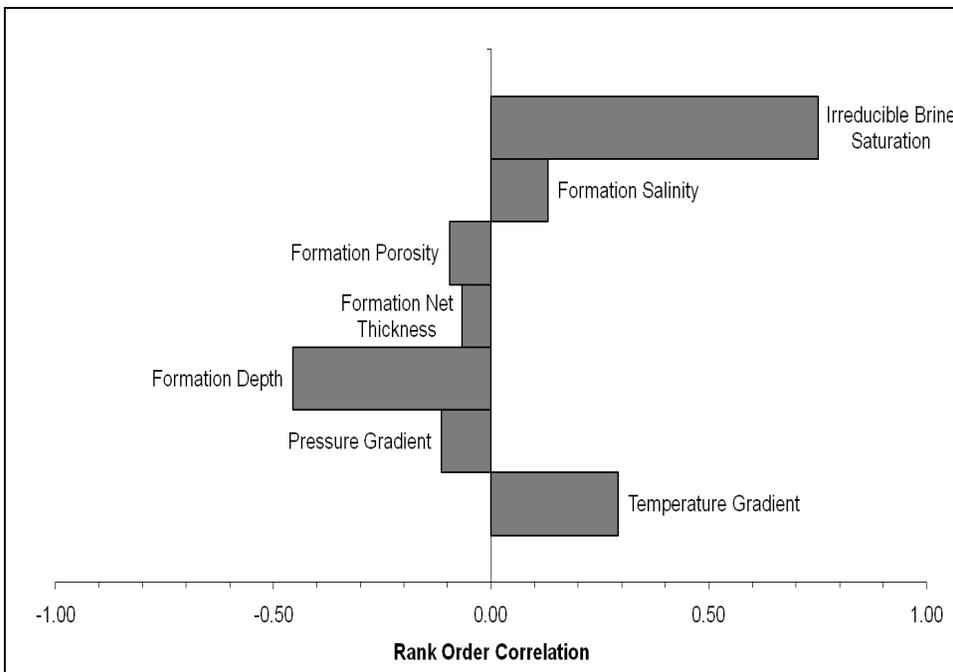


Figure A8: Rose Run Sandstone rank order correlation between the results of the Monte Carlo sensitivity analysis and the parameters assigned triangular distributions.

Pipeline Model Annualized Costs

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Table A3: Pipeline Annualized Costs					
	Pipeline Length		Proportion of	Annualized Cost	
	(km)	(miles)	Total Pipeline Length	(\$/yr)	(\$/tonne)
			(%)		
Volant, PA to Mattoon, IL					
(2 segments; 1 booster station)					
<i>Northeast Region</i>	20	12	3%	\$47,000,000	\$8.6
<i>Capital Cost</i>				\$44,000,000	
<i>Operational Cost</i>				\$2,500,000	
<i>Energy Cost for Booster</i>				\$500,000	
<i>Midwest Region</i>	690	429	97%	\$41,000,000	\$7.5
<i>Capital Cost</i>				\$38,000,000	
<i>Operational Cost</i>				\$2,500,000	
<i>Energy Cost for Booster</i>				\$500,000	
Total	710	441		\$41,180,000	\$7.6
Volant, PA to Jackson, MS					
(4 segments; 3 booster stations)					
<i>Northeast Region</i>	20	12	1%	\$117,000,000	\$21.5
<i>Capital Cost</i>				\$109,000,000	
<i>Operational Cost</i>				\$6,450,000	
<i>Energy Cost for Booster</i>				\$1,000,000	
<i>Midwest Region</i>	310	193	16%	\$103,000,000	\$18.9
<i>Capital Cost</i>				\$96,000,000	
<i>Operational Cost</i>				\$6,450,000	
<i>Energy Cost for Booster</i>				\$1,000,000	
<i>Southeast Region</i>	970	603	49%	\$113,000,000	\$20.8
<i>Capital Cost</i>				\$105,000,000	
<i>Operational Cost</i>				\$6,450,000	
<i>Energy Cost for Booster</i>				\$1,000,000	
Jackson, MS to TX Gulf Coast					
(No new construction required)					
<i>Southeast Region</i>	160	99	8%	\$7,400,000	\$1.4
<i>Operational Cost</i>				\$6,450,000	
<i>Energy Cost for Booster</i>				\$1,000,000	
<i>Southwest Region</i>	540	336	27%	\$7,400,000	\$1.4
<i>Operational Cost</i>				\$6,450,000	
<i>Energy Cost for Booster</i>				\$1,000,000	
Total	1,860	808		\$74,526,000	\$13.7

