Pouring Out Our Soils: Facing the Challenge of Poorly Defined Property Rights in Subsurface Pore Space for Carbon Capture and Storage

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As the United States strives to reduce greenhouse-gas emissions, and particularly carbon dioxide ("CO_2") emissions from the generation of electricity, one of the promising technological options is carbon capture and storage ("CCS"), a practice that involves injecting large volumes (millions of tons) of CO_2 deep underground for what is essentially permanent storage.[1] However, as is often the case with new practices and technologies, the interest in CCS has raised a number of regulatory and legal issues, including that of property ownership of deep-subsurface pore space that would hold the compressed gas.

While analysts have suggested that there are a number of apt analogs for this new application of subsurface geological enterprise, none provide a completely applicable set of principles.[2] At the same time, much can be learned from the analogs to state legislative strategies and courts' reasoning for resolving conflicts between existing or vague property regimes and efficient use of natural resources.

The absence of controlling legal precedent governing deep-subsurface pore space property rights has led a number of states that anticipate hosting CCS facilities to develop regulatory regimes and to clarify applicable property laws.[3] States have taken a number of different approaches to this issue.[4] A handful of states have passed CCS legislation that directly addresses subsurface ownership; Montana, North Dakota, and Wyoming all clearly define ownership of subsurface property rights in pore space.[5] In each of these cases, the state has declared that the property rights to the subsurface pore space reside with the owners of the surface estate.[6] Other states, including Kansas, Louisiana, Oklahoma, and Utah, appear to acknowledge private subsurface pore-space ownership without directly specifying who holds the interest in such subsurface pore space under applicable property law.[7]

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1. For general information on CCS, see *Overview of Geological Sequestration*, EPA, http://www.epa.gov/climatechange/emissions/co2_gs_tech.html (last visited Oct. 2, 2011); *Carbon Dioxide Capture and Storage*, World Resources Inst., http://www.wri.org/project/carbon-dioxide-capture-storage (last visited Oct. 2, 2011).
2. *See infra* Part II.B.
3. For a comprehensive catalog of state legislation and initiatives related to CCS, see *State CCS Policy*, CCS Reg Project, http://www.ccsreg.org/bills.php (last visited Nov. 11, 2011).
4. *Id.*
5. Mont. Code Ann. § 82-11-180(3) (2011) ("If the ownership of the geologic storage reservoir cannot be determined from the deeds or severance documents related to the property by reviewing statutory or common law, it is presumed that the surface owner owns the geologic storage reservoir."); N.D. Cent. Code § 47-31-03 (2011) ("Title to pore space in all strata underlying the surface of lands and waters is vested in the owner of the overlying surface estate."); Wyo. Stat. Ann. § 34-1-152(a) (2011) ("The ownership of all pore space in all strata below the surface lands and waters of this state is declared to be vested in the several owners of the surface above the strata.").
6. *Supra* note 5.
7. *See* La. Rev. Stat. Ann. § 30:22(C)(1) (2011) (declaring that reservoirs will only be subject to use if all paying quantities of hydrocarbons have already been produced or the reservoir has greater utility for storage than hydrocarbon production and at least three-fourths of interest *owners'* (excluding lessors) consent in writing to use of the reservoir for storage); Okla. Stat. tit. 27A, § 3-5-101(C)(2) (2011) (stating that state regulatory body will regulate any unitization process established by the state to support carbon sequestration facilities); Utah Code Ann. § 54-17-701(1)(g) (2011) (directing governmental divisions and boards to develop recommended rules for aspects of geological sequestration, including "issues concerning ownership of subsurface rights and pore space"); Kan. Admin. Regs. § 82-3-1101(c)(13) (2011) ("[Applications for a CCS storage facility must include] a statement confirming that the applicant holds the necessary property and mineral rights for construction and operation of the CO_2 facility.").

In contrast, some states seem to have skirted or postponed the issue. Texas, for example, has passed three laws addressing geologic carbon sequestration,[8] none of which discuss subsurface-property-rights issues beyond stating that "[s]ecuring the necessary capacity for geologic sequestration is essential to the success of carbon capture strategies."[9] In 2009, West Virginia called for the establishment of a working group to study, among other things, "issues regarding ownership and other rights and interest in subsurface space that can be used as storage space for carbon dioxide . . . commonly referred to as 'pore space.'"[10]

As part of an effort to develop a state policy for CCS, the California Public Utilities Commission and other state agencies established a CCS Review Panel charged with developing a legal and regulatory framework for CCS projects.[11] This panel appears to have followed the lead of Montana, North Dakota, and Wyoming.[12] The Review Panel's initial background report provides an overview of alternative approaches for the state to address property rights in deep-subsurface pore space without an overt preference for any single option.[13] However, the separate report of recommendations issued by the Review Panel states that "[t]he State legislature should declare that the surface-owner is the owner of the subsurface 'pore space' needed to store CO_2."[14] The report goes on to recommend that "[t]he legislature should further establish procedures for aggregating and adjudicating the use of, and compensation for, pore space for CCS projects."[15]

States must be cautious, however, about simply transferring regulatory and legislative approaches from other states. Property law is the domain of state law,[16] and deep-subsurface pore space is a particularly underdeveloped area of property law.[17] The approach that is used in one state may not fit the circumstances of another; the best approach to clarifying pore-space ownership issues will depend upon both the geology and the demographics of the individual states.

The purpose of this article is to provide insight into how states might approach the task of defining and clarifying property rights to subsurface pore space, particularly rights to the types of structures that are relevant to CCS. While much has been written in a relatively short time about alternative approaches to property rights in pore space for CCS, this article offers new insights.

The discussion begins in section I with a brief description of the CCS practice, highlighting the technological, geological, and economic dimensions. That section includes a brief discussion of the role of pore space and geological structures in the use of the CCS technology. The important conclusion is that the likely design of CCS operations will not be uniform across states, in part because the geological structures are not uniform across states.

Section II then considers a number of approaches to analyzing the control and ownership of pore space. The discussion addresses the question of whether there is clear common-law precedent to indicate who owns deep-subsurface pore space, concluding that the issue has not been fully resolved and will vary from state to state.

The analysis then reviews a number of the analogs that have been proposed to guide the development of CCS policy and law, drawing on the fields of energy; waste disposal; and water supply, storage, and transportation for insight into the regulation of CCS in general, and the relevant subsurface property law in particular. That discussion demonstrates that none of the analogs are perfectly suited to CCS. The overview also shows that most of the relevant law is at the state level, and therefore that most of the court decisions are not binding on all states. More importantly, the discussion demonstrates a consistent attempt by the courts, both in the application of common law and in the review of legislative action, to promote efficient use of resources, in part by minimizing transaction costs.

Given that courts, at least in part, seek efficiency, it is important to ask what arrangement of property rights would best promote efficient use of the pore-space resources. Section III provides a normative approach to this question. The section commences by considering the purposes and the limitations of the institutions of property, drawing on the concept of the tragedy of the anticommons. Section III then goes on to consider four options for addressing potential approaches to subsurface pore space property rights. Each approach demonstrates a different mix of market approaches, property-rights regimes, and government control, and each approach faces limitations and challenges.

Drawing on analogs from natural-gas storage field practices in the Midwest, section III concludes with a simple calculation that demonstrates the inefficiency of undertaking negotiations to aggregate subsurface property rights. Although the direct costs of paying landowners for their deep-subsurface property rights are likely to be relatively small compared to the overall costs of CCS, the transaction

8. An Act Relating to the Development of Carbon Dioxide Capture and Sequestration in this State, 2009 Tex. Gen. Laws ch. 1125 (codified in scattered sections of Tex. Heath & Safety Code Ann.); An Act Relating to the Ownership and Use of Carbon Dioxide Captured by a Clean Coal Project, Tex. Nat. Res. Code Ann. §§ 119.001–.006 (West 2011); Implementation of Projects Involving the Capture, Injection, Sequestration, or Geologic Storage of Carbon Dioxide, 2009 Tex. Gen. Laws ch. 224 (codified in scattered sections of Tex. Nat. Res. Code Ann. and Tex. Water Code Ann.).
9. An Act Relating to the Development of Carbon Dioxide Capture and Sequestration in this State § 30, 2009 Tex. Gen. Laws ch. 1125.
10. W. Va. Code § 22-11A-6(d) (2011).
11. Cal. Inst. for Energy & Envt., Background Reports for the California Carbon Capture and Storage Review Panel 1-1 to -2 (2010), *available at* http://www.climatechange.ca.gov/carbon_capture_review_panel/documents/2010-12-31_Background_Reports_for_CCS.pdf.
12. *See supra* notes 5–6 and accompanying text.
13. Cal. Inst. for Energy & Envt., *supra* note 11, at 13-1 to -11.
14. Cal. Carbon Capture & Storage Review Panel, Findings and Recommendations by the California Carbon Capture and Storage Review Panel 5 (2010), *available at* http://www.climatechange.ca.gov/carbon_capture_review_panel/documents/2011-01-14_CSS_Panel_Recommendations.pdf.
15. *Id.*
16. *See* Victor B. Flatt, *Paving The Legal Path For Carbon Sequestration From Coal*, 19 Duke Envtl. L. & Pol'y F. 211, 234 (2009) ("The property law of each state will control ownership of the depleted oil and gas reservoir pore space.").
17. Owen L. Anderson, *Geologic CO_2 Sequestration: Who Owns the Pore Space?*, 9 Wyo. L. Rev. 97, 99 (2009) ("As between the surface owner and mineral owner, most jurisdictions . . . have not specifically determined the ownership of subterranean pore spaces."); Flatt, *supra* note 16, at 233 ("There is no clear consensus on whether the ownership of the pore space lies with the surface estate or the mineral estate, and consideration of these rights varies significantly from state to state.").

costs potentially could dwarf any royalty payments. That conclusion is, however, specific to local conditions. Each state should carry out a similar calculation before reaching conclusions.

Section IV provides a set of conclusions to guide public strategy to maximize the value of the subsurface pore-space resource and minimize potential conflicts and transaction costs.

I. CCS: Technology, Geology, and Economics

The future of the large-scale deployment of CCS technology and the property rights to deep-subsurface pore space are inextricably linked. Understanding one requires understanding the other.

Casting the issue one way, the future deployment of the CCS practice critically depends upon the availability—both physically and legally—of the pore space necessary to store compressed CO_2.[18] Cast in the other direction, brine-filled pore space in the deep subsurface is currently only used for the underground storage of natural gas in some selected storage fields within the United States,[19] but CCS shows great promise in being a highly beneficial use of this pore-space resource in the near and long term.[20] To better understand the importance of the role of pore-space property rights, it is necessary to appreciate the basics of the technology and geology associated with the CCS practice. Therefore an examination of the pore-space property-rights regime should commence with consideration of the requirements of CCS technology.

This section provides a basic overview of technologies associated with the CCS practice, starting with the underlying processes to separate and transport CO_2. The discussion then moves to a review of the geological considerations required for storing CO_2 in the deep subsurface, emphasizing the types of pore space that are most amenable to CCS. The section concludes with a brief consideration of the economics of CCS.

A. *CCS Technology*

CCS is a technology that involves capturing the CO_2 generated at a stationary source, such as a coal-consuming electricity-generation plant, and injecting the compressed liquid into porous rock found deep underground to prevent emission into the atmosphere.[21] The process comprises three steps: First, the CO_2 must be captured at the source where it is produced; then it must be compressed and transported to a storage site; finally, it is injected into a deep-subsurface reservoir that securely confines the injected fluid.[22]

There are three primary methods for capturing CO_2: postcombustion, oxyfuel combustion, and precombustion.[23] In a postcombustion or "end-of-pipe" system, CO_2 is captured and separated from the rest of the emissions stream using chemical or physical absorption.[24] Solvents capture the CO_2 from the exhaust stream, which is typically three to fifteen percent CO_2 in modern pulverized-coal or natural-gas combined-cycle plants.[25] The absorbed CO_2 is then stripped from the solvent, creating a highly concentrated CO_2 stream that is fed into a storage reservoir.[26] This is the method that would be required to capture CO_2 emissions from conventional pulverized-coal power plants,[27] but postcombustion capture can increase a plant's auxiliary energy consumption by twenty-four to forty percent, severely hampering the efficiency and effectiveness of such carbon-capture technology.[28]

18. *See Overview of Geological Sequestration*, *supra* note 1.
19. For example, in Indiana the maximum depth to formation for natural gas storage fields is 1,000 meters and the vast majority are under 700 meters, suggesting that CCS occurring at depths greater than 1,000 meters would not interfere with natural-gas storage applications. *See* Am. Gas Ass'n, Survey Of Underground Storage Of Natural Gas In The United States And Canada (2004). It is also possible that compressed-air energy storage ("CAES") systems could compete with CCS for pore space in the future, but that conflict is likely to be minimal. Most plans for compressed-air energy-storage systems focus on geological formations at 500 to 1,500 meters, Compressed Air Energy Storage (CAES) Scoping Workshop: Enabling Solar and Wind Energy Technologies on a Grand Scale 16, 155, 234, 249, 251 (Vasilis Fthenakis, Columbia Univ. ed., 2008), *available at* http://www.clca.columbia.edu/papers/CAES_WorkshopReport_web.pdf, whereas CCS typically occurs at depths greater than 800 meters, Peter Folger, Cong. Research Serv., RL 33801, Carbon Capture and Sequestration (CCS) 8 (2009). More importantly, CAES focuses on structures such as salt caverns and depleted mines. *Id.* at 16, 228, 232, 246, 249, 271, 287. The only operating CAES system in the United States, the McIntosh plant in Alabama, *see* Bob Downing, *Utility Mines New Power Source,* Ohio.com (Nov. 24, 2009), http://www.ohio.com/news/utility-mines-new-power-source-1.130603, is based in a salt dome, *Early CAES Plant Works for PowerSouth; More Air on Horizon?*, SmartGridToday (June 3, 2011), http://www.smartgridtoday.com/public/2998print.cfm, a different kind of formation from the saline aquifers on which CCS will focus, *see* Folger, *supra* at 8, 10. A CAES project in Norton, Ohio, is based on an abandoned limestone mine, *see* Downing, *supra*, while a project in New York state will use a salt cavern. U.S. Dep't of Energy, New York State Electric & Gas: Advanced Compressed Air Energy Storage (2010), *available at* http://solarplan.org/Research/CAES%20Plant%20in%20New%20York_NYSEG.pdf. The project to develop an aquifer as a CAES system, *see Early CAES Plant Works for PowerSouth; More Air on Horizon?*, *supra*, the Iowa Stored Energy Park in Dallas Center, Iowa, was recently terminated due to the unsuitability of the formation for CAES. Press Release, Iowa Stored Energy Plant Agency, Iowa Stored Energy Park Project Terminated (July 28, 2011), http://www.isepa.com/ISEP%20Press%20Release.pdf.
20. *See* Alexandra B. Klass & Elizabeth J. Wilson, *Climate Change, Carbon Sequestration, and Property Rights*, 2010 U. Ill. L. Rev. 363, 374–76; *CCS Overview: What is CCS?*, World Resources Inst., http://www.wri.org/project/carbon-dioxide-capture-storage/ccs-basics (last visited Nov. 11, 2011) ("[CCS] is a critical option in the portfolio of solutions available to combat climate change, because it allows for significant reductions in CO2 emissions from fossil-based systems, enabling it to be used as a bridge to a sustainable energy future.").
21. *See Overview of Geological Sequestration*, *supra* note 1.
22. *Id.*
23. Intergovernmental Panel on Climate Change, Carbon Dioxide Capture and Storage 25 (Bert Metz et al. eds., 2005), *available at* http://www.ipcc.ch/pdf/special-reports/srccs/srccs_wholereport.pdf.
24. *Id.*
25. Partha S. Chaudhuri et al., Nat'l Regulatory Research Inst., Commissioner Primer: Carbon Dioxide Capture and Storage 10 (2006), *available at* http://nrri.org/pubs/electricity/06-02.pdf.
26. Intergovernmental Panel on Climate Change, *supra* note 23, at 109.
27. Howard Herzog et al., Advanced Post-Combustion CO_2 Capture 4–5 (2009), *available at* http://web.mit.edu/mitei/docs/reports/herzog-meldon-hatton.pdf.
28. Ananth P. Chikkatur & Ambuj D. Sagar, Pew Ctr. for Global Climate Change, Coal Initiative Reports: Positioning the Indian Coal-Power Sector for Carbon Mitigation: Key Policy Options 23 (2009), *available at* http://www.pewclimate.org/docUploads/IndiaCoalPower-Feb09.pdf.