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Appendix B: Model Framework for Pore Space Access & Use

TITLE I—Injection PERMITS AND PORE SPACE ACCESS FOR GEOLOGIC CO₂ SEQUESTRATION PROJECTS

SUBTITLE A—GENERAL

SEC. 101. DEFINITIONS

For the purposes of this title:

(a) CO₂ INJECTION PERMIT.—The term “CO₂ Injection Permit” refers to a UIC permit issued by the UIC CO₂ Regulator under subtitle B for the permanent geologic sequestration of carbon dioxide.

(b) INTERSTATE GEOLOGIC SEQUESTRATION PROJECT.—The term “interstate geologic sequestration project” means a geologic sequestration project that will require the use of pore space located in more than one State.

(c) SDWA.—The term “SDWA” means the Safe Drinking Water Act.

(d) SUBSURFACE PROJECT BOUNDARY.—The term “subsurface project boundary” refers to the ex ante estimated spatial extent of free-phase injected CO₂, delineated both by the lateral and vertical boundaries from the time injection commences to the time that free-

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phase CO₂ ceases flowing, and taking into account a margin of error in predictions.

(e) UIC.—The term “UIC” means underground injection control.

(f) UIC CO₂ REGULATOR.—Except as provided in section 112(f) of this title, the term “UIC CO₂ Regulator” means a State that has primary enforcement authority under section 1422 of the SDWA for the underground injection of carbon dioxide, and the Administrator of the Environmental Protection Agency for any other State.

(g) UNDERGROUND SOURCE OF DRINKING WATER.—The term “underground source of drinking water” means underground water with less than 10,000 mg/l total dissolved solids.

SEC. 102. SEVERABILITY OF PROVISIONS.

If any provision of this act, or the application of any provision of this act to any person or circumstance, is held invalid, the application of such provision to other persons or circumstances and the remainder of this act shall not be affected thereby.

SUBTITLE B—PERMITS TO CONSTRUCT AND OPERATE GEOLOGIC SEQUESTRATION PROJECTS

SEC. 111. PURPOSE.

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The purpose of this title is to establish a permitting procedure for the permanent geologic sequestration of carbon dioxide that balances the need for permanent geologic sequestration of CO₂ with the need to protect underground drinking water supplies so as to ensure the overall safety and protection of human health and the environment.

SEC. 112. PERMITTING UNDERGROUND INJECTION OF CARBON DIOXIDE FOR GEOLOGIC SEQUESTRATION.

(a) CO₂ UIC PROGRAM.—Not later than one year after the date of enactment of this Act, the Administrator shall promulgate regulations that provide for a comprehensive program for the administration of permits for underground injection of carbon dioxide for the purpose of geologic sequestration, and that integrate such program with existing State and Federal UIC programs.

(b) PERMIT REQUIRED.—Except in accordance with a CO₂ injection permit issued by the UIC CO₂ Regulator under subsection (e), the following shall be unlawful:

- (1) The construction of any injection well or underground facility for geologic sequestration, and
- (2) The underground injection of carbon dioxide for geologic sequestration.

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(c) PROGRAM REQUIREMENTS.—The regulations under subsection (a) shall:

(1) provide that the UIC CO₂ Regulator shall issue a CO₂ injection permit in accordance with subsection (e) to any applicant that meets the requirements of this section;

(2) require, to the extent practicable, that the UIC CO₂ regulator take an adaptive and performance-based approach to permitting the underground injection of carbon dioxide for permanent geologic sequestration;

(3) require that the applicant for the CO₂ injection permit satisfy the UIC CO₂ Regulator that the underground injection of carbon dioxide for permanent geologic sequestration will not endanger drinking water sources, unless the UIC CO₂ Regulator makes a SDWA applicability determination under subsection (d);

(4) require States seeking primary enforcement authority under the UIC program for permanent geologic sequestration of CO₂ to develop a framework and codify statutory authority for acquiring the necessary ownership interests, easements, or licenses necessary to occupy pore space.

(5) require State UIC programs to take into account the effects that permanent geologic sequestration of CO₂ in the permitting State will have in any other State; and

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(6) ensure that any State with a reasonable prospect of being affected by the grant of a CO₂ injection permit by another State shall have the right to intervene and participate in proceedings conducted by the permitting State for consideration of a petition of a permit for underground injection of CO₂ for permanent geologic sequestration.

(7) include requirements for—

(A) inspection, monitoring, recordkeeping, and reporting for carbon dioxide associated with injection into, and loss of containment from, sequestration sites that consider:

(i) the specific geologic setting,

(ii) the design and operation of the sequestration project,

(iii) surface features, including political and property boundaries,

(iv) other considerations as determined by the Administrator,

(B) public participation in the permitting process that maximizes transparency,

(C) sharing of data among States, the United States Geologic Survey, and the Environmental Protection Agency, and

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(D) other elements or safeguards necessary to conform to the requirements described in subsection (c) of this section;

(8) require enhanced hydrocarbon recovery projects to hold a valid CO₂ injection permit in order to be considered a geologic sequestration project for the purposes of any federal greenhouse gas emissions reduction program; and

(9) establish a coordinated approach to certifying and permitting underground injection of CO₂ for permanent geologic sequestration, taking into account, and reducing redundancy with, all relevant statutory authorities.

(d) SDWA DETERMINATION.—

(1) DEFINITION.—For purposes of this section, a SDWA determination is a determination that one or more provisions of Part C of the Safe Drinking Water Act are inapplicable in whole or in part to a specific source of underground drinking water affected by the CO₂ injection permit.

(2) DETERMINATION.—The UIC CO₂ Regulator may make a SDWA determination only if the regulator finds that the public benefit of geologic sequestration of carbon dioxide outweighs the protection of the underground drinking water source at issue after carefully balancing the goals of:

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(A) minimizing the present and future threats to human health and the environment imposed by global climate change with

(B) the protection and safety of underground drinking water sources.

(3) FACTORS.—In making a SDWA determination, the CO₂ Regulator shall consider:

(A) direct and indirect impacts to underground sources of drinking water and human health and the environment resulting from geologic sequestration of carbon dioxide,

(B) local impacts of potential surface leakage of sequestered carbon dioxide, assessing both probability and magnitude of potential harm,

(C) the nation's need to deploy and use CCS technology to control GHG emissions, and

(D) any other factors as the UIC CO₂ regulator determines to be relevant.

(e) OPEN APPLICATION FOR AND ISSUANCE OF CO₂ INJECTION PERMITS.—

(1) Application for a CO₂ injection permit shall be made in writing to the UIC CO₂ Regulator. This application shall be

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verified under oath and be in such form and contain such information as the Administrator shall, by regulation, require.

(2) If a geologic sequestration project developer applies for CO₂ injection permit under this subtitle, the UIC CO₂ Regulator shall:

(A) Publish in the Federal Register and provide such additional public notice as the UIC CO₂ Regulator shall require.

(B) Afford a period of 90 days for geologic sequestration project developers and operators who wish to contend that the grant of a CO₂ injection permit under this subtitle and, if applicable, a pore space permit under subtitle C may impair their ability to develop and operate an alternative and potentially competing geologic sequestration project, or impair the operation of a currently operating geologic sequestration project to intervene and file a competing application, such that:

(i) Interveners shall be entitled to equal consideration with the original applicant if they file a competing application within 90 days of public notice for the original application.