Oxyfuel combustion involves the introduction of pure oxygen rather than ambient air during the combustion process.[29] The result is a stream of emissions that is greater than eighty percent CO_2 by volume,[30] making separation unnecessary and capture relatively easy and more efficient.[31]

Precombustion capture requires the creation of a synthesis gas ("syngas") from coal, oil, or other solid hydrocarbons, and the separation of CO_2 from the syngas prior to utilization.[32] In the case of coal, however, precombustion capture is only an option in integrated-gasification combined-cycle ("IGCC") coal-fired plants, where the coal is first gasified using oxygen.[33] Once the syngas has been produced, additional processing concentrates and captures the CO_2.[34] Precombustion capture of CO_2 is currently the cheapest and most efficient option for CO_2 capture,[35] but it can only be used in conjunction with IGCC technology.[36]

In the second phase of the CCS process, the CO_2 must be transported from the plant to the site of injection via pipeline, ship, or tanker.[37] Within the continental United States, a 2,000-mile system of pipelines is used to gather and distribute CO_2 for enhanced oil recovery ("EOR") operations.[38] To transport CO_2 by pipeline, the gas is compressed to a pressure above 8 megapascals to increase its density.[39] A second option is to transport the CO_2 by ship; however, this is cost-effective only if the CO_2 must be moved a distance greater than 1,000 miles.[40] Road and rail tankers could also be utilized to transport CO_2.[41] However, these options are generally less economical than pipelines and ships, except on a very small scale.[42]

The third phase of the process is the injection of the compressed CO_2 into deep-subsurface geological formations.[43] While the use of terms such as "field," "structure," and "formation" might conjure images of large, empty, underground spaces, the CO_2 in fact will be pumped into porous, underground materials in which the storage space is composed of numerous tiny, interconnected pores.[44] The pores exist in a given strata or unit, termed a "reservoir."[45] The CO_2 fills the pore spaces in these underground reservoirs in a manner analogous to the way a sponge absorbs water.[46] In many cases, these are the same types of reservoirs that hold oil and natural gas in their natural state.[47] Geologic storage of CO_2 would take place in sedimentary basins where the porosity of the rock creates a storage capacity large enough to be of interest.[48]

B. *Pore Space and the Geology of CCS*

Three types of geological formations are considered the most promising options for geological storage of CO_2: deep saline aquifers, depleted oil and gas reservoirs, and unminable coal seams.[49] In each of these three formations, geologic storage or pore volume of the reservoirs would have enough storage capacity to effectively store significant volumes of injected CO_2, namely the millions of tons that would be captured by a project that lasted for decades.[50] Of the three primary options, saline aquifers provide the greatest potential for storing large volumes of CO_2.[51] The porous rock units that serve as reservoirs must be capped by nonporous units or "seals" that confine the CO_2 in the deep subsurface.[52]

The storage capacity of saline reservoirs is estimated to be between 1,000 and 10,000 gigatons of CO_2 worldwide,[53] and 240 gigatons of CO_2 within the United States.[54] Gas would be injected at depths greater than 800 meters below the surface to store the CO_2 in a liquid-like, supercritical state.[55] Because of the pressure, its density would range from fifty to eighty percent of the density of the saline water that currently resides in the pore spaces.[56] At this density, the CO_2 is more buoyant than the ambient saline water in the reservoir and would therefore move upwards more strongly than oil but less strongly than natural gas.[57] Initially, ten to thirty percent of the CO_2 can dissolve into the saline water,[58] and it is predicted that over very long periods of time, most of

29. Intergovernmental Panel on Climate Change, *supra* note 23, at 25.
30. *Id.*
31. Jon Gibbins & Hannah Chalmers, *Fossil Power Generation with Carbon Capture and Storage (CCS): Policy Development for Technology Deployment*, *in* Carbon Capture: Sequestration and Storage 61 (Ronald E. Hester & Roy M. Harrison eds., 2010).
32. Anand B. Rao, *Technologies: Separation and Capture*, *in* Carbon Capture and Sequestration: Integrating Technology, Monitoring and Regulation 20–24 (Elizabeth J. Wilson & David Gerard eds., 2007).
33. *Id.*
34. *Id.*
35. Jennie Stephens & Bob Van der Zwaan, *The Case for Carbon Capture and Storage*, 22 Issues Sci. & Tech. 69, 70 (2005).
36. Rao, *supra* note 32, at 20–24.
37. Intergovernmental Panel on Climate Change, *supra* note 23, at 29–30.
38. Jason J. Heinrich et al., MIT, Environmental Assessment of Geologic Storage of CO_2 6 (2003), *available at* http://sequestration.mit.edu/pdf/heinrich_et_al_MIT_paper.pdf.
39. Intergovernmental Panel on Climate Change, *supra* note 23, at 29.
40. Stephens & Van der Zwaan, *supra* note 35.
41. Intergovernmental Panel on Climate Change, *supra* note 23, at 30.
42. *Id.*
43. *Id.* at 31.
44. *Overview of Geological Sequestration*, *supra* note 1.
45. Intergovernmental Panel on Climate Change, *supra* note 23, at 31.
46. *Overview of Geological Sequestration*, *supra* note 1.
47. Olav Karstad, Statoil R&D Ctr., *Geological Storage, Including Costs and Risks, in Saline Aquifers*, *in* Intergovernmental Panel on Climate Change Workshop on Carbon Dioxide Capture and Storage, Regina, Can., Nov. 18–21, 2002, *Proceedings* 53, 54, *available at* http://www.ipcc.ch/pdf/supporting-material/ipcc-workshop-proceedings-cdcs-regina-2002.pdf.
48. *Id.*
49. Intergovernmental Panel on Climate Change, *supra* note 23, at 31.
50. *Id.* at 33 tbl.TS.5.
51. Nat'l Energy Tech. Lab., U.S. Dep't of Energy, Carbon Sequestration Atlas of the United States and Canada 27 (3d ed. 2010), *available at* http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlasIII/2010atlasIII.pdf.
52. Intergovernmental Panel on Climate Change, *supra* note 23, at 225.
53. Int'l Energy Agency, Prospects for CO_2 Capture and Storage: Energy Technology Analysis 16 (2004), *available at* http://www.gwpc.org/e-library/documents/co2/Report%20IEA%20CCS%20Prospects%2011-17-2004.pdf.
54. J.J. Dooley et al., Global Energy Technology Strategy Program, Carbon Dioxide Capture and Geologic Storage: A Core Element of a Global Energy Technology Strategy to Address Climate Change 26–27 (2006), *available at* http://www.battelle.org/news/06/CCS_Climate_Change06.pdf.
55. Intergovernmental Panel on Climate Change, *supra* note 23, at 31.
56. *Id.*
57. Karstad, *supra* note 47, at 54.
58. Sally M. Benson, Lawrence Berkley Nat'l Lab., *Carbon Dioxide Capture and Storage in Underground Geologic Formations* 5, *in* Final Proceedings of the Pew Center/NCEP Workshop on the 10-50 Solution: Technologies and Policies for a Low-Carbon Future, at pt. III (Pew Ctr. on Global Climate Change & Nat'l Comm'n on Energy Policy eds., 2004), *available at* http://www.pewclimate.org/docUploads/10-50_Full%20Proceedings.pdf.

the CO_2 will eventually dissolve into the saline water in the pore space.[59] Some of the CO_2 will be trapped in the capillaries between the pores, and a small amount will react with the minerals in the rock matrix to form solid precipitates.[60] Unlike oil and gas reservoirs that demonstrate by their existence their long-term, secure storage ability, the permanence of storage in saline aquifers has not been evaluated over extended time periods.[61] However, because no valuable resource has been developed in these reservoirs, there are minimal oil and gas wells penetrating the storage zones in saline reservoirs, lowering the potential for upward migration and escape of any stored CO_2.[62]

Depleted oil and gas reservoirs have an estimated capacity of approximately 920 gigatons of CO_2 worldwide[63] and 35 gigatons of CO_2 within the United States.[64] Like injection into deep saline aquifers, the CO_2 would be stored below 800 meters where the CO_2 would be in a supercritical state.[65] An advantage to storage in these reservoirs is that additional oil and gas can be produced by injecting CO_2 into these hydrocarbon-bearing reservoirs for enhanced oil or gas recovery.[66] The presence of securely confined oil and gas is a testament to the fact that there is some underground storage capacity available that offers a high likelihood of permanence. The cap rock that sealed the fossil fuel in the reservoir also would prevent escape of the CO_2.[67] An additional advantage of using oil or gas fields for storage is that there has already been significant investment in infrastructure resulting in added knowledge about the storage potential in the area.[68] However, extracting the oil and gas requires drilling wells that, if uncapped or improperly sealed, would create the potential for upward migration and leakage of stored CO_2.[69]

Unminable coal seams also have been explored as potential storage reservoirs for CO_2.[70] The capacity of unminable coal seams is estimated to be 148 gigatons of CO_2 worldwide[71] and 30 gigatons of CO_2 in the United States.[72] Storage would generally be at shallower depths than CO_2 stored in depleted oil and gas reservoirs or saline formations.[73] When injected into the coal seams, the CO_2 is absorbed into the coal, displacing the coal methane that resides within the coal.[74] The methane potentially can be extracted and sold.[75] The CO_2 will remain trapped and stored as long as pressures and temperatures are stable.[76] Complications during CO_2 injection could arise if the coal reacts with the injected CO_2 and swells, potentially obstructing the flow of CO_2 deeper into the formation.[77] This potential problem, coupled with the relatively low storage capacity of unminable coal seams, has led experts to consider unminable coal seams to not have a high potential for CO_2 storage.

The movement of injected CO_2 within saline aquifers is not yet well understood.[78] At a minimum, there will be significant uncertainty regarding the mode in which injected CO_2 will exist in a storage reservoir.[79] If a measured amount of CO_2 per year were injected into a homogenous saline aquifer for the life of the project, the plume from that injection would rise to the cap rock and expand into a disk-shaped area with a generally predictable geometry.[80] The number of tons of CO_2 stored per acre of surface land will vary with the geological conditions and the injection practices of a particular location.[81] Particularly important is whether the injection is designed to utilize a single reservoir, rising to a single cap-rock layer, or multiple stacked reservoirs, each at a different depth and confined by a different layer of cap rock.[82] The latter approach will have a much higher density of storage per surface area. Additionally, because of the variability in both thickness and pore-volume-per-unit of a given reservoir, there could be very significant variability in the plume geometry, from tall and narrow to thin and wide.[83] However, prediction of the exact geometry of the plume has significant uncertainty.[84] Most reservoirs into which CO_2 might be injected are not homogenous; rather, they are highly irregular so that the CO_2 will flow in patterns that could resemble streams more than disks.[85]

Because of the large volume of storage capacity required for CO_2 (tens of millions of tons per generating facility), the duration of the injection process (multiple decades), and the uncertainty of the geometry of the plume, legal access to significant areas of subsurface pore volume will need to be secured for each project. For example, an estimate of the amount of acreage that would be affected by the volume of CO_2 produced by a moderate-sized emitter (e.g., 4.5 million tons per year, at a 100% capture rate, for a 700-megawatt facility for 30 years) potentially could be accommodated by a 200-foot-thick saline aquifer with 12% porosity at a 10%

59. *Id.*; *see also* Victor K. Der, *Carbon Capture and Storage: An Option for Helping to Meet Growing Global Energy Demand While Countering Climate Change*, 44 U. Rich. L. Rev. 937, 951 (2010).
60. *See* MIT Energy Initiative, Role of Enhanced Oil Recovery in Accelerating the Deployment of Carbon Capture and Sequestration 6 (2010), *available at* http://web.mit.edu/mitei/research/reports/110510_EOR_Report.pdf; *see also* Benson, Lawrence Berkley Nat'l Lab., *supra* note 58.
61. Intergovernmental Panel on Climate Change, *supra* note 23, at 34.
62. Karstad, *supra* note 47, at 54.
63. Int'l Energy Agency, *supra* note 53, at 16.
64. Dooley et al., *supra* note 54, at 27; *see also* Nat'l Energy Tech. Lab., U.S. Dep't of Energy, *supra* note 51, at 142.
65. Intergovernmental Panel on Climate Change, *supra* note 23, at 32.
66. Int'l Energy Agency, *supra* note 53, at 39.
67. Intergovernmental Panel on Climate Change, supra note 23, at 32.
68. Int'l Energy Agency, *supra* note 53, at 41.
69. Intergovernmental Panel on Climate Change, supra note 23, at 33.
70. *Id.* at 32.
71. Int'l Energy Agency, *supra* note 53, at 89.
72. Dooley et al., *supra* note 54, at 17.
73. *See, e.g.*, *Assessment of Reservoirs for Geologic Storage of CO_2*, Va. Dep't Mines Minerals & Energy, http://www.dmme.virginia.gov/DMR3/carbonstorage.shtml (last visited Nov. 12, 2011) (citing Peter J. Cook, *Sustainability and Nonrenewable Resources*, 6 Envtl. Geosciences 185, 185–90 (1999)); *Carbon Dioxide Capture and Storage*, *supra* note 2.
74. Nigel Bankes et al., *The Legal Framework for Carbon Capture and Storage in Alberta*, 45 Alta. L. Rev. 585, 592 (2008).
75. *Id.*
76. Intergovernmental Panel on Climate Change, *supra* note 23, at 32.
77. Int'l Energy Agency, *supra* note 53, at 89.
78. Philip M. Marston & Patricia A. Moore, *From EOR to CCS: The Evolving Legal and Regulatory Framework for Carbon Capture and Storage*, 29 Energy L.J. 421, 439–40(2008).
79. Marston & Moore, *supra* note 78, at 439–41(2008).
80. Int'l Energy Agency, *supra* note 53, at 91.
81. Intergovernmental Panel on Climate Change, supra note 23, at 197.
82. Nat'l Energy Tech. Lab., U.S. Dep't of Energy, supra note 51, at 26.
83. *Id.* at 144.
84. *Id.*
85. *Id.* at 144–45.

efficiency factor over an area of approximately 90 square miles (57,000 acres).[86]

C. Economics of CCS

To determine the relative importance of the potential costs associated with pore-space property rights, it is necessary to assess the other costs associated with the CCS practice. In the context of electricity production, the costs of CCS depend directly upon the costs of the underlying power technology, and thus indirectly upon the relative costs of natural gas and coal.[87] When natural gas is relatively inexpensive, the underlying power technology will be natural-gas combined cycle. In this case, the cost of adding on CCS capacity will range from $55 to $60 per ton of avoided CO_2 emissions.[88] When natural-gas prices are higher so that coal technologies are favored, IGCC provides the lowest-cost approach for CCS, ranging from $35 to $40 per ton of avoided CO_2 emissions.[89]

II. Control of Pore-Space Resources

Before carbon dioxide is injected for underground storage, it is necessary to address the issue of who, if anyone, owns the pore space that will store the CO_2. It is conceivable that if there are clear owners of the pore space, they would have the right to demand payment for its use as a storage medium. In the absence of contractual agreements, owners of subsurface structures might also have the right to sue for damages in trespass if injected CO_2 migrates into their pore space or if development of an adjoining subsurface field affects the conditions in their pore space.

In this article, we consider the issue of pore-space ownership from two perspectives. The discussion starts with an examination of whether there is any controlling law to suggest that the property rights and conditions of ownership to deep-subsurface pore space have been settled. In short, the conclusion is that property rights to subsurface pore space are ambiguous, and are increasingly so as the depth of the pore space in question increases.

The discussion then turns to the question of whether there are particularly helpful analogs that courts might find persuasive, or at least informative, if courts were presented with the challenge of defining these property rights.

From the discussion of analogs emerge several important observations. One is that when faced with the task of deciding property rights and control of resources, the courts seek to promote efficient use and often rely on a set of legal doctrines and recognized government powers to advance that goal. This section concludes with a brief discussion of some of the doctrines and powers upon which the courts rely.

A. Property Rights in Pore Space

For the CCS technology to be effectively deployed, it is necessary to resolve the question of whether the surface-owner or the mineral-owner holds title to some portion of the subsurface rights and has a clear claim to the pore space in deep-subsurface structures.

It is generally accepted in the United States that rights to use substances and structures beneath a given property are connected with the surface interest.[90] Whoever owns the surface of the land also typically has rights to potable ground water, for example.[91] The surface-owner might also have mineral rights, unless those rights have been severed from the surface and sold or leased to another party.[92] If mineral rights have been severed from the surface estate, it is unclear to what extent the surface-owner retains rights to other subsurface resources.