(ii) If a competing application is filed more than 90 days after the original application, the

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original application shall be considered and resolved upon its own merits without the necessity of consideration of the secondary competing application.

(iii) If the losing applicant, prior to filing its application, acquired the ownership interests, easements, or licenses necessary to occupy pore space through state statutory authority or voluntary contract, the prevailing applicant must compensate the losing applicant for all expenses incurred in securing rights to occupy the pore space. Upon payment, all rights and interests in the pore space as well as obligations to landowners will be transferred to the prevailing applicant.

(3) The UIC CO₂ Regulator shall have the authority to attach to the issuance of the CO₂ injection permit, and to exercise the rights and privileges granted thereunder, such terms and conditions as are reasonable and necessary to effectuate the purposes of this title.

(4) The UIC CO₂ Regulator shall grant applications under this subsection upon a finding that the applicant is able and willing to properly do the acts and perform the service proposed in good faith, meet all relevant statutory and

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regulatory-imposed financial responsibilities and requirements, and conform to the requirements of this title, the rules thereunder, and the conditions of the CO₂ injection permit; otherwise, such application shall be denied.

(5) The UIC CO₂ Regulator may, after notice and opportunity for comment, revoke in whole or in part a UIC CO₂ injection permit issued under this section if the Regulator determines that the permit-holder has failed to comply with the requirements of this title, the rules thereunder, or conditions of the permit.

(6) EPA shall have authority to revoke or override any CO₂ injection permit issued by a State UIC CO₂ Regulator if:

(A) the State UIC CO₂ Regulator fails to take into account the effects that permanent geologic sequestration of CO₂ in the permitting State will have in any other State; and

(B) the permanent geologic sequestration of CO₂ as authorized by the permit is determined to substantially endanger underground sources of drinking water (unless a SDWA determination is made under subsection (d)) and/or pose a threat to human health and the environment in neighboring States.

(f) INTERSTATE GEOLOGIC SEQUESTRATION PROJECTS.—

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(1) States may enter into agreements with respect to permitting and regulating a geologic sequestration project that will require the use of geologic formations and pore space located in more than one State.

(2) The EPA is the UIC CO₂ Regulator for any interstate geologic sequestration project if the States where the project is located fail to enter into an agreement with respect to permitting and regulating the interstate project.

SEC. 113. CONFORMING AMENDMENTS.

(a) ENERGY INDEPENDENCE AND SECURITY ACT.—
The first sentence of section 706 of Title VII of the Energy Independence and Security Act (42 U.S.C. § 17254) is amended—

(1) by striking out “The” at the beginning of the first sentence and inserting “Subject to Title I of the Carbon Capture and Sequestration Regulatory Act of 2010, the”; and

(2) by striking out “Nothing” at the beginning of the second sentence and inserting “Subject to such title, nothing”.

(b) SAFE DRINKING WATER ACT.—

(1) Section 1421(b)(1) of the Safe Drinking Water Act of 1974 as amended (42 U.S.C. § 300h) is amended by:

(A) inserting at the beginning of subparagraph (B) “except as provided in section 112(d) of the Carbon Capture and Sequestration Regulatory Act of 2010,” and

(B) inserting a new subparagraph “(E)”, which shall read “Shall meet all requirements of the regulations in effect under Title I of the Carbon Capture and Sequestration Regulatory Act of 2010.”

(2) Section 1422(b)(1)(A)(i) of the Safe Drinking Water Act (42 U.S.C. § 300h-1) is amended by inserting at the end thereof “and Title I of the Carbon Capture and Sequestration Regulatory Act of 2010.”

SUBTITLE C—ACCESS TO PORE SPACE FOR GEOLOGIC SEQUESTRATION

SEC. 121. PURPOSE.

The purpose of this subtitle is to establish a fair, equitable, and elective permitting procedure for the allocation, management, and use of subsurface pore space for permanent geologic sequestration of carbon dioxide, thereby reducing carbon dioxide emissions to the atmosphere; and, to the maximum extent practicable, protecting private property interests and preventing subsurface property disputes from arising.

SEC. 122. DEFINITIONS.

For the purpose of this subtitle:

(a) **MATERIAL IMPAIRMENT.**—The term “material impairment” means the subsurface interest-holder has suffered actual and

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substantial damages resulting from the injection or migration of carbon dioxide.

(b) NON-SPECULATIVE ECONOMIC INTEREST.—The term “non-speculative economic interest” means the ability to recover actual mineral resources or engage in other current or imminent subsurface activities that have substantial economic value. It shall be presumed, subject to rebuttal, that use of pore space for which a CO₂ injection permit is required under subtitle B is a speculative interest until such a permit is issued. This presumption shall be overcome if the geologic strata containing the pore space is actively being characterized and tested for the purposes of developing a geologic sequestration project *and* the ownership interests, easements, or licenses necessary to use the pore space for permanent geologic sequestration of CO₂ have been acquired by the project developer either through State statutory authority or voluntary contract.

(c) PORE SPACE PERMIT.—The term “pore space permit” refers to a permit issued by the UIC CO₂ Regulator under subtitle C authorizing the exclusive right to access and use pore space for the permanent geologic sequestration of CO₂ within the subsurface project boundary. A pore space permit has the effect of a perpetual easement.

(d) PREEXISTING INTEREST.—The term “preexisting interest” means an interest in demonstrated economically-recoverable mineral

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resources or in other subsurface activities that are non-speculative economic interests.

(e) **SUBSURFACE TRESPASS.**—The term “subsurface trespass” means geologic sequestration by a site operator that results in a physical invasion of pore space in which the site operator does not have the requisite ownership interest, easement, or license to occupy.

SEC. 123. MANAGING ACCESS AND USE OF PORE SPACE FOR PERMANENT GEOLOGIC SEQUESTRATION OF CARBON DIOXIDE.

(a) **EFFECT OF CO₂ INJECTION PERMIT.**—

(1) If a CO₂ injection permit issued to a site operator under subtitle B is in effect, no permit may be issued to any other person to inject CO₂ for the purposes of geologic sequestration within the subsurface project boundary defined in the existing permit, unless the existing permit provides otherwise.

(2) A CO₂ injection permit under subtitle B does not relieve the site operator of any liability for failure to obtain the ownership interests, easements, or licenses necessary to occupy pore space unless the CO₂ injection permit incorporates a pore space permit issued under this section.

(b) **REGULATIONS.**—Not later than one year after the date of enactment of this Act, the Administrator shall promulgate rules and procedures for allocating and managing the use of subsurface pore

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space for the purpose of permanent geologic sequestration of CO₂, and shall integrate the administration of these rules and procedures with existing State and Federal UIC programs such that if a pore space permit is issued under this section in connection with a CO₂ injection permit, the pore space permit conveys the exclusive Federal privilege to access and use of pore space for geologic sequestration of carbon dioxide within the subsurface project boundary defined by the permit.

(c) APPLICATION FOR PORE SPACE PERMIT.—If a CO₂ injection permit applicant seeks to develop a geologic sequestration project in a State (or States) that has (or have) not codified statutory authority for acquiring and using pore space for permanent geologic sequestration of CO₂ *and* the applicant has not acquired through voluntary contract the ownership interests, easements, or licenses necessary to occupy pore space, the project developer, in connection with an application for a CO₂ injection permit under subtitle B, may include a request for a pore space permit.

(1) If a request is made for a pore space permit, the UIC CO₂ Regulator shall:

(A) Publish the request in the Federal Register and provide such additional public notice as the UIC CO₂ Regulator shall require, and

(B) afford a period of 60 days for participation in the permit application proceeding to all interested parties

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and holders of preexisting interests that would be materially impaired by the granting of the pore space permit.