More importantly, the depth to which subsurface property rights extend may be limited, though it is unclear to what extent.[93] Not only was the concept of ownership "*ad coelum et ad inferos*"[94] decisively limited by *United States v. Causby*,[95] but the principle was never good law, because no binding U.S. case was ever decided on that basis.[96] The received wisdom that rights extend to the center of the earth is mistaken. Rather, "the law of subsurface ownership is so confused that it is impossible to know how deep property rights extend."[97] Moreover, the deeper the surface-owner's claim extends, the less likely the courts are to support the claim.[98]

An examination of courts' treatment of subsurface property rights suggests:

> [I]nstead of vesting absolute ownership of the subsurface in one party or another, courts appear to allow regulated use of the subsurface (by either the government or private parties) when the use is in the public interest without always requiring compensation for surface owners or mineral owners in the absence of actual harm or loss.[99]

The literature suggests, then, that rather than ask, "Who owns the pore space?" it might be better to inquire, "Does anyone own the pore space?" The answer to the latter question appears to be that ownership in shallow pore space is

86. *See* Sean T. Brennan & Robert C. Burruss, U.S. Geological Survey, Open-File Report 03-452, Specific Storage Volumes: A Useful Tool for CO_2 Storage Capacity Assessment (2003), *available at* http://pubs.usgs.gov/of/2003/of03-452/of03-452-tagged.pdf.
87. *See* Emily Giovanni & Kenneth R. Richards, *Determinants of the Costs of Carbon Capture and Sequestration for Expanding Electricity Generation Capacity*, 38 Energy Pol'y 6026, 6033–34 (2010).
88. *Id.*
89. *Id.*
90. John S. Lowe, Oil and Gas Law in a Nutshell 42–43 (4th ed. 2003).
91. 93 C.J.S. *Waters* § 255 (2011) ("An owner of land owns its surface water by the same title as he or she owns the land itself and has the right to collect and appropriate such surface water to his or her own use . . . .").
92. Carlos B. Masterson, *Adverse Possession and the Severed Mineral Estate*, 25 Tex. L. Rev. 139, 139–45 (1946).
93. John G. Sprankling, *Owning the Center of the Earth*, 55 UCLA L. Rev. 979, 1039 (2008).
94. "Up to the sky and down to the center of the earth." Black's Law Dictionary 40 (8th ed. 2004). This is also known as the "heaven to hell" rule. C.G. van der Merwe, *Interpenetration of Common Law and Civil Law as Experienced in the South African and Scottish Law of Property*, 78 Tul. L. Rev. 257, 265 (2003)
95. United States v. Causby, 328 U.S. 256, 260–61 (1946).
96. Sprankling, *supra* note 93, at 999.
97. *Id.* at 981.
98. *Id.* at 982.
99. Klass & Wilson, *supra* note 20, at 386. For a similar conclusion focused on Texas, see Anderson, *supra* note 17, at 115.

highly situation-specific and ownership in deep pore space very ambiguous at best.[100]

B. Technology and Law Analogs to CCS and Pore Space

Given the ambiguity of property rights in deep-subsurface pore space, it may be informative to examine whether similar legal issues have arisen in other contexts and, if so, how they were resolved. In fact, there is a substantial body of work that provides legal analogies for both the injection and storage components of geological sequestration, which are useful when analyzing the regulatory feasibility of long-term CO_2 storage. The common-law and legislative approaches used in other contexts can help facilitate implementation of the technologies associated with carbon storage.[101] Here we consider analogies drawn from the fields of energy, waste management, water resources, and transportation.[102] The discussion illustrates three other important concepts: (1) courts use experience and analogies from other applications to help them develop law in new areas; (2) courts seek to develop efficient outcomes for new applications; and (3) there is an interplay between legislatures and courts in the development of new law.

1. Energy Analogs

The range of energy applications discussed here covers several key legal concepts potentially relevant to CCS, particularly the coordination of multiple property holders where ownership scale does track the scale of the resource being developed. The applications include pooling and unitization for oil and gas extraction, as well as natural-gas storage.

a. Oil and Gas Extraction

Our inquiry into analogs for CCS starts with one of the most basic geological activities: the extraction of oil and natural gas. From this discussion we develop three interrelated concepts that are core to understanding subsurface geological property: (1) the rule of capture; (2) correlative rights; and (3) legislative constraints on the extraction process.

It is a basic physical behavior in the subsurface that oil and gas migrate from areas of high pressure to areas of low pressure.[103] Relatively lower-pressure areas are created whenever the petroleum resources are extracted.[104] Thus, when a landowner taps a pool of oil or gas under her property, reducing the pressure in the field around the point of extraction, oil and gas from neighboring properties can flow toward the producing wells.[105]

The tendency of oil and gas to migrate from beneath one property to another[106] raises the question of who owns the moving resources. Early court cases, faced with this question, drew on analogies from two different areas: percolating waters and wild animals. Analogizing to percolating waters, courts found that, as with water, it is impossible to control the subsurface flow of oil and gas or to determine what portion of an extracted resource originated below another's property.[107] Hence, early courts reasoned, as with water, one may extract from beneath his or her land not only the oil and gas that originated there, but also that which flows there.[108] If it flowed, it was mobile and therefore could be extracted.[109] Other courts cite the established doctrine of the law of capture,[110] which states that a beast does not become private property until it is reduced to capture.[111] This does not give an individual a right to trespass onto another's property to pursue the wild animal, but does allow property-owners to take creatures that wander ("flow") onto their lands, even if a neighbor had planned on hunting it.[112] Arguably, the rule of capture is a pragmatic solution to the problem of migration, or the "fugitive nature" of petroleum resources: it avoids the inevitable costs and uncertainty associated with tracking the

100. *See, e.g.*, Sprankling, *supra* note 93, at 979 ("Broadly speaking, the deeper the disputed region, the less likely courts are to recognize the surface owner's title.").
101. Sarah M. Forbes, Nat'l Energy Tech. Lab., Regulatory Barriers for Carbon Capture, Storage and Sequestration 2 (2002), *available at* http://netl.doe.gov/technologies/carbon_seq/refshelf/reg-issues/Capture.PDF.
102. *See United States v. Kammersell*, 196 F.3d 1137, 1139 (10th Cir. 1999) ("Because this is a case of first impression, both sides must rely on analogies.").
103. U.K. Offshore Oil & Gas Indus. Ass'n, *Migration*, Oil & gas UK, http://www.oilandgasuk.co.uk/publications/Geological_Settings/Migration.cfm (last updated 2010).
104. *Oil Industry Production: So, How is Oil Produced?*, oilprimer.com, http://www.oilprimer.com/oil-industry-production.html (last visited Nov. 21, 2011).
105. *See generally id.* ("Oil is produced through the creation of a significant pressure drop between the outer reaches of the reservoir and the wellbore at depth. With pressure drops sufficient to overcome pore pressures, oil stored deep in reservoirs will flow to the low-pressure sink."); William L. Russell, Principles of petroleum geology 180–237 (1st ed. 1951).
106. Courts have addressed the issues related to the flow of oil and gas from beneath one property to another. *E.g.*, Elliff v. Texon Drilling Co., 210 S.W.2d 558, 562 (Tex. 1948) ("He may thus appropriate the oil and gas that have flowed from adjacent lands without the consent of the owner of those lands, and without incurring liability to him for drainage.").
107. *See, e.g.*, Gray-Mellon Oil Co. v. Fairchild, 292 S.W. 743, 745 n.6 (Ky. 1927) ("Oil and gas in the earth stand much as water percolating under the earth. The owner in fee owns to the center of the earth. But he does not own a specific cubic foot of water, oil, or gas under the earth until he reduces it to possession."); *Elliff*, 210 S.W.2d at 581 ("In the absence of common law precedent, and owing to the lack of scientific information as to the movement of these minerals, some of the courts have sought by analogy to compare oil and gas to other types of property such as wild animals, birds, subterranean waters and other migratory things, with reference to which the common law had established rules denying any character of ownership prior to capture."). For earlier cases, see Ohio Oil Co. v. Indiana, 177 U.S. 190 (1900); Westmoreland v. DeWitt, 18 A. 724 (Pa. 1889); Dark v. Johnston, 55 Pa. 164 (1867); Wood Cnty. Petroleum Co. v. W. Va. Transp. Co., 28 W. Va. 210 (1886).
108. *See generally* Stephen E. Snyder, Comment, *Ground Water Management: A Proposal for Texas*, 51 Tex. L. Rev. 289, 290 n.8 (1973) ("The classic statement of the English rule comes from Acton v. Blundell, 12 M. & W. 324, 152 Eng. Rep. 1223 (Ex. 1843). '[T]he person who owns the surface may dig therein, and apply all that is there found to his own purposes, at his free will and pleasure.' *Id.* at 354, 152 Eng. Rep. at 1235. If his activit[i]es intercept waters flowing to his neighbor's well, they come under 'the description of damnum absque injuria, which cannot become the ground of an action.' *Id.*").
109. *See* cases cited *supra* notes 106–07.
110. *See, e.g.*, N. Natural Gas Co. v. Nash Oil & Gas, Inc., 526 F.3d 626, 631–32 (10th Cir. 2008) (referring to the law of capture).
111. Pierson v. Post, 3 Cai. 175, 178 (N.Y. Sup. Ct. 1805) ("It is admitted that a fox is an animal *feræ naturæ*, and that property in such animals is acquired by occupancy only."). Furthermore, the court noted that occupancy requires that the animal be deprived "of his natural liberty" and brought within "certain control." *Id.*
112. *Id.*

origin of resources, substituting the point of capture as an observable indicator of ownership.

As the understanding and technology associated with oil and gas extraction improved, however, it became clear that the rule of capture raised certain problems. It was not uncommon for property-owners to engage in wasteful activities such as excessive drilling to extract oil or gas too fast from a deposit and to prevent the flow of oil and natural gas off of their property for production by their neighbors.[113] The unregulated drilling of many wells very close to the border of one's property prevented the flow of oil across the border to a neighbor's wells but came at the cost of decreasing the recovery of oil by all of the producers in a field.[114] Such wasteful "poaching" practices resulted in the significant loss of resources when short-term individual gain outweighed the common benefit of all in a producing oil or gas field.[115] Examples of this unfortunate circumstance are present in a number of states where such behavior occurredprior to the establishment of a regulatory framework prohibiting it.[116]

One unintended effect of these preemptive and strategic activities was to reduce overall fossil-fuel extraction from the field.[117] When many wells are extracting hydrocarbons at an excessive rate, the reservoir pressure can be decreased to the point at which significant resources become stranded, reducing the total volume of oil that can be produced under existing technologies.[118] Thus, there is an optimal rate of extraction that uses the natural pressure of the underground formation to move oil and gas to the surface, thereby allowing the petroleum trapped within the deposit enough time to migrate under the controlled and managed conditions.[119] Accelerating extraction above the optimal rate has the effect of both increasing the cost of extraction and reducing the amount of the deposit that is ultimately recoverable.[120]

i. Pooling and Unitization

The rule of capture, while pragmatic as applied to wildlife and waters, and arguably efficient in the early stages of oil and gas development, proved inefficient in long-term oil-recovery operations.[121] Employment of only the rule of capture in a given field led to overinvestment in extraction equipment, excessive depletion of the reservoir pressure within the pools, and less resource recovery compared to an approach that employed coordinated development of the resource as a whole.[122]

Legislatures and courts both responded to ameliorate the most negative effects induced by use of only the rule of capture.[123] Where state legislatures have enacted such requirements to increase the efficient use of the oil and gas resources, courts have generally upheld the requirements.[124] Under their police powers, state legislatures have instituted rules for minimum well spacing and required amounts of acreage assigned to a well ("production unit").[125] These rules require owners of small tracts to "pool" their mineral interests to aggregate enough acreage "to operate a known oil and gas reservoir as a single project."[126] Pooling can be voluntarily entered into among multiple parties.[127] However, many states have provisions for "forced pooling" if a minority of the mineral-rights-owners are unwilling to join in the formation of a production unit.[128]

"Unitization" was initially developed as a management and conservation measure so that large numbers of oil producers producing from a single reservoir within a given field would employ practices that would be less likely to damage the reservoir's production potential.[129] Unitization is the practice of creating an inclusive organization that jointly decides upon and benefits from (proportionate to the members' shares) practices that enhance the value of the aggregated field.[130] In such an arrangement, management of the

113. Rachel Amann et al., Interstate Oil & Gas Compact Comm'n, New Energy Technologies: Regulating Change 3 (2010).
114. *See id.*
115. *See id.*
116. See Lawrence H. Wickstrom & John D. Gray, *Boomtowns—Oil and Gas in Northwestern Ohio*, 11 Timeline, no. 6, 1994 at 2–15.
117. Amann et al., Interstate Oil & Gas Compact Comm'n, *supra* note 113, at 3.
118. Gérard Gaudet et al., *Private Storage of Common Property*, 43 J. Envtl. Econ. & Mgmt. 280, 281 (2002).
119. *See* Bruce M. Kramer & Owen L. Anderson, *The Rule of Capture—An Oil and Gas Perspective*, 35 Envtl. L. 899, 902 n.5 (2005).
120. Gaudet et al., *supra* note 118, at 281, 283.
121. Amann et al., Interstate Oil & Gas Compact Comm'n, *supra* note 113, at 3.
122. *See* Gaudet et al., *supra* note 118. It is interesting to note that the Interstate Oil and Gas Compact Commission was created "to conserve oil and gas by the prevention of physical waste thereof from any cause." Interstate Oil & Gas Compact Comm'n, Interstate Oil and Gas Commission Charter art. II (1935), *available at* http://www.iogcc.state.ok.us/charter (amended in 1970).
123. *See, e.g.*, Cline v. Am. Aggregates Corp., 474 N.E.2d 324, 327 (Ohio 1984) (overruling the application of the rule of capture to groundwater, and replacing it with the more equitable reasonable-use doctrine).
124. *See, e.g.*, Ohio Oil Co. v. Indiana, 177 U.S. 190, 211–12 (1900) (holding that an Indiana law prohibiting the waste of oil or natural gas by well owners was a regulation and not a taking, that law was valid, and Indiana was not required to pay just compensation to affected well owners); Russell v. Walker, 15 P.2d 114, 115 (Okla. 1932) ("Under the police power of the state, the Legislature may regulate and restrict the use and enjoyment of landowners of the natural resources of the state, such as oil and gas, so as to protect them from waste, and prevent the infringement of the rights of others. Such legislation does not infringe the constitutional inhibitions against taking of property without due process of law, denial of the equal protection of the laws, or taking property without just compensation."); Big Piney Oil & Gas Co. v. Wyo. Oil & Gas Conservation Comm'n, 715 P.2d 557, 563 (Wyo. 1986) (holding that it is the statutory duty of a state commission to prevent waste of natural resources, and thus, an order restricting production from gas wells does not constitute a taking without just compensation.)
125. *See, e.g.*, 312 Ind. Admin. Code 16-5-1 (2011) (well-spacing requirements).
126. Marston & Moore, *supra* note 78, at 476–77.
127. Phillip E. Norvell, *Prelude to the Future of Shale Gas Development: Well Spacing and Integration for the Fayetteville Shale in Arkansas*, 49 Washburn L.J. 457, 463 (2010).
128. Marie C. Baca, *Forced Pooling: When Landowners Can't Say No to Drilling*, ProPublica (May 18, 2011), http://www.propublica.org/article/forced-pooling-when-landowners-cant-say-no-to-drilling/single.
129. *See, e.g.*, Gulf Oil Corp. v. Deese, 153 So.2d 614, 618 (Ala. 1963) ("For instance, there may be a pool of oil under several tracts of land with each tract having a different ownership, yet all of such oil might be removed by a single well on one of the tracts simply because of its fluidity, to the detriment of the owners of the other tracts. Basically, this is the reason for the need of laws providing for the pooling of diverse interests into one or more drilling units for the production of oil, as has been done in Alabama . . . .").
130. Amoco Prod. Co. v. Heimann, 904 F.2d 1405, 1410–11 (10th Cir. 1990) ("Unitization refers to the consolidation of mineral or leasehold interests in oil or gas covering a common source of supply. . . . The goals of unitization are

extraction process is designed to maximize productivity of oil or gas and minimize waste, so that all benefit.[131] From the unitized mineral-rights-owners, one producer is selected to manage the operations on behalf of all the other owners.[132] As with pooling, discussed above, unitization agreements can be voluntary or compulsory.[133] The costs and benefits of entering into a unitization agreement are divided proportionally among the participants.[134]

Even in the absence of legislative action, courts have identified the establishment of "correlative rights" that mitigate the negative effects and perverse incentives encouraged by the rule of capture.[135] These rights include a duty of care imposed on oilfield developers requiring efforts not to damage the common resource (such as requiring developers to cap wells when the wells are no longer operating, in order to preserve pressure) and to make productive use of the resource once extracted (to prevent competitors from drawing down a pool for the sole purpose of depriving others of its use).[136]

ii. Enhanced Oil Recovery

CO_2 is already currently injected into gas reservoirs, though for a purpose other than long-term CO_2 sequestration. Following the initial stages of oil extraction (termed "primary recovery"), a substantial amount of the resource remains in the reservoir, often as much as 90% of the original oil.[137] It is often economical to increase the yield of a field by flushing the reservoir with produced water or brine (termed "secondary recovery" or "water flooding"), or by injecting CO_2 (termed "tertiary recovery" or "enhanced oil recovery") into it to facilitate the recovery of some remaining oil.[138] In enhanced-oil-recovery ("EOR") operations, CO_2 from either natural or industrial sources is pumped into a producing oil or gas reservoir.[139] The gas helps maintain the pressure of the reservoir and lowers the viscosity of the oil, thereby increasing the production potential of the reservoir.[140] This practice is encouraged through tax incentives.[141] In 2000 there were eighty-four operations worldwide using CO_2 floods for EOR.[142] On average, current EOR operations use about thirty megatons of CO_2 each year at a cost of about $15 per ton.[143] At one of the largest EOR operations operated by Amerada Hess near Seminole, Texas, nearly 260 million standard cubic feet of CO_2 are injected underground each day.[144]

The practice of unitization could have a significant impact on EOR operations because, without unitization, problems can arise with adjoining property-owners who have shared access to the field.[145] Because EOR activities can be costly,[146] it is possible that one landowner could benefit from the investments of another, while making no contribution.[147] Moreover, the injected CO_2 can migrate even more than the oil itself.[148] This creates the possibility that the CO_2 injected by one developer could cross over below a neighbor's property, possibly even interfering with ongoing extraction activities.[149]

If all producers in a field participate in the unit, then no participants will sue for trespass when CO_2 injected for EOR migrates into their space or if oil under their property is extracted by the unit. Where a unitization agreement is in the public interest and a nonunitized producer refuses a fair opportunity to participate, courts have held that such a producer cannot bring a suit based on trespass for an injunction of the operation.[150]

It has been argued that forced unitization could be an option for minimizing the potential for underground trespass associated with the geological sequestration of carbon.[151] When the subsurface pore space is owned by private parties, certain states have a "compulsory joinder of interest," which declares that a unit is created when a developer comes to an agreement with a substantial percentage of the property-owners (fifty to eighty percent) to create a unit in the field.[152]

Court rulings regarding EOR operations provide additional insight into how a case of CO_2 migration might be

conserving resources by preventing waste and protecting landowners' correlative rights." (footnotes omitted) (citations omitted)).