(2) If an interested party or the holder of a preexisting interest fails to intervene in the pore space permit application not later than the date of filing of notice paragraph (1)(A):

(A) Except as provided in subparagraph (B), such party shall be deemed to have waived any and all rights and property interests that become impaired by the project that is the subject of the proceeding should a pore space permit be issued by the UIC CO₂ Regulator.

(B) An interested party or the holder of a preexisting interest may be permitted late intervention in a proceeding under this section upon a showing of good cause.

(3) A competing geologic sequestration project applicant who intervenes under paragraph (1)(B) must indicate their intention to file a competing CO₂ injection permit application within 90 days of the original project application in accordance with section 112(e)(2)(B) of subtitle B.

(d) CONSIDERATION OF PREEXISTING INTERESTS IN SCOPE OF PROJECT.—

(1) If it is demonstrated that a preexisting interest would be materially impaired by the granting of a CO₂ injection permit

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for permanent geologic sequestration of carbon dioxide, the geologic sequestration project should be permitted only in accordance with:

(A) a modification of the project that avoids the impairment;

(B) a contractual agreement between the owner of the preexisting interest and the project applicant; or

(C) a finding by the UIC CO₂ Regulator that condemnation of the preexisting interest through the exercise of eminent domain pursuant to subsection (e) of this subtitle, with appropriate compensation, is necessary to the proper operation the geologic sequestration project under application.

(2) In connection with a pending application proceeding for geologic sequestration of carbon dioxide under this subsection, the UIC CO₂ Regulator may exclude from the subsurface project boundary, or authorize the exercise of eminent domain under subsection (e) for, any portion of a geologic formation where the formation is:

(A) subject to active and properly licensed exploration or production of hydrocarbon or hard minerals resources;

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(B) actively used for the properly licensed injection of brines or other fluids for the purpose of enhanced recovery of hydrocarbon resources;

(C) actively used for storage of crude oil;

(D) actively used for injection of fluid wastes or municipal wastewater for disposal pursuant to a valid UIC permit;

(E) actively used for certificated natural gas storage;

(F) actively used for properly licensed groundwater recovery and storage;

(G) actively used for properly licensed compressed air energy storage;

(H) actively used for geothermal electric power generation;

(I) actively being subjected to geophysical and environmental testing for the purpose of developing a geologic sequestration project, provided that the ownership interests, easements, or licenses necessary to occupy the pore space for permanent geologic sequestration of CO₂ have been acquired by the project developer either through State statutory authority or voluntary contract; or

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(J) actively used for other purposes the UIC CO₂

Regulator deems relevant.

(e) RIGHT OF EMINENT DOMAIN.—When the UIC CO₂ Regulator finds that condemnation of a preexisting interest is necessary to the proper operation of the geologic sequestration project under application:

(1) the holder of a CO₂ injection permit to whom a pore space permit was issued under subsection (c) of this subtitle, when it cannot acquire by contract, or is unable to agree with the owner of the preexisting interest to the compensation to be paid for the necessary surface and subsurface property rights to construct, operate, and maintain underground wells and facilities for the permanent sequestration of carbon dioxide, may acquire the same by the exercise of the right of eminent domain in the district court of the United States for the district in which such property interest is located; and

(2) the practices and procedures in any action or proceeding for that purpose in the United States shall conform as nearly as possible with the practices and procedures in a similar action or proceeding in the courts of the State where the property is situated.

(f) DOMINANCE OF MINERAL ESTATE.—

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(1) The provisions of this subtitle shall not be deemed to preempt the mineral rights laws of any State, except to the extent necessary to ensure that mineral exploration and production activities will not cause leakage of permanently sequestered carbon dioxide, or compromise the integrity of the geologic sequestration site.

(2) The holder of a State-law right to conduct mineral exploration or production activities shall not be entitled to compensation as a result of any such activities being precluded or restricted, to the extent necessary, to protect the integrity of the geologic sequestration site.

(3) As with all other property interests, mineral rights are subject to condemnation through the exercise of eminent domain under this subtitle.

(g) FEDERAL REMEDY FOR CLAIMS OF SUBSURFACE

TRESPASS.—

(1) A claim of subsurface trespass shall not be actionable against a site operator conducting geologic sequestration in accordance with a valid CO₂ injection permit issued by the UIC CO₂ Regulator and to whom a pore space permit has been issued under subsection (c) of this subtitle unless the injection or migration of carbon dioxide materially impairs:

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(A) preexisting interests that were identified to the UIC CO₂ Regulator during permit proceeding pursuant to subsections (c) and (d) of this subtitle or

(B) interests outside the subsurface project boundary.

(2) The issuance of a CO₂ injection permit shall not protect a site operator from claims of subsurface trespass if the injection or migration of carbon dioxide materially impairs preexisting interests established during the permit proceeding that have not been compensated via a contractual agreement between the owners of the preexisting interests and the project applicant, or condemned through the valid exercise of eminent domain pursuant to subsection (e) of this subtitle.

(3) A surface or subsurface property interest-holder shall be permitted to recover money damages only for loss of a non-speculative value resulting from the injection and migration of carbon dioxide.

(A) The standard for calculating money damages shall be the present value of the demonstrated impairment, or the otherwise expected value of the future income stream that would have accrued had the interest not been impaired.

(B) Punitive damages shall be barred if the site operator who causes the material impairment acts in compliance with the terms of the CO₂ injection permit.

(C) Any damage award shall be discounted by the cost of the mineral extraction or current and actual subsurface activity

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that is not a result of impairments caused by the injection and migration of carbon dioxide.

(4) Injunctive relief for subsurface trespass shall not be allowed unless the holder of the property interest shows that the harm to the property interest clearly outweighs the utility of the sequestration of carbon dioxide.

(5) The United States district court for the district in which a trespass claim arises shall have exclusive jurisdiction over such a claim, and the United States Court of Appeals for the District of Columbia shall hear any appeal of a district court ruling under this subsection.

(h) PHYSICAL AND REGULATORY TAKINGS.—

(1) Any claim for a physical or regulatory taking without just compensation that arises out of an action by the United States or a State under this title shall be filed against the United States in the United States Court of Federal Claims pursuant to chapter 91 of title 28 of the United States Code.

(2) No such claim may be filed against a State by reason of its action as a UIC CO₂ Regulator in accordance with this title.

SUBTITLE D—GEOLOGIC SEQUESTRATION OF CARBON DIOXIDE ON FEDERAL LANDS

SEC. 131. PURPOSE.—

The purpose of this section is to expressly authorize the Secretary of the Interior, through the Bureau of Land Management, to license the use of Federal lands for the permanent geologic sequestration of carbon dioxide.

SEC. 132. DEFINITIONS.

For the purposes of this subtitle:

(a) BLM.—The term “BLM” means the Bureau of Land Management.

(b) FEDERAL LANDS.—The term “Federal lands” refers to lands managed by the BLM and FS that have been determined by each agency to be available for use for permanent geologic sequestration of carbon dioxide.

(c) FS.—The term “FS” means the Forestry Service.

(d) PLAN OF DEVELOPMENT.—The term “Plan of Development” means a detailed description of the design of the geologic sequestration project and its facilities submitted by a project development license applicant to the BLM. The Plan of Development

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helps the BLM assess the public safety and environmental effects of the proposed geologic sequestration project and its facilities.

(e) SECRETARY.—Unless otherwise specified, the term “Secretary” means the Secretary of the United States Department of the Interior.

(f) SPLIT ESTATE.—The term “split estate” means lands in which the Federal government owns the surface rights, but the mineral rights are privately owned.

SEC. 133. PERMITTING AND LICENSING GEOLOGIC SEQUESTRATION ON FEDERAL LANDS.

(a) REGULATIONS.—Not later than one year after the date of enactment of this title, the Secretary shall promulgate rules and procedures for allocating and managing the use of deep subsurface pore space for the purpose of geologic sequestration of carbon dioxide on Federal lands and split estates.