131. Gary D. Libecap & James L. Smith, *The Economic Evolution of Petroleum Property Rights in the United States*, 31 J. Legal Stud. 589, 596 (2002).
132. Chukwuemeka Mike Okorie, *Have The Modern Approaches to Unit Development of Straddling Petroleum Resources Extinguished the Applicability of the Primordial Law of Capture?*, 18 Currents: Int'l Trade L.J. 41, 45 (2010) ("In the [Unit Operating Agreement], the licensees shall appoint one of their numbers to be the unit operator, to develop and produce the deposit on behalf of all.") (citing J. Lang Weaver et al., *International Unitization of Oil and Gas Fields: The Legal Framework of International Laws, National Laws, and Private Contracts*, 5 Oil, Gas & Energy L. Intelligence, no. 2, 2007 at 96).
133. *Amoco Prod. Co.*, 904 F.2d at 1411 ("Two methods exist whereby separately-owned tracts can be combined in a single unit: voluntary unitization by contract or forced unitization by regulatory authority." (citation omitted)).
134. *See* Okorie, *supra* note 132, at 43.
135. *See Elliff*, 210 S.W.2d at 562 (noting that the owners of land with a common pool had correlative rights, which existed due to the peculiar physical and geological aspects of oil and gas fields rather than being created by statute).
136. *See, e.g.*, John Burritt McArthur, *The Restatement (First) of The Oilfield Operator's Fiduciary Duty*, 45 Nat. Resources J. 587, 609–10 (2005) (discussing a case in which the court found that the operator had a "higher duty of care by the nature of his undertaking") (citing Britton v. Green, 325 F.2d 377, 383 (10th Cir. 1963).
137. *See Enhanced Oil Reocovery/CO2 Injection*, U.S. Dep't Energy, http://fossil.energy.gov/programs/oilgas/eor/ (last updated Aug. 2, 2011).
138. *See id.*
139. *See id.*
140. *See id.* Perry M. Jarrell et al., Soc'y of Petroleum Eng'rs, Practical Aspects of CO2 Flooding (2002).
141. *See* I.R.C. § 43 (2006).
142. Heinrich et al., MIT, *supra* note 38, at 1.
143. Elizabeth J. Wilson et al., *Regulating the Ultimate Sink: Managing the Risks of Geologic CO2 Storage*, 37 Envtl. Sci. & Tech. 3476, 3481 (2003).
144. Heinrich et al., MIT, *supra* note 38, at 5.
145. *See* Elizabeth J. Wilson & Mark A. de Figueiredo, *Geologic Carbon Dioxide Sequestration: An Analysis of Subsurface Property Law*, [2006] 36 Envtl. L. Rep. (Envtl. Law Inst.) 10,114, 10,119 (Feb. 2006).
146. Ivan Sandrea & Rafael Sandrea, *Global Oil Reserves—Recovery Factors Leave Vast Target for EOR Technologies*, 105 Oil & Gas J. 44, 45 (2007).
147. Jongwook Kim & Joseph T. Mahoney, *Resource-Based and Property Rights Perspectives on Value Creation: The Case of Oil Field Unitization*, 23 Managerial & Decision Econ. 225, 238 n.11. *But see*, Steven N. Wiggins & Gary D. Libecap, *Oil Field Unitization: Contractual Failure in the Presence of Imperfect Information*, 75 Am. Econ. Rev. 368, 376 (1985) ("[H]olding out to free ride on secondary recovery projects is . . . not empirically important.").
148. *See* Wilson et al., *supra* note 143, at 3477 (noting that CO_2 could leak into lake waters, infiltrate karst caverns, and be released into the atmosphere).
149. Anderson, *supra* note 17, at 110.
150. John S. Lowe et al., Cases and Materials on Oil and Gas Law 817 (4th ed. 2002); *see also* Baumgartner v. Gulf Oil Corp., 168 N.W.2d 510, 518 (Neb. 1969).
151. *See* Wilson & Figueiredo, *supra* note 145, at 10,118–19.
152. *Id.* at 10,119.

handled. When CO_2 associated with EOR has escaped into adjacent formations, courts typically have found in favor of injecting parties, protecting them from liability.[153] If this pattern is upheld and the conditions of geological sequestration are considered similar enough to these cases, it could potentially mean that underground migration of stored CO_2 would only become a trespass issue under abnormal circumstances.[154]

There is a growing body of law regarding EOR-related CO_2 migration in which courts have declined to find liability for nuisance or trespass when the migration of injected CO_2 is associated with hydrocarbon production.[155] The reasoning behind this is that the efforts to enhance hydrocarbon production are considered to serve a public interest of such importance that it overrides most claims associated with CO_2 trespass.[156]

A key case in establishing the rule of nonliability is *Railroad Commission of Texas v. Manziel*. In that case, a well for an EOR operation using a water-flooding technique was placed 206 feet from the property boundary, instead of the regular 660 feet.[157] The uncommon placement was authorized by the Railroad Commission of Texas to protect the correlative rights of the Whelans, the party that had been issued the authorization by the Commission.[158] According to the Whelans, the Manziels were utilizing secondary-recovery techniques to produce far in excess of what was considered their "fair share" of the oil, based on what was expected to be directly below their land.[159] This secondary-recovery operation created a pressure differential that was sweeping oil that otherwise would have been recovered by the Whelens through primary recovery.[160] Requesting permission to drill an irregularly placed water-injection well was an attempt by the Whelans to recover the oil beneath their land before the Manziels could capture what the Whelans viewed as their property.[161] The Manziels objected to the waterflooding on the grounds that the water would travel across the property line, thereby giving rise to the issue of trespass from the resulting "loss and injury to their oil and gas interests due to premature flooding."[162]

The Texas Supreme Court dismissed the trespass argument raised by the Manziels.[163] The court stated that "the subsurface invasion of adjoining mineral estates by injected salt water of a secondary recovery project is to be expected."[164] The court further ruled that because the Whelans were acting in the public interest by seeking to maximize oil production, they should not be held liable for the underground trespass of the water associated with their operation.[165] The court argued that the important public interest of maximizing the supply of energy resources could outweigh the damage suffered by an individual operator.[166]

In arriving at the *Manziel* decision, the court also attempted to define trespass as it relates to subsurface property and authorized water injection. The opinion cites the case *Gregg v. Delhi-Taylor Oil Corp.*, in which trespass was identified as a physical entry upon the land by some "thing."[167] The opinion in *Manziel* questions whether water injected for the purposes of enhanced hydrocarbon recovery constitutes the type of "thing" that renders the well operator liable for trespass.[168]

The Texas court also cited an emerging concept called the "negative rule of capture" that applies the ownership-by-extraction doctrine from established oil and gas law to reinjection practices.[169] The original rule of capture was developed to clarify whether a well-owner could be held liable for extracting hydrocarbons from beneath adjacent properties. Under this original rule, oil and gas are not considered owned until they are captured and reduced to possession; therefore, there is no liability for causing the oil from beneath a neighbor's land to migrate up one's own well, if all other statutes and regulations have been observed.[170] The inverse of this rule, or its "negative," states that there is no liability for materials traveling in the reverse direction and intruding into the subsurface of the adjacent property.[171]

Courts have stipulated that certain requirements must be met, however, for the injector to qualify for nonliability, including that the injection be authorized as part of an approved EOR operation.[172] Approval, in most cases, is authorized by the U.S. Environmental Protection Agency ("EPA") or a designated state regulatory body.[173] If an individual acts to inject substances without authorization, that individual will be liable for any resulting damage to adjacent wells.[174] However, even if the injecting party fails to obtain authorization, that party will be exempt from liability if the adjoining formation was extremely sizable and the relatively small quantity of injected materials could not be considered to do any harm.[175]

Additional issues arise if migration of the injected material damages the wells on surrounding lands. In some cases, compensation has been awarded even if the injection was authorized. This was the case in *Tidewater Oil Co. v. Jackson*, in which damages were awarded to compensate for lost wells

153. *See id.* at 10,119–20.
154. *See id.* at 10,121.
155. Richard W. Hemingway, The Law of Oil and Gas 175 (3d ed. 1991).
156. *See id.* at 190.
157. R.R. Comm'n of Tex. v. Manziel, 361 S.W.2d 560, 561–62. (Tex. 1962).
158. *Id.* at 561.
159. *Id.* at 573.
160. *Id.*
161. *Id.* at 574.
162. *Id.* at 566.
163. *Id.* at 568.
164. *Id.* at 564.
165. *See id.* at 568.
166. *Id.*
167. *Id.* at 567; *Gregg v. Delhi-Taylor Oil Corp.*, 344 S.W.2d 411, 416 (Tex. 1961).
168. *Manziel*, 361 S.W.2d at 567.
169. *Id.* at 568.
170. Lowe, *supra* note 90, at 10; *see also supra* notes 105–107 and accompanying text.
171. Lowe et al., *supra* note 150, at 815.
172. *Id.* at 816.
173. *See* Office of Water, EPA, EPA 816-R-02-025, Technical Program Overview: Underground Injection Control Regulations 2–6 (2002), *available at* http://www.gwpc.org/e-library/documents/general/Technical%20Program%20Overview-%20Underground%20Injection%20Control%20Regulations.pdf.
174. *See* W. Edmond Hunton Lime Unit v. Lillard, 265 P.2d 730, 730–33 (Okla. 1954).
175. *See* W. Edmond Salt Water Disposal Ass'n v. Rosecrans, 226 P.2d 965, 969 (Okla. 1950), *appeal dismissed*, 340 U.S. 924 (1951).

on the basis that property values were lost by private action.[176] Generally, under programs in which action to serve the public interest is authorized by a regulatory body, such authorization is considered an exercise of police power and therefore no compensation is recognized.[177] However, it is possible that because EOR operations benefit the private producer—not just the public—the situation might be different enough from a traditional use of police power to require compensation for damages.[178]

A similar situation could arise with geological sequestration where an adjoining reservoir is damaged by the injection of CO_2. It would be simple to apply the argument that the action causing the damages was conducted in the public interest. Mitigating global warming could certainly be viewed as beneficial to the public. But, if *Tidewater* is applied, the injector could still have to pay compensation if the damages resulted from private action.

One significant detail in *Tidewater* is that the court did not consider the authorization of EOR to be a traditional use of police power,[179] thereby keeping the door open for a finding that compensation was justified. But if the authorization of carbon-sequestration activity is determined to be a traditional exercise of police power, compensation would not be recognized and no payment would be required for damages resulting from underground intrusion.

Where the EOR analogy begins to fail, however, is in predicting what will happen after the CO_2 is injected and left below ground. Typical EOR operations try to recycle and reuse as much of the CO_2 initially pumped into the reservoir as possible.[180] In contrast, in the case of CCS projects, the injection wells would be plugged and the hope would be for the CO_2 to remain underground indefinitely.[181] However, the potential exists for CO_2 to migrate away from the injection site to a lower-pressure area.[182] The degree and range of the migration is uncertain and depends on specific geologic and other attributes of each site.[183]

Following a review of two subsurface trespass cases in Texas,[184] the Interstate Oil and Gas Compact Commission ("IOGCC") concluded:

> The implication of these cases for carbon dioxide storage is debatable. Whether a court would find the storage of carbon dioxide to be a public necessity where adjacent property owners' rights are trumped by the importance of carbon sequestration is uncertain. On the one hand, the storage of carbon dioxide may lower greenhouse gas pollution, but on the other it is questionable whether the potential benefit of lowered greenhouse gas is more important than the property rights of the adjacent property owners. Secondary recovery methods are producing fungible resources in the form of oil and gas whereas the storage of carbon dioxide will not yield fungible resources. Both *Manziel* and *Garza Energy Trust* seem to key on the importance of secondary recovery of oil and gas, and the argument[] why a trespass cause of action should not be actionable is based on fungible resources being produced. A regulatory program for [geologic storage] should include a declaration that the activity is of high public importance.[185]

Assessing the potential to apply the negative rule of capture to CCS, a New Mexico state government report observed:

> This approach may be justified by positing that sequestration of CO2, and the consequent reduction of greenhouse gas emissions, is a public benefit, or a mitigation of a public nuisance. A likely impediment to this approach is the 5th Amendment of the U.S. Constitution, which provides that no property shall be taken for public use without just compensation. Assuming that the pore space containing the mineral estate is the property of the surface owner and not the mineral estate, this property right presents problems for the application of the negative rule of capture because the non-consensual occupation of privately held space is considered a taking.[186]

There are many similarities between the needs for coordination among landowners in oil production and in CCS. Both involve productive use of a field whose boundaries cover multiple—potentially many—landowners. Both also involve some use of the surface to access the subsurface resources, and potential trespass issues. But the analogy is limited. Perhaps most obviously, the injected gas is left for permanent storage in the case of CCS. More importantly, the financial arrangements for the two operations would be substantially different. In a typical unitization operation, the product is a commodity that has significant value in competitive markets. All owners are entitled to a royalty on the extracted resource.[187] In contrast, the CCS operation does not produce a commodity. Therefore, the notion of royalties that drives the unitization process of oil and gas development has no meaning in the CCS setting.

176. *Tidewater Oil Co. v. Jackson*, 320 F.2d 157, 166 (10th Cir. 1963), *cert. denied*, 375 U.S. 942 (1963).
177. Hemingway, *supra* note 155, at 190.
178. *Id.*
179. *Tidewater*, 320 F.2d at 157–65.
180. Marston & Moore, *supra* note 78, at 424.
181. *See id.* at 437–39.
182. *Overview of Geological Sequestration*, *supra* note 1.
183. Heinrich et al., *supra* note 38, at 1–2; Nat'l Energy Tech. Lab., U.S. Dep't of Energy, FE0002441, Modeling and Evaluation of Geophysical Methods for Monitoring and Tracking CO_2 Migration in the Subsurface 1–2 (2010), *available at* http://www.netl.doe.gov/publications/factsheets/project/FE0002441.pdf.
184. R.R. Comm'n of Tex. v. Manziel, 361 S.W.2d 560 (Tex. 1962); Mission Res., Inc. v. Garza Energy Trust, 166 S.W.3d 301, 310 (Tex. App. 2005), *overruled by* Coastal Oil & Gas Corp. v. Garza Energy Trust, 268 S.W.3d 1 (Tex. 2008).
185. Task Force on Carbon Capture & Geologic Storage, Interstate Oil & Gas Compact Comm'n, Storage of Carbon Dioxide in Geologic Structures: A Legal and Regulatory Guide for States and Provinces 21 (2007), *available at* http://www.gwpc.org/e-library/documents/co2/IOGCC%20Master%20CO2%20Regulatory%20Document%209-2007.pdf.
186. Mark E. Fesmire et al., N.M. Energy, Minerals, Natural Res. Dep't, A Blueprint for the Regulation of Geologic Sequestration of Carbon Dioxide in New Mexico 15 (2007), *available at* http://www.emnrd.state.nm.us/ocd/documents/CarbonSequestrationFINALREPORT1212007_000.pdf.
187. Wiggins & Libecap, *supra* note 147, at 368.

iii. Separation of Surface-Estate and Mineral Interests

One of the questions that complicates the issue of pore-space property rights is whether the right to control, and perhaps lease, the pore space resides with the surface-owner or the mineral-owner.

The ruling in *Tate v. United Fuel Gas Co.* summarizes the property law of pore space in West Virginia under varying circumstances.[188] In that case, United Fuel entered into an agreement[189] with the oil-, gas-, and mineral-owners to store gas in the limestone stratum associated with the mineral-owners' titles.[190] This agreement came out of a deed to mineral interests in which the underlying "coal, clay, sand, stone or surface minerals" were excepted.[191] Based on this exception, the surface-owner objected, alleging continuing trespass and requesting cessation of the activity.[192] The Supreme Court of Appeals of West Virginia ruled that the mineral-owners did not possess the right to grant use of the subsurface pore space for the purpose of storing natural gas.[193] The decision cited *Lillibridge v. Lackawanna Coal Co.* and subsequent limitations thereon that stated that the mineral-interest-owner may utilize the subsurface space only so long as there remain recoverable minerals.[194] Because the complaint in *Tate* alleged that there were no recoverable minerals, the court ruled that the mineral-owner did not have a right to use the subsurface space.[195]

It is crucial to note, however, that the court in *Tate* went on to acknowledge that in West Virginia, the term "mineral" typically includes all but the "superficial" part of the land.[196] The opinion in *Tate* cited a decision supporting the determination that a mineral interest tends to mean "primarily all substances, other than the agricultural surface of the ground."[197] The ruling in *Tate* is therefore limited to the particular case based on the exception in the deed under consideration.[198]

The outcome of applying the opinion in *Tate* to CO_2 sequestration would be dependent on how various mineral interests were deeded. Though the ruling ends up in favor of the surface-owner, the opinion clearly states that this is an exception based on the terms of a specific deed.[199] Without this exception, the mineral-interest-owner would retain use of the subsurface, so long as there were recoverable minerals, as stipulated by the limitations to *Lillibridge*.[200]

This decision is unclear, however, regarding when a subsurface can be considered to be depleted of its recoverable minerals.[201] The court does not specify whether "depleted" means that the mineral is gone in its entirety or that further recovery simply is no longer economically feasible.[202] This is significant because it is technologically impossible to remove all oil from a reservoir, and typically one-quarter to one-half of a reservoir's oil remains underground.[203] If this means that the geologic formation still contains minerals, then the property right to the formation belongs to the mineral-owner.[204] However, if it is not simply the presence but the ability to further produce that determines whether the geologic formation still contains minerals, then pore-space storage sites would be owned by the surface-owner according to the *Tate* ruling.[205]

Perhaps more importantly for the future of CCS operations, *Tate* illustrates the potentially high transaction costs that can be associated with identifying owners. As discussed above, CCS fields may be large relative to the areas involved in mineral extraction.[206] Clarifying ownership rights across many tracts may be extremely cumbersome and costly.

b. Natural-Gas Storage

Some analysts have suggested that underground storage of natural gas provides a particularly useful analogy for CCS, noting the similarity between proposed CCS operations and the existing practice of storing natural gas in the subsurface.[207] For example, the IOGCC considered the laws related to four analogs but concluded that natural-gas storage provides the best analog for how to manage the property-rights issue.[208] There is, in fact, much to be learned from this analog, though the distinctions are also important.[209] Certain physical characteristics of natural gas are similar to those of CO_2,[210] and the extensive experience with natural-gas storage and the associated technology could guide the CCS industry, government policymakers, and the courts in the process of implementing geological carbon sequestration.

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188. Tate v. United Fuel Gas Co., 71 S.E.2d 65, 71–72 (W. Va. 1952).
189. The lease to United Fuel came from the deed to the mineral interest with the exception: "an undivided one-fourth interest each in the oil and gas and other minerals, 'except coal, clay, sandstone or surface minerals' underlying the 244 acre tract." *Id.* at 68.
190. *Id.* at 71 ("Defendants, in effect, contend that, assuming certain space has been vacated by the production of the gas in the Big Lime stratum, the individual defendants now own such space and have the right to the exclusive use thereof.").
191. *Id.* at 68.
192. *Id.*
193. *Id.* at 72.
194. *Id.* at 71 (citing Lillibridge v. Lackawanna Coal Co., 22 A. 1035 (Pa. 1891); Webber v. Vogel, 42 A. 4 (Pa. 1899); Westerman v. Pa. Salt Mfg. Co., 103 A. 539 (Pa. 1918); Everly v. Shannopin Coal Co., 11 A.2d 700 (Pa. Super. Ct. 1940)).
195. *Id.* ("Under the rule of the cases cited, we do not think that the individual defendants or the corporate defendant have a right to use the space in the Big Lime stratum, if any such space exists.").
196. *Id.* at 72.
197. *Id.* (quoting Rock House Fork Land Co. v. Raleigh Brick & Tile Co., 97 S.E. 684, 685 (W. Va. 1918)).
198. *Id.*
199. *Id.*
200. *See id.* at 71.
201. *See id.*
202. *See id.*
203. *Soaps, Bugs and Other Ways to Produce Oil,* U.S. Dep't Energy, http://fossil.energy.gov/education/energylessons/oil/oil4.html (last updated Mar. 29, 2011).
204. *Tate*, 71 S.E.2d at 71.
205. *Id.*
206. *See supra* note 86 and accompanying text.
207. Anderson, *supra* note 17, at 115–18.
208. Task Force on Carbon Capture & Geologic Storage, Interstate Oil & Gas Compact Comm'n, *supra* note 185, at 14–15. The other three analogs were naturally-occurring CO_2, EOR, and the injection of acid gas.
209. *Id.* at 27.
210. *Processing Natural Gas*, NaturalGas.org, http://www.naturalgas.org/naturalgas/processing_ng.asp (last visited Nov. 15, 2011).

The demand for natural gas is subject to substantial seasonal and even time-of-day cycles.[211] Combined with market fluctuations in the price of natural gas, many gas utilities have found it efficient to store natural gas in underground storage fields during times of low price or low demand in anticipation of rises in each.[212]

There are three types of facilities used for natural gas storage.[213] First, and by far the most common, are depleted oil and gas reservoirs.[214] These are areas that have produced fossil fuels but can no longer economically produce such fuels.[215] The fields are generally charged with natural gas in the summer and drawn down in the winter.[216] Second, a relatively small percentage of facilities are located in salt caverns formed from underground salt domes or formations.[217] These facilities cycle more easily than the depleted reservoirs and are often used to manage peak-day demands.[218] Third, companies store natural gas in aquifers—water-bearing, porous rocks—in enclosed structural or stratigraphic traps.[219] In this case the natural gas displaces the water.[220]

Of these three, the depleted reservoirs are the least expensive to establish and the aquifers are the most expensive.[221] Depleted reservoirs are often thoroughly studied and characterized, they tend to be located near natural-gas pipelines, and they are often already fitted with wells that can be used for injection and production.[222] Because they have held oil and natural gas in the past, depleted reservoirs have proven storage capabilities.[223] In contrast, aquifers are generally less characterized and require greater amounts of pressurization with "cushion gas" in addition to the "working gas."[224]

In 2003, there were 415 underground natural-gas-storage facilities in the United States, approximately half of which were under the jurisdiction of the Federal Energy Regulatory Commission ("FERC").[225] Nearly half of all storage capacity is in the Midwest.[226] In 2007, Indiana had 22 active natural-gas-storage facilities.[227] Of these facilities, 10 were located in depleted reservoirs and 12 were in aquifers.[228] The average depth of the formations in the active facilities is 1,200 feet (366 meters), and the average area of active facilities is 4,736 acres (1,917 hectares).[229] The total area covered by active facilities in Indiana is 94,728 acres, or 0.4% of the entire area of the state.[230]

Because the development of a natural-gas-storage field can require assembling property rights previously held by many individuals who might be reluctant participants in the field development, states have created avenues to grant eminent-domain rights to public utilities seeking to develop subsurface natural-gas-storage fields.[231] One variation of the eminent-domain power is the "quick-take" provision by which the condemning authority takes immediate control of the property.[232] This provision is particularly important in natural-gas-development projects where there is a strong public interest in expeditious development.[233]

To analogize from existing gas-storage practices and law to CCS practices and law, it is important to recognize both the similarities and differences between the two. Both natural gas and CO_2 have a tendency to rise within a storage structure,[234] and depleted oil and gas reservoirs may be used as storage sites for both natural gas and CO_2.[235] Importantly, monitoring protocols for underground natural-gas storage already exist (though regulations and required monitoring

211. *Why Do Natural Gas Prices Fluctuate So Much?*, U.S. Energy Info. Admin., ftp://ftp.eia.doe.gov/pub/oil_gas/natural_gas/analysis_publications/why_do_prices_fluctuate/html/ngbro.html (last visited Nov. 15, 2011).
212. James Tobin & James Thompson, U.S. Energy Info. Admin., Natural Gas Storage in the United States in 2001: A Current Assessment and Near-Term Outlook 3 (2001), *available at* ftp://ftp.eia.doe.gov/features/storage.pdf.
213. *The Basics of Underground Natural Gas Storage*, U.S. Energy Info. Admin., http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/storagebasics/storagebasics.html (last updated Aug. 2004).
214. *Id.*
215. *Id.*
216. *Id.*
217. *Storage of Natural Gas*, NaturalGas.org, http://www.naturalgas.org/naturalgas/storage.asp (last visited Nov. 15, 2011).
218. *Id.*
219. *Id.*
220. *Id.*
221. *Id.*
222. *Id.*
223. *Id.*
224. *Id.*
225. Fed. Energy Regulatory Comm'n, Docket No. AD04-11-000, Current State of and Issues Concerning Underground Natural Gas Storage 7 (2004), *available at* http://www.ferc.gov/eventcalendar/files/20041020081349-final-gs-report.pdf.
226. *Id.*
227. *Underground Natural Gas Storage*, U.S. Energy Info. Admin., http://ftp.eia.doe.gov/pub/oil_gas/natural_gas/analysis_publications/ngpipeline/undrgrnd_storage.html (last visited Nov. 15, 2011).
228. *Id.*
229. Stanley J. Keller, Ind. Geological Survey, Special Report 59, Underground Storage of Natural Gas in Indiana (1998).
230. Indiana area is 35,826.11 square miles. *State & County QuickFacts: Indiana*, U.S. Census Bureau, http://quickfacts.census.gov/qfd/states/18000.html (last visited Nov. 18, 2011).
231. *See, e.g.*, Kan. Stat. Ann. § 55-1205 (2009); Owen L. Anderson, *Geologic CO_2 Sequestration: Who Owns the Pore Space?*, 9 Wyo. L. Rev. 97, (2009) ("[Natural gas utilities in Texas may acquire [underground] gas storage rights by eminent domain.") (citing Tex. Nat. Res. Code Ann. §§ 91.171–.184 (West 2011)).
232. *E.g.*, Moorhead Econ. Dev. Auth. v. Anda, 789 N.W.2d 860, 868 (Minn. 2010) ("A quick-take proceeding allows a condemning authority to take title to and possession of property more quickly than it would in a standard eminent domain proceeding. In a standard eminent domain proceeding, court-appointed commissioners meet, hold a hearing, and make an award of damages before the condemnor takes title to and possession of the property. Because the standard eminent domain procedure can be lengthy, Minnesota's quick-take statute enables a condemning authority to take title to and possession of the owner's property *before* the commissioners file their award. The procedure can be utilized when the condemnor 'require[s] title and possession of all or part of the owner's property prior to the filing of an award by the court appointed commissioners.' Under a quick-take proceeding, a district court may transfer title to and possession of property to the condemnor after the condemning authority has given the property owner at least a 90-day notice of its intention to take early title and possession and has paid to the owner or deposited with the court an amount equal to the condemnor's approved appraisal of the property's value. Under the quick-take procedure, the court-appointed commissioners file their award after the transfer of title to and possession of the property. Even though title to and possession of the property have already been transferred, the property owner still retains the right to appeal the commissioners' award after it has been filed." (citations omitted)).
233. For a discussion of the "quick-take" provision in the context of natural-gas development, see Jim Behnke & Harold Dondis, *The* Sage *Approach to Immediate Entry by Private Entities Exercising Federal Eminent Domain Authority Under the Natural Gas Act and the Federal Power Act*, 27 Energy L.J. 499, 512 (2006).
234. Heinrich et al., MIT, *supra* note 38, at 6.
235. Marcelo J. Lippmann & Sally M. Benson, Ernest Orlando Lawrence Berkeley Nat'l Lab., Relevance of Underground Natural Gas Storage to Geologic Sequestration of Carbon Dioxide 1 (2008), *available at* http://www.osti.gov/bridge/servlets/purl/813565-MVm7Ve/native/813565.pdf; *see supra* notes 61–67 and accompanying text.

vary by state),[236] showing that analogous monitoring protocols for underground storage of CO_2 could be developed.

There are, however, significant differences as well. Natural gas is stored temporarily and often re-extracted in less than one year after having been injected into the storage reservoir,[237] whereas geologic CO_2 sequestration is intended to be permanent.[238] In addition, the volumes of natural gas stored (and therefore the associated amounts of acreage and pore space required) are an order of magnitude smaller than those that would be needed for the storage of injected CO_2.[239] A further difference is that a major risk associated with natural-gas storage—the flammability of the gas—does not exist in the case of CO_2.[240]

As discussed above, the rule of capture states that ownership of oil or gas is obtained when the mineral is reduced to possession by physical extraction.[241] Some parties have argued that when natural gas is re-injected into the subsurface, the injecting party loses title to it by returning the gas to its previous, uncaptured state.[242] Under this theory, if the injected natural gas migrated beneath neighboring property, the neighbor had the legal right to extract it and thereby claim title to the resource as if no prior claim existed.[243]

The leading case articulating this theory is *Hammonds v. Central Kentucky Natural Gas Co.*[244] In *Hammonds*, Della Hammonds owned land within the boundaries of a gas company's underground storage site.[245] Ms. Hammonds sued for trespass, arguing that the company's stored gas had been "placed" without her consent in the section of the formation that underlay her land.[246] Kentucky's highest court ruled against Hammonds's trespass claim, saying that once the gas was re-injected, the gas company lost the property rights and could only regain those rights by extraction a second time.[247] The court's reasoning was based on the fugacious nature of oil and gas and an analogy to wild animals.[248] A wild animal, the court said, was only the property of an individual when it was in direct possession of that individual.[249] If a person released the animal into an area of common property, that person lost claim to the animal and it could be recaptured by anyone.[250] The Kentucky court argued that this same logic applied to oil and gas.[251]

Since this case, however, several courts have rejected both the ruling from *Hammonds* regarding ownership and the analogy drawn between wild animals and injected gas.[252] Such cases include *White v. New York State Natural Gas Corp.*[253] and *Lone Star Gas Co. v. Murchison*.[254] The court in *White* stated that the gas company owned the extent of the storage reservoir and therefore retained control of the gas.[255] The stored gas never escaped from its owners,[256] unlike in *Hammonds* where it migrated to a neighboring portion of the reservoir owned by another party.[257] In addition, the portion of the opinion in *Hammonds* stating that injected gas could be reextracted with a new claim to title was based on the presumption that the gas was returned to its "natural habitat."[258] This was not the situation in *White,* the court said, because the type of gas stored by the company was not native to the sands of the storage site being used.[259] Based on these discrepancies between the cases' details, *Hammonds* was rejected as a binding precedent for *White*.[260]

The reasoning in *Hammonds* was rejected again in *Lone Star*, but this time the decision had broader reach than in *White*, because it discarded the premise on which *Hammonds* was decided instead of merely distinguishing the facts of the case.[261] The court worded its rejection of *Hammonds* very strongly and reflected the prevailing criticism of the decision circulating in law reviews at the time.[262] The opinion first stated, "Gas has no similarity to wild animals," and then continued to debase the wild-animal analogy by describing the dissimilar characteristics of movement between animals and gas.[263] The final blow to *Hammonds* was issued when the *Lone Star* decision declared that "in Texas, the owner of gas does not lose title thereof by storing the same in a well-defined underground reservoir."[264]

In *Texas American Energy Corp. v. Citizens Fidelity Bank & Trust Co.*, a Kentucky court declared that *Hammonds* was overruled.[265] *Texas American* involved a loan agreement between the plaintiff, Texas American, and the respondent, Citizens Fidelity.[266] Texas American had purchased the assets and property of Western Kentucky Gas Company, which was primarily in the business of purchasing natural gas for resale to consumers.[267] Western stored surplus gas in underground storage fields during seasons of low demand.[268]

236. Lippmann & Benson, *supra* note 235, at 3.
237. *Id.* at 1.
238. *See* Klass & Wilson, *supra* note 20.
239. Lippmann & Benson, *supra* note 235, at 1.
240. *Id.* at 3.
241. *See supra* notes 106–112 and accompanying text.
242. Hammonds v. Cent. Ky. Natural Gas Co., 75 S.W.2d 204, 206 (Ky. 1934), *overruled by* Tex. Am. Energy Corp. v. Citizens Fid. Bank & Trust Co., 736 S.W.2d 25 (Ky. 1987).
243. *Id.*
244. *Id.*
245. *Id.* at 204.
246. *Id.*
247. *Id.* at 206.
248. *Id.* at 205–06.
249. *Id.* at 206.
250. *Id.*
251. *Id.* ("We are of opinion, therefore, that if in fact the gas turned loose in the earth wandered into the plaintiff's land, the defendant is not liable to her for the value of the use of her property, for the company ceased to be the exclusive owner of the whole of the gas—it again became mineral ferae naturae.").
252. White v. N.Y. State Natural Gas Corp., 190 F. Supp. 342 (W.D. Pa. 1960); Lone Star Gas Co. v. Murchison, 353 S.W.2d 870 (Tex. Civ. App. 1962).
253. *White*, 190 F. Supp. at 342.
254. *Lone Star*, 353 S.W.2d at 870.
255. *White*, 190 F. Supp. at 348.
256. *Id.*
257. *Hammonds*, 75 S.W.2d at 204.
258. *Id.* at 206.
259. *White*, 190 F. Supp. at 348.
260. *Id.* at 345 n.2.
261. Lone Star Gas Co. v. Murchison, 353 S.W.2d 870, 879 (Tex. Civ. App. 1962).
262. John S. Lowe et al., *supra* note 150, at 20.
263. *Lone Star*, 353 S.W.2d at 879.
264. *Id.* at 879.
265. Tex. Am. Energy Corp. v. Citizens Fid. Bank & Trust Co., 736 S.W.2d 25, 28 (Ky. 1987).
266. *Id.*
267. *Id.*
268. *Id.*

When Texas American applied for a loan, the ownership of the stored natural gas needed to be determined to properly calculate the conveyable assets for a security interest.[269] Citizens Fidelity and other banks involved in the loan initially agreed to grant the loan with the protection of such a security interest.[270] But then an argument arose over whether the stored gas qualified as personal property and was therefore eligible for inclusion in a security interest, as stipulated by Kentucky's commercial code.[271] If the injected gas was not personal property, then the loan agreement would have to leverage the gas in terms of a real-estate mortgage.[272] The banks argued that, when injected, the gas reverted back to a real-estate interest, but Texas American argued that it remained personal property.[273]

Following a review of *Hammonds*, *White*, and *Lone Star*, the court decided that even in Kentucky, where *Hammonds* originated, the injector of natural gas into underground storage sites retained title to the resource.[274] However, the court included certain stipulations and limitations on its decision.[275] It stated that, to ensure retention of ownership, the underground reservoir should be defined with certainty and the integrity should be maintainable.[276] If these qualifications are met, any language in *Hammonds* that indicates stored natural gas reverts back to a common resource upon injection is specifically overruled by *Texas American*.[277]

The evolution of case law concerned with subsurface migration from underground storage of natural gas and other energy-related injection practices demonstrates a potential path for CO_2 litigation. Past subsurface-migration cases have determined how the rule of capture applies to gas that humans send back into subsurface structures after initial capture and how ownership of injected materials is determined.[278] Other cases have dealt with the issues of trespass, correlative rights, and property damage.[279]

The analogy between injection of natural gas for storage and the injection of CO_2 for disposal is not perfect, however. Philip Marston and Patricia Moore argue that the analogy between CCS and natural-gas storage is flawed because CO_2 is a foreign substance (although they focus much attention on the CO_2 obtained from naturally occurring sources for EOR).[280] Jeffrey Moore observed additional differences between natural-gas storage and CO_2 disp osal:

> Natural gas storage, while an analog for [onshore geologic sequestration], is exempt from regulation under the [Underground Injection Control] program. Natural gas is injected into shallow, porous formations for temporary storage to maintain reserves. Subsurface natural gas storage has been performed for nearly a century and is considered safe and effective. The natural gas exemption will not apply to supercritical CO_2 injected for geologic sequestration. Even though CO_2 is a naturally-occurring gas, the natural gas exemption applies only to "natural gas as it is [commonly] defined" (i.e. gaseous hydrocarbons), and "not to other injections of matter in a gaseous state." The EPA has concluded that CO_2 is not a natural gas under the UIC program. Moreover, the United States Court of Appeals for the Tenth Circuit has concluded that CO_2 is not a natural gas under the [Safe Drinking Water Act].[281]

In short, while the natural-gas-injection analog provides useful insights for approaching development of a CCS regulatory structure that in part governs property rights, it is far from being a perfect analog.