(b) REQUIREMENTS.—

(1) Through an integrated permitting system, the BLM and the EPA should jointly license sequestration projects on Federal lands and split pursuant to the UIC permitting procedures and requirements under subtitle B of this title.

(2) TWO-PHASE APPLICATION PROCEDURE.—The BLM shall issue perpetual easements under Title V of the Federal Land Management and Policy Act for geologic sequestration

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exploration and development projects on Federal lands through a two-phase license procedure.

(A) PHASE I: PROJECT AREA LICENSE.—A project area license grants the geologic sequestration project applicant the exclusive right to conduct environmental and geological testing and monitoring within the proposed subsurface project boundary.

(i) Priority of application will be given to the first complete application the BLM receives.

(ii) The project area license term shall be five years.

(iii) During the five-year project area license term, the pore space within the proposed subsurface project boundary shall not be available for other geologic sequestration project easements.

(iv) The holder of a project area license shall formulate a Plan of Development during the five-year license term.

(B) PHASE II: PROJECT DEVELOPMENT LICENSE.—A project development license, in combination with a CO₂ injection permit issued pursuant to subtitle B, grants the project applicant the right to construct, operate, and maintain underground wells as well as surface and sub-

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surface facilities for the permanent geologic sequestration of CO₂ within the subsurface project boundary defined in the CO₂ injection permit and project development license.

(i) A project development license shall be awarded based on the merits of the applicant's Plan of Development.

(ii) No CO₂ injection permit or project development license may be issued to any other person to inject CO₂ for the purpose of geologic sequestration of CO₂ within the subsurface project boundary defined in the existing CO₂ injection permit and project development license.

(3) LICENSING GEOLOGIC SEQUESTRATION PROJECTS ON SPLIT ESTATES.—The EPA CO₂ injection permit proceedings conducted under subtitle B for geologic sequestration projects proposed on split estates shall be subject to the requirements under subtitle C of this title if the project applicant has not acquired the ownership interests, easements, or licenses necessary to occupy pore space in all applicable states through state statutory authority or voluntary contract, and instead elects to apply for a pore space permit pursuant to subtitle C.

(4) COLLECTION OF ANNUAL FEES AND RENT.—The BLM shall annually charge administrative fees and collect an annual

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nominal rent from project operators for the administration and management of geologic sequestration licenses.

(5) ENVIRONMENTAL REVIEW OF FEDERAL ACTIONS AUTHORIZING PRIVATE GEOLOGIC SEQUESTRATION PROJECTS ON FEDERAL LANDS AND SPLIT ESTATES.—The BLM shall be the lead agency for the purpose of Federal environmental review pursuant to the National Environmental Policy Act of 1969 (42 U.S.C. § 4321 et seq.) and, in consultation with all relevant agencies, shall prepare a single environmental review document for each license application phase to be used as the basis for decisions under Federal law related to each project phase

(A) NEPA REVIEW OF THE PROJECT AREA LICENSE.—The environmental review for the project area license shall only assess likely environmental effects of the testing facilities to be constructed and operated under the terms of that license. The environmental effects of permanent geologic sequestration shall not be considered for environmental review of the project area license.

(B) NEPA REVIEW OF THE PROJECT DEVELOPMENT LICENSE.—The environmental review for the project development license shall assess the likely environmental

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effects of permanent geologic sequestration of CO₂ and the facilities and wells constructed for such purpose.

SEC. 134. CONFORMING AMENDMENTS.

(a) Section 302 (b) of the Federal Land Policy and Management Act of 1976 (43 U.S.C. § 1732) is amended by inserting after “utilize public lands for habitation, cultivation,” the following:

(1) “permanent geologic sequestration of carbon dioxide,”.

(b) Section 501 (a) of the Federal Land Policy and Management Act of 1976 as amended (43 U.S.C. § 1761) is amended by adding a new paragraph “(a)(8)” and inserting “pipelines and other systems for the transportation or distribution carbon dioxide and for the permanent geologic sequestration carbon dioxide and terminal facilities in connection therewith.”