2. Waste Analogs

While natural-gas injection for underground storage bears many similarities to CCS, there are still significant differences. Some researchers have suggested that deep injection of waste for long-term disposal is a more apt analog. Here we consider two applications: hazardous-waste injection and wastewater injection. Both are regulated under the Underground Injection Control ("UIC") program, implemented under the Safe Drinking Water Act.[282] EPA issued a final CCS rule under the UIC program in December 2010, but this rule does not address the property-rights issue.[283]

a. Hazardous-Waste Injection

Hazardous-waste injection offers an important analogy for implementing geological sequestration of carbon dioxide. Acid gas is a hazardous byproduct of the natural-gas sweetening process and is disposed of by underground injection.[284] In the case of acid gas, CO_2 and hydrogen sulfide are removed from an oil or gas stream from a geological formation and injected into deep wells located in different geological formations.[285] The purpose of injection is to dispose of the acidic hydrogen sulfide, but CO_2 is often the largest component of the gas stream—at times making up more than ninety percent of the total volume of gas injected.[286] Because the gas is injected for disposal and long-term storage, acid-gas injection is an especially applicable comparison for large-scale CO_2 sequestration. In addition, an EPA regulatory regime (UIC Class II) already governs this practice.[287]

269. *Id.* at 26.
270. *Id.*
271. *Id.*
272. *Id.*
273. *Id.*
274. *Id.* at 28.
275. *Id.*
276. *Id.*
277. *Id.*
278. *See, e.g.*, *id.*
279. *See, e.g.*, *Chance v. BP Chems. Inc.*, 670 N.E.2d 985 (Ohio 1996).
280. Marston & Moore, *supra* note 78, at 475.
281. Jeffrey W. Moore, *The Potential Law of On-Shore Geologic Sequestration of CO_2 Captured from Coal-Fired Power Plants*, 28 Energy L.J. 443, 462 (2007) (footnotes omitted).
282. EPA Underground Injection Control Program, 40 C.F.R. § 144.6 (2011).
283. Federal Requirements Under the Underground Injection Control (UIC) Program for Carbon Dioxide (CO_2) Geologic Sequestration (GS) Wells, 75 Fed. Reg. 77,230 (codified at 40 C.F.R. pts 124, 144–47).
284. *See generally* Tim B. Boyle & John J. Carroll, *Study Determines Best Methods for Calculating Acid-Gas Density*, Oil & Gas J., Jan. 14, 2002, at 45.
285. Heinrich et al., MIT, *supra* note 38, at 4.
286. *Id.* at 5.
287. 40 C.F.R. § 144.6.

As with natural-gas storage or injection of CO_2 for EOR, hazardous-waste injection can result in the migration of the injected material below the surface into neighboring subsurface properties.[288] This raises the question of whether the migration constitutes a trespass onto the property of others.

The leading court case on this point is *Chance v. BP Chemicals*.[289] In simplest terms, the plaintiff Chance complained that the defendant had injected hazardous waste that had migrated below Chance's property.[290] The court found no liability for BP:

> The Ohio court . . . extended the reasoning of *Hinman v. Pacific Air Transp.*, 84 F.2d 755, 758 (C.A. 9, 1936) ("We own so much of the space above the ground as we can occupy or make use of, in connection with the enjoyment of our land") to apply equally to below-ground interests. The Ohio court in *Chance*, however, recognized that appellants did have a limited property interest in the rock into which the injectate was placed, so that injectors could be liable in situations where there is demonstrable interference with the surface owner's "*reasonable and foreseeable* use of their properties" (emphasis added). Thus, the court held, "appellants [had] the burden of establishing that the injectate interfered with the reasonable and foreseeable use of their properties."[291]

In other words, the court would find liability only if the loss of the space into which the injectate intruded could be demonstrated to have caused the plaintiff a real economic loss; speculative or abstract losses were not enough to establish the defendant's liability for the intrusion.[292] This places the burden on the plaintiff to provide convincing evidence not only of demonstrable interference, but also that the use to which the plaintiff was putting the pore space was both reasonable and foreseeable.[293] The IOGCC has interpreted this to mean that trespass is actionable even with a valid operating permit, but that the plaintiffs in *Chance* lost because they had not meet their burden of proof.[294]

While the *Chance* case is an Ohio Supreme Court holding and therefore not binding outside of Ohio, it suggests that other courts might find that the migration of CO_2 injectate below the property of others will only be actionable if those parties can demonstrate interference with a "reasonable and foreseeable" use of their property.

b. Wastewater Injection

The analogy of CCS to wastewater warrants at least a brief mention. Florida disposes of a substantial amount of municipal wastewater by injecting it deep underground, at depths between 250 and 1,250 meters.[295] The activity is regulated under the UIC Program.[296] The primary purpose behind the regulation of municipal wastewater injection is to avoid injectate migration, particularly migration that could contaminate drinking water sources.[297] What is most interesting, perhaps, is that in the literature on wastewater injection, there is virtually no mention of pore-space ownership or of the possibility that migration constitutes trespass. The emphasis is purely on human-health concerns.[298]

3. Freshwater Resource Analogs

Water law and management also provide a useful set of analogies for CCS application. Particularly useful concepts that emerge from this field include the public-trust doctrine and the public-servitude doctrine.

a. Surface Waters

It is clear that individual states are vested with control over navigable waters under the doctrine of public trust.[299] This means that no individual can claim a private right to surface waters.[300] Those waters belong to the public and are held in trust by the government on behalf of the people.[301]

That trust also extends to the beds underlying the waters.[302] *Arnold v. Mundy,* one of the earliest cases on point, demonstrated that "not only do people have common rights of fishing and navigation on tidal and navigable waters, but the state, acting as trustee for the people, owns the tide-washed and submerged lands."[303]

It might be argued that deep-subsurface pore space is as much in need of protection and management under the public-trust doctrine as are the surface waters—that the resource should be available for uses that benefit all, not appropriated by individuals. Four decades ago, Joseph Sax argued for a much broader interpretation of the public-trust doctrine,[304] and Jeffrey Henquinet and Tracy Dobson have argued that the doctrine is one of the tools that could be used to conserve fishery resources and to protect the ecosystem in which the fish reside in the Great Lakes Basin.[305]

288. EPA, EPA 816-R-01-007, Class I Underground Injection Control Program: Study of the Risks Associated with Class I Underground Injection Wells 13 (2001), *available at* http://www.epa.gov/ogwdw/uic/pdfs/study_uic-class1_study_risks_class1.pdf.
289. *Chance v. BP Chems., Inc.*, 670 N.E.2d 985 (Ohio 1996).
290. *Id.* at 993.
291. Fesmire et al., N.M. Energy, Minerals, Natural Res. Dep't, *supra* note 186, at 21 (citations omitted).
292. *Chance*, 670 N.E.2d at 993.
293. *Id.*
294. Task Force on Carbon Capture & Geologic Storage, Interstate Oil & Gas Compact Comm'n, *supra* note 185, at 10.
295. David W. Keith et al., *Regulating the Underground Injection of CO_2*, 39 Envtl. Sci. & Tech. 499A, 501A (2005).
296. *Id.*
297. *Id.*
298. *See, e.g.*, 40 C.F.R. § 144.6 (2009).
299. *See, e.g.*, Ill. Cent. R.R. Co. v. Illinois, 146 U.S. 387, 458–60 (1892).
300. *Id.*
301. *Id.*
302. *See* Arnold v. Mundy, 6 N.J.L. 1 (1821)
303. Bonnie J. McCay, Oyster Wars and the Public Trust: Property, Law, and Ecology in New Jersey History 45 (1998).
304. Joseph L. Sax, *The Public Trust Doctrine in Natural Resource Law: Effective Judicial Intervention*, 68 Mich. L. Rev. 471, 474 (1970).
305. Jeffrey W. Henquinet & Tracy Dobson, *The Public Trust Doctrine and Sustainable Ecosystems: A Great Lakes Fisheries Case Study*, 14 N.Y.U. Envtl. L.J. 322,

Some states have incorporated the doctrine into their constitutions and used it to protect natural resources. For example, article XI, section 1 of the Hawaii Constitution states:

> For the benefit of present and future generations, the State and its political subdivisions shall conserve and protect Hawaii's natural beauty and all natural resources, including land, water, air, minerals and energy sources, and shall promote the development and utilization of these resources in a manner consistent with their conservation and in furtherance of the self-sufficiency of the State.
>
> All public natural resources are held in trust by the State for the benefit of the people.[306]

The Pennsylvania Constitution includes a similar provision regarding a range of natural resources and provides that "[a]s trustee of these resources, the Commonwealth shall conserve and maintain them for the benefit of all the people."[307] Just as these states have extended the public-trust doctrine beyond surface water to include other natural resources, states may also be able to extend the public trust to include the subsurface pore-space, particularly such space in saline aquifers.

b. Groundwater

As state governments exercise control over navigable waters and the beds that lie beneath them,[308] so too are they increasingly exercising control over groundwater.[309] This control is conducted under the exercise of the police powers to control for "overdraft, subsidence, saltwater intrus[]ion, reduced surface stream flow, increased pumpage costs, and general social and economic disruption."[310]

But the states may also control groundwater under the public-trust doctrine. In a 2006 case involving a claim of damages by the state of New Mexico for contamination of groundwater, the Tenth Circuit Court of Appeals wrote:

> No one doubts the State of New Mexico manages the public waters within its borders as trustee for the people and is authorized to institute suit to protect those waters on the latter's behalf. *See, e.g.*, *State ex rel. Reynolds v. Mears*, 86 N.M. 510, 525 P.2d 870, 875 (N.M. 1974); *Bliss, State ex rel. v. Dority*, 55 N.M. 12, 225 P.2d 1007, 1010 (N.M. 1950). In *State ex rel. Reynolds v. Mendenhall*, 68 N.M. 467, 362 P.2d 998, 1000 (N.M. 1961), the New Mexico Supreme Court declared all underground waters within the State to be public waters subject to appropriation for beneficial use. *See* N.M. Stat. Ann. § 72-12-18 (codification of the public trust doctrine as to groundwaters). Similarly, no one doubts the duty of the State [Attorney General] generally to prosecute a state law civil action in which the State is a party. *See id.* § 8-5-2.B. In view of the foregoing, neither GE nor ACF [Industries] challenges the State's Article III standing to pursue this state law action for harm to the public interest in its capacity as trustee of the State's groundwaters.[311]

Therefore, not only is it possible for states to codify the application of the public-trust doctrine to groundwater, it seems that the courts will defer to the states' power to do so. The relevant New Mexico statute reads:

> [A]ll underground waters of the state of New Mexico are hereby declared to be public waters and to belong to the public of the state of New Mexico and to be subject to appropriation for beneficial use. All existing rights to the beneficial use of such waters are hereby recognized.[312]

It is possible that subsurface pore space, especially pore space holding saline aquifers, might be managed by the government on behalf of the public. If New Mexico has successfully applied the public-trust doctrine to groundwater, it not difficult to imagine that the doctrine could also be applied to pore space—particularly saline aquifers—and enforced using the state police powers.

c. Freshwater Storage

Another useful analog relates to states' capacity to regulate the use of pore-space fields for storage of fresh water, a less expensive way to store water than by building above-ground storage reservoirs.[313] Some scholars have convincingly argued that the same legal principles that govern aquifer storage and recovery ("ASR") could support state regulation of property rights related to CCS.[314] While there is relatively little case law addressing the ownership of underground water-storage space, the following cases suggest that courts would look favorably on use of the pore space for a legitimate public purpose, such as long-term CO_2 storage.

In *Alameda County Water District v. Niles Sand and Gravel Co.*, for example, the California court found that when the water district's ASR operation flooded the plaintiff's gravel quarry, which had been pumped to keep it dry, there was no trespass or compensable damage because the operator's property rights were subject to a "public servitude for water and water conservation purposes."[315] In a similar Colorado case, *Board of County Commissioners of Park v. Park County Sportsmen's Ranch, LLP*, the court held that the surface-owner could not assert control over the pore space underlying the surface estate and thereby prevent public operation of an ASR program, stating that "just as a property-owner must accept some limitation on the ownership rights extending above the surface of the property, we find that there are also limitations

371–73 (2006).

306. Haw. Const. art. XI, § 1.

307. Pa. Const. art. I, § 27.

308. *See supra* Part II.B.3.a.

309. Richard J. Lazarus, *Changing Conceptions of Property and Sovereignty in Natural Resources Law: Questioning the Public Trust Doctrine*, 71 Iowa L. Rev. 631, 699 n.406 (1986).

310. *Id.* (citation omitted).

311. New Mexico v. Gen. Elec. Co., 467 F.3d 1223, 1243 (10th Cir. 2006) (footnote omitted).

312. N.M. Stat. Ann. § 72-12-18 (2011).

313. *Aquifer Storage and Recovery*, GSI Water Solutions, Inc., http://www.gsiwatersolutions.com/services/ASRinfo.shtml (last visited Nov. 16, 2011).

314. Jerry R. Fish & Thomas R. Wood, *Geologic Carbon Sequestration: Property Rights and Regulation*, 54 Rocky Mtn. Min. L. Inst. 3-1, 3-32 (2008).

315. Alameda Cnty. Water Dist. v. Niles Sand & Gravel Co., 112 Cal. Rptr. 846, 855 (Ct. App. 1974).

on property-owners' subsurface rights."[316] The court differentiated the law pertaining to the ASR program from that covering oil and gas law by stating simply, "Water is not a mineral." Rather, the court stated that the state legislature "in authorizing the use of aquifers for storage of artificially recharged waters . . . has . . . supplanted the Landowners' common-law property ownership theory."[317]

Significantly, the Colorado court also found that "neither surface water, nor ground water, nor the use rights thereto, nor the *water bearing capacity of natural formations* belong to a landowner as a stick in the property rights bundle".[318] Explaining the rationale behind its finding, the court observed:

> Allowing property owners to control who may store water in natural formations, or charging water right use holders for easements to occupy the natural water bearing surface or underground formations with their appropriated water, would revert to common-law ownership principles that are antithetical to . . . the public's interest in a secure, reliable, and flexible water supply . . . . It would inflate and protract litigation by adding condemnation actions to procedures for obtaining water use decrees. It would counter the state's goals of optimum use, efficient water management, and priority administration.[319]

Notice the court's intent not only to protect the public's interest in a "secure, reliable, and flexible water supply," but also its intent to establish a property-rights regime that optimizes the value of the resource, reduces friction, and minimizes litigation—essentially minimizing transaction costs.[320]

Alameda County and *Park County Sportsmen's Ranch* demonstrate two important aspects of the pore-space issue. First, the California case suggests that private pore-space rights are limited by a "public servitude" enforced by the legitimate exercise of the police power.[321] Second, the Colorado case suggests that courts are motivated by furthering the public's interest in optimal use, efficient management, and minimized transaction costs.[322]

The same arguments could be used to support a similar stance regarding CCS. CO_2 is not a mineral. Its permanent, safe disposal serves an important public purpose. Arguably, the use of the pore space for CCS, particularly in saline aquifers, is the highest-value use of a resource that has little or no other purpose. The issues of ownership and public servitude should be guided by an interest in maximizing the value of the resource and minimizing the transaction costs associated with moving the resource to that use.

316. Bd. of Cnty. Comm'rs of Park v. Park Cnty. Sportsmen's Ranch, LLP, 45 P.3d 693, 701 (Colo. 2002) (appellants alleging trespass for the injection of water for aquifer recharge).
317. *Id.* at 703.
318. *Id.* at 707 (emphasis added).
319. *Id.* at 714 (citation omitted).
320. *Id.*
321. Alameda Cnty. Water Dist. v. Niles Sand & Gravel Co., 112 Cal. Rptr. 846, 851–52 (Ct. App. 1974).
322. *Park Cnty. Sportsmen's Ranch*, 45 P.3d at 714.

4. Transportation Analogs

Our final category of analogs draws on examples from the transportation industry. These applications illustrate the role (and limitations) of eminent domain in aggregating property rights for public purposes as well as the limits of surface-owners to prevent the public use of space far removed from the surface.

a. Highway Development

It is often the case that the government needs to assemble contiguous tracts of land: when building a new highway. Although there might be some flexibility regarding placement of the road, the government generally must persuade landowners to yield ownership of the land once a route is chosen.[323] The state government generally will attempt to negotiate the sale of the needed parcels, offering to pay the "fair market value."[324] However, landowners do not always willingly agree to the exchange, perhaps because of a genuine difference of opinion about the fair market value, or because their personal valuation of the land is greater than an objective fair market value, or for strategic purposes such as attempting to extract a particularly high price as one of the last pieces in the assemblage.[325]

To support the public's interest in infrastructure development, states have eminent-domain statutes that allow the state to appropriate ("condemn") property for public purposes. Often, the exercise of eminent domain requires that the state actors first make a good-faith effort to negotiate the purchase of the property.[326] If the owner refuses, then the government body condemns the property by filing a court action.[327] If the court authorizes the condemnation, the hearings expand to determine the level of compensation required.[328] In many cases, only a portion of an owner's property is taken.[329] If that

323. While highway construction may be the most common public enterprise requiring the assembly of land, similar challenges arise in the acquisition of land for a school, public building, park, and even the redevelopment of "blighted" areas. Aaron Larson, *Eminent Domain*, ExpertLaw (July 2004), http://www.expertlaw.com/library/real_estate/eminent_domain.html.
324. Carpenter Tech. Corp. v. City of Bridgeport, 180 F.3d 93, 96 (2d Cir. 1999) (plaintiff disputing the fair market value calculated by the defendant as part of negotiations prior to condemnation proceedings).
325. *See, e.g.*, Coniston Corp. v. Vill. of Hoffman Estates, 844 F.2d 461, 464 (7th Cir. 1988).
326. *See, e.g.*, United States v. Muñiz, 540 F.3d 310, 312 (5th Cir. 2008) (noting that negotiation for the purchase of property is a condition precedent for eminent-domain proceedings taking private property to protect U.S. borders); Kerr v. Raney, 305 F. Supp. 1152, 1154 (W.D. Ark. 1969) ("Ark.Stat.Ann. § 80-3318 (1967 Supp.) grants the University of Arkansas Board of Trustees the right and power of eminent domain to condemn property whenever and wherever the acquisition of property is necessary for the use of the University. It is therein provided, however, that before the power is exercised in any case, the Board of Trustees shall exercise every reasonable effort to obtain the property in question at a reasonable price by negotiation.").
327. *See* Hele v. United States, 100 Ct. Cl. 289, 293 (1943) ("The situation is analogous to proceedings by the United States to acquire lands. If the land owner refuses to accept a sum offered, the United States must institute suit in a District Court to condemn the land.").
328. *See* Monongahela Navigation Co. v. United States, 148 U.S. 312, 314 (1893).
329. *See, e.g.*, Celico v. Chorney, No. M.P. 70-26, 1978 WL 196068, at *2 (R.I. Super. Ct. Apr. 18, 1978) ("One exception to this rule is where the state takes only a portion of an owner's property by eminent domain. In such cases, the

is the case, the compensation must be for the value of the portion plus any loss of value associated with the rest of the property.[330] After the appropriate compensation is paid, the government acquires title.

This condemnation process can in some cases last years.[331] The cost of negotiations, hearings, and delays can add significantly to the cost of a project. In some cases, the landowners can use the threat of delay to extract additional payment from the government or developer with eminent-domain authority.

Most of the recent legal scholarship on eminent domain has centered on the definition of "public use" and the potential for abuse when the government condemns land that ultimately is to be used for private development.[332] However, the recent focus on the potential abuses of eminent domain obscures the importance of this authority to enable public projects. In many cases, there is no other reasonable alternative for putting together all of the contiguous property needed to execute and maintain the public project.[333]

The aggregation of property rights for CCS is similar to the combination of rights for economic development. Like public-infrastructure projects, CCS requires that developers acquire the right to physically occupy contiguous property for a goal related to public "safety, health, interest, or convenience."[334] And, as with other public-infrastructure projects, there is the potential for a holdout problem among property-owners who seek to gain economic advantage from their strategic position.

Although these similarities might lead one to think that eminent domain would be a simple avenue for obtaining subsurface pore space ownership for CCS, there are significant differences between those projects typically achieved through the exercise of eminent domain rights and CCS. First, eminent domain is generally used to support linear projects, such as roads or electric-transmission lines; or development projects for buildings or parks over small areas.[335] The plume from a CCS project could extend across as much as 1,000 square miles.[336] The number of surface-owners above the plume, therefore, could be substantial. Second, loss of the surface property through application of eminent domain often involves displacement of families from their homes.[337] Loss of the pore-space property rights involved in CCS has very little or no opportunity cost, and the transfer of rights generally is not going to affect ongoing uses.[338]

Thus, while eminent-domain authority provides an option for aggregating rights in contiguous properties necessary for pursuing public goals, this tool was developed for use under very different circumstances. Whereas eminent domain was developed to aggregate rights to high-value property, potentially displacing the owners from their homes, CCS requires aggregating rights to low-value resources that will leave surface-owners virtually unaffected.

b. Airplane Overflight

Perhaps the most intriguing analog for the use of pore space by CCS operations might be airspace rights over private property. *United States v. Causby* involved the use of airspace above private property owned by the plaintiff, who sued, claiming the United States effectively had taken an easement over the property without paying.[339] The noise from the airplanes also caused depreciation in property value and damage to the property-owner's chicken business.[340]

The Supreme Court ruled that ownership of the surface interest did not provide the owner unlimited rights above and below the surface.[341] Common-law precedent previously provided that ownership of the land "extended to the periphery of the universe."[342] This is sometimes referred to as the "heaven to hell" principle.[343] However, in *Causby*, the infinite reach of the surface interest was effectively severed.[344] The Court declared that there was no place for such a doctrine in the modern world, for it would open the door to countless

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owner is not restricted to compensation for the land taken. He is also entitled to recover for the damages caused to his remaining property. In Rhode Island these severance damages are measured by the difference between the fair market value of the remainder before and after the taking." (citations omitted)).

330. *Id.*

331. *See, e.g.*, City of Buffalo v. J. W. Clement Co., 269 N.E.2d 895, 900 (N.Y. 1971).

332. *See, e.g.*, Alexandra B. Klass, *The Frontier of Eminent Domain*, 79 U. Colo. L. Rev. 651 (2008); Harold L. Lowenstein, *Redevelopment Condemnations: A Blight or a Blessing Upon the Land?*, 74 Mo. L. Rev. 301 (2009).

333. *See, e.g.*, Michael Heller & Rick Hills, *Land Assembly Districts*, 121 Harv. L. Rev. 1465, 1467 (2008); Nathan Alexander Sales, *Classical Republicanism and the Fifth Amendment's "Public Use" Requirement*, 49 Duke L.J. 339, 340 (1999).

334. Larson, *supra* note 323.

335. *See, e.g.*, Amnon Lehavi & Amir N. Licht, *Essay: Eminent Domain, Inc.*, 107 Colum. L. Rev. 1704, 1710 (2007); Leigh Raymond & Sally K. Fairfax, *The "Shift to Privatization" in Land Conservation: A Cautionary Essay*, 42 Nat. Resources J. 599, 616–17 (2002).

336. In a presentation to the West Coast Regional Carbon Sequestration Partnership, Jerry Fish estimated that a 1,000-megawatt, coal-fired power plant would generate 5 million to 8 million metric tons of CO_2 per year. Jerry R. Fish, Presentation at West Coast Regional Carbon Sequestration Partnership: Acquiring Property Rights for Carbon Sequestration: Common Law and New Statutes 2 (Sept. 15–17, 2009), http://www.westcarb.org/pdfs_scottsdale/FISH.pdf. If that CO_2 were pumped into porous sandstone, after fifty years it would create a single-layer subsurface plume covering an area of roughly thirty kilometers in radius, or 2,826 square kilometers. *Id.* This is equivalent to 1,091 square miles. While this is a crude estimate, it provides an indication of the potential size of the plume from a large power plant. Similarly, it has been estimated that the plume associated with the U.S. government's primary commercial demonstration project, FutureGen 2.0, which is designed to sequester 1.3 million metric tons of CO_2 per year, could spread across approximately thirty to sixty square miles. Jeff Tollefson, *Is FutureGen Betting on the Wrong Rock?*, 472 Nature 398 (2011). On a smaller scale, a simulation of a pilot test in San Joaquin Valley in California, designed to inject 250,000 metric tons per year, predicted that the plume would spread as far as two kilometers from the injection point (approximately five square miles). Preston Jordan & Christine Doughty, Lawrence Berkley Nat'l Lab., Sensitivity of CO_2 Migration Estimation on Reservoir Temperature and Pressure Uncertainty 4 (2009), *available at* http://www.osti.gov/bridge/servlets/purl/948569-na1kfM/948569.pdf.

337. *See* Ronald J. Krotoszynski, Jr., *Expropriatory Intent: Defining the Proper Boundaries of Substantive Due Process and the Takings Clause*, 80 N.C. L. Rev. 713, 733 (2002); Donald W. Tuegel, *Airport Expansions: The Need for a Greater Federal Role*, 54 Wash. U. J. Urb. & Contemp. L. 291, 293 (1998).

338. *See* sources cited *supra* note 20. It is also the case that legislation designed to clarify the property rights in deep-subsurface pore space could limit CCS development to those depths and types of fields where there are no preexisting economic activities.

339. United States v. Causby, 328 U.S. 256, 258–59 (1946).

340. *Id.* at 259.

341. *Id.* at 261.

342. *Id.* at 260–61.

343. *See* Lowe, *supra* note 91, at 9.

344. *Causby*, 328 U.S. at 261.

unfounded trespass suits.[345] "Common sense revolts at the idea," the Court said.[346]

Of course, the *Causby* decision was limited to airspace. The Court did not specify the precise location at which the "heaven to hell" principle was severed. With respect to subsurface pore space, it is uncertain if the surface-owner has rights to a geologic formation 100 meters below the surface but not 200 meters below. Subsequent cases have not defined the depth at which surface-interest rights are no longer valid. CCS geologic activity is expected to occur 800 meters or more below the surface.[347] In many parts of the country, this exceeds the depths at which meaningful economic activity, such as mining and fossil fuel extraction, takes place.[348]

C. Technological Change and Legal Adaptation

The above review and discussion of analogs raises several important points. First, as a legal matter, none of these analogs is sufficiently close to geologic CCS that it is likely to be binding on the development of property law related to pore space. Equally important, property rights are addressed under state law, so with the exception of the U.S. Supreme Court cases, none of these cases is binding across all states even if considered to be directly applicable. In short, state courts largely would address the issue of ownership of deep-subsurface pore space as a matter of first impression. This makes it challenging to predict how a state's courts would respond to any specific claims regarding deep-subsurface ownership, particularly if they do not have guidance from the state legislative branch.

At the same time, the analogs suggest that, with respect to pore-space property rights, the right to exclude others or to collect tort damages for trespass depends on the identity of the defendant, the purpose of the defendant's intrusion, the nature of the plaintiff's use of the pore space, and the extent of loss the plaintiff can demonstrate.[349] Therefore, to the extent that the surface- or mineral-owners hold any claim on the pore space, it is not an absolute claim.

More importantly, courts will most likely attempt to establish property-rights rules that promote efficient resource use and protect public interests. Courts tend to support efforts to increase the productivity and social benefit of resources where doing so does not clearly violate existing law, particularly property law. Taken as a whole, these analogous activities demonstrate several circumstances in which courts had to "find" law in response to new technological or resource-management developments. Where ambiguity about property rights exists, courts will attempt to find grounds to support the most efficient approach. Courts have used the public-trust doctrine, promoted the concept of the public servitude, and recognized the police powers of the government to support efforts to move resources to their highest-value use.[350]

Finally, while a state legislature cannot assure the chosen approach for addressing a new property-rights issue will pass constitutional muster with the courts, they can take steps to increase the likelihood of being upheld by courts. In particular, legislation should contain language that bolsters the legal arguments that will be used to defend the legislative approach. We now turn to the legal doctrines, mentioned in the discussion of analogs, that legislatures might reference to provide courts with the legal grounds to support efficient outcomes.

III. Property Rights and the Efficient Use of Resources

The above discussion of property rights in deep-subsurface pore space reaches a conclusion that is simultaneously unsatisfying and encouraging. On the one hand, the property rights related to the potentially important resource of subsurface pore space are poorly developed, muddying the waters for CCS policymakers and project-developers. To the extent that the property-rights issue has been addressed, the focus has been on applications involving higher-valued uses of pore space at depths closer to the surface than will be the case for the CCS practice.[351]

On the other hand, the ambiguity presents an opportunity for state regulators and courts to influence development in this area of law, pushing it in the direction of a regime that supports efficient use of the pore-space resource. In previous applications, faced with new technologies and competing demands for resources, courts and legislatures have employed a variety of techniques to facilitate the movement of resources to their highest-valued use. This, of course, begs

345. *Id.*
346. *Id.*
347. *See* Folger, *supra* note 20, at 8.
348. *See supra* note 20. Also for example, coal mining below 350 meters is considered very deep. *See* Energy Info. Admin, DOE/EIA-0529(95), U.S. Coal Reserves: A Review and Update 66, 68 (1996), *available at* ftp://ftp.eia.doe.gov/coal/052995.pdf ("[I]n practice, reliable coal measurement points deeper than 1,000 feet are relatively few in most regions."); *see also* Office of Indian Energy & Econ. Dev., U.S. Dep't of Energy, *Coal Mining Technologies*, Tribal Energy & Envtl. Info. Clearinghouse, http://teeic.anl.gov/er/coal/restech/tech/index.cfm (last visited Nov. 16, 2011); U.S. Energy Info. Admin., U.S. Dep't of Energy, *Coal*, Energy Kids, http://205.254.135.24/kids/energy.cfm?page=coal_home-basics (last visited Nov. 16, 2011).
349. *See supra* Part II.B.
350. The courts have also recognized the common-property nature of some resources. In *Pennsylvania Natural Weather Ass'n v. Blue Ridge Weather Modification Ass'n*, a weather association sought to enjoin a corporation and a weather-modification association from continued weather-modification activities. Pa. Natural Weather Ass'n v. Blue Ridge Weather Modification Ass'n, 44 Pa. D. & C.2d 749, 749 (Ct. Com. Pl. 1968). The defendants flew planes over certain areas, and the planes emitted smoke. *Id.* The Court of Common Pleas of Fulton County cited *Causby* and stated that "the landowner has a right not to have the air space used to his detriment except as is reasonably necessary for aircraft flights." *Id.* at 759. However, the court held that clouds and the moisture in them are considered common property and thus "[e]very owner of land has a property right in the moisture in the clouds and the right to receive that moisture in its natural form subject to such weather modification activities as shall be carried out by governmental authorities in the public, as opposed to private, interest." *Id.* at 763.
351. Sally M. Benson, Lawrence Berkeley National Laboratory, Carbon Dioxide Capture and Storage: Assessment of Risks from Storage of Carbon Dioxide in Deep Underground Geological Formations 21 (Ver. 1.0, Apr. 2, 2006) ("Natural gas storage projects . . . generally operate at shallower depths than CO2 storage projects . . . ."), *available at* http://southwestcarbonpartnership.org/_Resources/PDF/GeologicalStorageRiskAssessmentV1Final.pdf.

the question of how an efficient property-rights regime would be structured.

The logical next step in this inquiry is to ask the normative policy question: who should own the pore space? To begin addressing that question, we turn to a more general discussion of the purpose of property rights, how they can improve economic performance and efficiency, and one particular set of circumstances under which private property rights can actually reduce efficiency.

A. *The Function of Property Rights*

It is perhaps axiomatic that the function of property rights is to provide individuals with the incentive to invest their energy and resources into activities and materials that increase the economic value and productivity of the property.[352] By recognizing the right to exclude others from private property, society assures individuals that they will collect the fruits of their labor.[353]

A less publicly recognized role of property rights is to facilitate transfer of the property at issue—whether real or personal—to the user that most highly values that particular property.[354] This right of transfer is arguably as important as the right to exclude. Meanwhile, these two rights are only a part of the array of rights that might be associated with a particular item of property—two of the sticks in the bundle of property rights, so to speak. Often, all of the sticks in the bundle of rights pertaining to a particular resource are owned by a single party, but that is not always the case.[355] The rights to extract minerals can be severed from the rights to use, exclude, and transfer the surface estate.[356] The right to exclude others from one's property might be limited by an exception that allows the government to intrude with a water main or a sidewalk.[357] The property right, then, is a "socially recognized right[] of action" that defines the extent—and limits—of the individual's control over resources.[358] "In its original meaning, property referred solely to a right, title, or interest, and resources could not be identified as property any more than they could be identified as right, title, or interest."[359]

The purpose of the institution of property rights is to encourage the efficient use of resources.[360] However, those actions that accompany the institution of property rights—defining the rights, developing markets, separating or aggregating the rights into efficient combinations, policing the rights, and settling disputes about the rights—carry a social cost.[361] Hence, property rights are only a beneficial institution where their existence increases the value of the resources by an amount greater than their costs of creation and maintenance.[362] This leads to the conjecture that we expect that property rights will be most defined, monitored, and enforced when applied to resources that are most valuable. Concomitantly, property rights in low-value resources will be least developed. This is an efficient outcome.

At some level, the initial assignment of property rights over resources does not affect the allocation of resources to their highest-valued use, provided the rights are transferable.[363] By the process of negotiation and trade, resources will end up in the hands of those who value them most.[364] However, that result depends upon the transfer process itself being relatively frictionless.[365] If the cost of transactions is not negligible, then an alteration in the identity of rights-holders can have allocative effect because negotiations toward a unique utilization of resources may be inhibited by positive transaction costs.[366]

This suggests that if property rights can be identified and transferred at little or no cost, then the initial assignment of rights does not affect efficiency.[367] However, where property rights are "sticky" due to the costs of transactions, then the initial assignment can matter a great deal. This point is particularly important when it comes to determining which property rights are private and which are public. Once property rights are in private hands, the efficient use of resources for public goods and services might be hampered by the transaction costs of reacquiring them for public use.

In the initial allocation of property rights then, an efficient system puts resources in the hands of those who are likely to ultimately find the rights to be of greatest value.[368] Referring to the issues addressed in *United States v. Causby*, Harold Demsetz observed:

> This prescription for the assignment of property rights is most clearly applicable when these rights are new. The age of air transportation suddenly made the right to traverse upper airspace a valuable right, whereas the airplane merely pro-

352. *See* Andrew Beckerman-Rodau, *The Supreme Court Engages in Judicial Activism in Interpreting the Patent Law in* eBay, Inc. v. MercExchange, L.L.C., 10 Tul. J. Tech. & Intell. Prop. 165, 167 n.4 (2007) (quoting Richard A. Posner, The Economic Analysis of Law 10–13 (1st ed. 1973) ("The legal protection of property rights has an important economic function: to create incentives to use resources efficiently.")).
353. *See* Richard A. Posner, The Economic Analysis of Law 12 (1st ed. 1973) ("[T]he more exclusive the property right, the greater the incentive to invest the right amount of resources in the development of the property.").
354. *See* G.S. Rasmussen & Assocs. v. Kalitta Flying Serv., Inc., 958 F.2d 896, 900 (9th Cir. 1992) (noting that private ownership is the principal incentive for the efficient allocation of commodities).
355. *See* Armen A. Alchian & Harold Demsetz, *The Property Right Paradigm*, 33 J. Econ. Hist. 16, 17 (1973).
356. *See, e.g.*, John W. Fisher, II, *A Survey of the Law of Easements in West Virginia*, 112 W. Va. L. Rev. 637, 653–56 (2010); *Recent Developments in Environmental Law*, 23 Tul. Envtl. L.J. 561, 587 (2010).
357. *See, e.g.*, Donald W. Large, *The Supreme Court and the Takings Clause: The Search for a Better Rule*, 18 Envtl. L. 3, 22–23 (1987).
358. Alchian & Demsetz, *supra* note 355, at 17.
359. *Id.*
360. *See* Harold Demsetz, *Toward a Theory of Property Rights*, 57 Am. Econ. Rev. 347, 356 (1967).
361. *See* Yoram Barzel, Economic Analysis of Property Rights 91–104 (James E. Alt & Douglass C. North eds., 2d ed. 1997) (providing examples in which the cost of defining and enforcing rights leads potential owners to forgo property rights).
362. *See* Demsetz, *supra* note 360, at 350 (arguing that only when the benefits of internalizing the costs of creating property rights are greater than the administrative costs will property rights emerge).
363. Ronald H. Coase, *The Problem of Social Cost*, 3 J.L. & Econ. 1, 15–16 (1960).
364. *See* Alchian and Demsetz, *supra* note 355, at 22.
365. *See id.*
366. *See id.*
367. *See* Harold Demsetz, *Some Aspects of Property Rights*, 9 J.L. & Econ., 61, 66 (1966).
368. *See id.* at 63.

> vided a competing claimant for the already valuable right to use lower airspace. The right to use upper airspace was not clearly defined because a definition was rarely demanded; it could be argued that there was no involuntary taking of property when the right to use upper airspace was assigned to airplane owners and to the government. Since a decision was needed and since it appeared that airplane owners would eventually acquire the right to use upper airspace, an efficient allocation seemed to demand that exchange costs be reduced by initially assigning the new right where it was finally expected to reside.[369]

Because deep-subsurface pore space only has value as part of a large field, and most fields are owned by multiple owners, the fields become, essentially, communal property. Demsetz argues that the presence of communal property increases the costs of negotiation not only among the owners, but also between the owners and others.[370] This additional type of transaction cost, in turn, further reduces the likelihood that the property will find its way to the highest-valued user.

B. *The Problem of the Anticommons*

In the seminal article *The Tragedy of the Commons*, Garret Hardin described the problem that arises when a resource is owned by multiple parties, each with rights of access and use, but none with the right to exclude others.[371] The commons in question can support a certain level of productive activity, but also can be overused, leading to less-than-maximal productivity and possibly to ultimate destruction.[372] In Hardin's parable, each owner of the commons acts to maximize his own return from the commons without regard to the cost to others.[373] Collectively, the owners overuse the commons and, in the long run, experience a lower yield from the resource than would have been possible through a coordinated effort.[374] The tragedy arises from the fact that individuals do not bear the full costs of their decisions to increase the use of the common resource, and they do not experience the full gain of decisions to decrease their use.[375] Because no individual owns the commons, but decisions are made at the individual level, no one has an incentive to care for the long-term health of the resource.[376]

Building on the concept of the tragedy of the commons, scholars Michael Heller and Rebecca Eisenberg described a coordination breakdown where the existence of multiple holders of property rights might impede the achievement of a socially desirable outcome.[377] This is what they called the "tragedy of the anticommons."[378] Heller and Eisenberg's metaphor, however, sought to describe how the existence of too many owners can lead to *underuse* of a resource.[379] In particular, they discussed how the privatization of biomedical research could spur private investment, but privatization could also lead to the pitfalls of a system characterized by fragmented and overlapping property rights.[380]

In a related article, Heller examined another example of a tragedy of the anticommons; he observed that in post-Soviet Moscow, storefronts were often empty while street kiosks were full of goods.[381] The problem, Heller concluded, was the existence of multiple owners, each with the right to exclude others from a scarce resource, while nobody had the effective privilege of use.[382] When Russia was transitioning into a market-based economy, storefront properties in Moscow were caught in a tangle of confusing (and conflicting) property rights and competing decision-makers.[383] Various categories of rights-holders, such as the national government; numerous state, regional, and local agencies; businesses; committees; and councils held and shared ownership rights in storefront properties.[384] Consequently, because there were too many "owners," the resource became underused.[385]

The concept of Heller and Eisenberg's anticommons prompted a spirited debate on how property rights should be assigned in the area of intellectual property (broadly defined) and how such decisions affect transaction costs.[386] Yet, the concept of the anticommons has been extended to an even broader range of applications, including forestry,[387] water rights,[388] cyberspace,[389] renewable-energy siting,[390] cable television,[391] oilfields,[392] and urban development.[393] In fact, Adam Smith recognized a type of anticommons problem in transportation: "The navigation of the Danube is of very little use to the different states of Bavaria, Austria and Hungary, in comparison of what it would be if any of them possessed the whole of its course till it falls into the Black Sea."[394]

369. *Id.* at 66.
370. *See* Demsetz, *supra* note 360, at 356.
371. Garrett Hardin, *The Tragedy of the Commons*, 162 Science 1243, 1244 (1968).
372. *Id.*
373. *Id.*
374. *Id.*
375. *Id.*
376. *Id.*
377. Michael A. Heller & Rebecca S. Eisenberg, *Can Patents Deter Innovation? The Anticommons in Biomedical Research*, 280 Science 698, 698 (1998).
378. *Id.*
379. *Id.*
380. *Id.*
381. Michael A. Heller, *The Tragedy of The Anticommons: Property in the Transition from Marx to Markets*, 111 Harv. L. Rev. 621, 622 (1998).
382. *Id.* at 623–24.
383. *Id.* at 635–40.
384. *Id.* at 638.
385. *Id.* at 639.
386. *See, e.g.*, F. Scott Kieff & Troy A. Paredes, *Engineering a Deal: Toward a Private Ordering Solution to the Anticommons Problem*, 48 B.C. L. Rev. 111, 112–17 (2007); Oskar Liivak, *Rethinking the Concept of Exclusion in Patent Law*, 98 Geo. L.J. 1643, 1654–56 (2010); Robert P. Merges, *Intellectual Property Rights and the New Institutional Economics*, 53 Vand. L. Rev. 1857, 1862–63 (2000).
387. Achim Schlueter, *Small-Scale European Forestry, an Anticommons?*, 2 Int'l J. Commons 248, 249–50 (2008).
388. *See, e.g.*, Sean Callagy, Comment, *The Water Moratorium: Takings, Markets, and Public Choice Implications of Water Districts*, 35 Ecology L.Q. 223, 224 (2008).
389. *See e.g.*, Dan Hunter, *Cyberspace as Place and the Tragedy of the Digital Anticommons*, 91 Calif. L. Rev. 439, 441 (2003).
390. *See, e.g.*, Hannah Wiseman, *Expanding Regional Renewable Governance*, 35 Harv. Envtl. L. Rev. 477, 480–81 (2011).
391. *See, e.g.*, Thomas W. Hazlett, *Cable TV Franchises as Barriers to Video Competition*, 12 Va. J.L. & Tech. 2, 41 (2007).
392. *See, e.g.*, Vijay Mohan & Prateek Goorha, *Competition and Unitization in Oil Extraction: A Tale of Two Tragedies*, 4 Rev. L. & Econ. 519, 521–22 (2008).
393. Steven J. Eagle, Kelo*, Directed Growth, and Municipal Industrial Policy*, 17 Sup. Ct. Econ. Rev. 63, 98 (2009).
394. 1 Adam Smith, An Inquiry into the Nature and Causes of the Wealth of Nations 25 (Edwin Cannan ed., Univ. of Chi. Press 1976) (1776); *see*

The anticommons theory is potentially applicable to the issue of deep-subsurface pore space. Heller stressed that if a government accidentally created anticommons property in the process of defining property rights, a subsequent market-based process of "bundling" various rights into "usable" property could fail altogether due to transaction costs of bundling that were sufficiently high compared to the benefits of such bundling.[395] If this "tragedy" were to take place, the property rights *and* the resource itself would become underused (or not used at all). In the case of CCS, the pore space could be thought of as something to which multiple parties can claim rights. To ensure that this situation does not turn into a tragedy of the anticommons, the legislature would have to pay attention not only to who owns the rights but also to how the various elements of property rights are bundled.

IV. Strategies for Ownership of Subsurface Pore Space

The previous section suggested that there is tension in the institution of private property rights. On the one hand, private property provides individuals with the incentives to invest in the use and improvement of the resource. The right to sell the property allows the resource to move to the control of the party who can put the resource to its highest-valued use. At the same time, the institution of property rights involves transaction costs. Thus, to justify property rights on efficiency grounds, the increase in the value that accompanies the recognition of private property must be greater than the transaction costs involved in the recognition of those rights.

In the case of deep-subsurface pore space filled with saltwater, at least in some states, such as in the Midwest, there is no contemporary competing use for this resource, so it could be used for CO_2 storage, although this resource could potentially be used for other purposes in the future, including compressed-air storage or low-temperature geothermal applications.[396] Moreover, given the size of the CO_2 plumes, it will be necessary to acquire the right to use large fields of subsurface pore space. The question from a policy perspective is whether it is better to acknowledge private-property rights in deep-subsurface pore space, as Wyoming, Montana, and South Dakota do, and to require CCS developers to aggregate those rights; or, alternatively, to adopt a policy that does not involve private-property rights when those rights are at odds with the highest-value use of the resource.

This section explores that question in two steps. First, the discussion considers four analytical schemes on which management of property rights in deep-subsurface pore space could be based. The choice among the options turns critically on the transaction costs associated with implementation, so this article then provides an estimated calculation of relevant transaction cost to provide insight into the relative merits of the alternative approaches.

James M. Buchanan & Yong J. Yoon, *Symmetric Tragedies: Commons and Anticommons*, 43 J.L. & Econ. 1, 1 (2000).

395. Heller, *supra* note 381, at 640–41.

396. *See supra* note 19 and accompanying text.

A. Analytical Schemes for Managing Pore-Space Ownership

A recent report prepared for the Midwestern Governors Association observed that there are many ways to obtain the property rights for storage space, including: "1) negotiation through lease or deed with the property owner(s); 2) an easement for the storage space, 3) determination that the pore space is in the public domain; 4) voluntary/compulsory unitization of the delineated area (oil and gas analogue); or 5) condemnation through eminent domain (natural gas analogue)."[397] However, the report does not provide a clear conceptual basis for choosing among the options. The purpose of this section is to develop a conceptual analysis of four basic alternative strategies for assigning and aggregating property rights in deep-subsurface pore space.

The first approach is to rely entirely on the market exchange of property rights. The theoretical basis for this approach lies in the First Fundamental Theorem of Welfare Economics, which loosely states that if traders act in a self-interested manner responding to prices that emerge from a perfectly competitive market, the distribution of goods and services that results will be efficient.[398] This result then suggests that property rights should be freely exchanged in the marketplace so that they can move to their highest-valued use.

Underpinning the First Fundamental Theorem, however, is the assumption that the rights are traded in a perfectly competitive market.[399] While there are variants on the definition of a perfectly competitive market, as a starting place, consider the following conditions as among the prerequisite conditions for a perfectly competitive market:

- many buyers and sellers so that no individuals can unilaterally influence prices;
- zero costs for suppliers to enter and exit the market;
- perfectly homogenous goods (or anonymity of producers, essentially) so that consumers are not bound to purchase from one supplier, or even a small subset of suppliers; and
- perfect information among buyers and sellers regarding the prices and quality.[400]

What is important to note in the context of CCS and pore-space rights is that none of these conditions for a competitive market apply. For any given field, there is a limited num-

397. Jennifer Johnson, Midwestern Governors Ass'n, Energy Security and Climate Stewardship Platform for the Midwest: Toolkit for Carbon Capture and Storage: Statutory and Regulatory Issues 33 (2009) (footnotes omitted), *available at* http://www.midwesterngovernors.org/Energy/Toolkit.pdf.

398. *See* Mark Blaug, *The Fundamental Theorems of Modern Welfare Economics, Historically Contemplated*, 39 Hist. Pol. Econ. 185, 186–87 (2007).

399. *Id.* at 187.

400. For definitions of the conditions for perfect competition, see Dennis Carlton & Jeffery Perloff, Modern Industrial Organization 57 (4th ed. 2004); Michael S. Jacobs, *Market Power Through Imperfect Information: The Staggering Implications of* Eastman Kodak Co. v. Image Technical Services *and a Modest Proposal for Limiting Them*, 52 Md. L. Rev. 336, 345 (1993).

ber of buyers and sellers. The supply of underground pore space in a given geographic region is fixed, so it is impossible for new suppliers to enter with more pore space. Far from being homogenous, the pore space offered by any supplier is unique in terms of its spatial location and its relation to other pore space and potential injection points. Developers cannot simply aggregate pore space underlying the surface estates of willing suppliers; they must aggregate contiguous property. In this setting, every supplier is unique and necessary.

Finally, no one has perfect information regarding implications of a transfer of property rights. Landowners do not understand the risks of this new technology, perhaps leading them to overestimate its potential to interfere with their use of property. Project developers are certain neither of who owns the property right in pore space nor of how far a plume will extend.

The consequence of these "market failures" is that the pure market approach cannot be expected to produce a clear price signal to serve as the basis for moving the pore-space property rights to their highest-value use. Thus, the pure market approach is unlikely to be a satisfactory solution.

If pure markets are not a promising mechanism to efficiently allocate property rights in pore space, is there an alternative? The Coase Theorem may provide an escape clause. It states that as long as property rights are clearly assigned, there are no transaction costs, and parties have perfect information, then regardless of who holds the property rights initially, bargaining will move the property rights to the user who most highly values those rights.[401]

Notice the difference between the Coase Theorem and the First Fundamental Theorem of Welfare Economics.[402] Where the latter requires many buyers and sellers, costless entry and exit of suppliers, and homogenous goods, the former does not. The Coase Theorem suggests that even in the case where there are few buyers or suppliers, where clear price signals do not emerge, and where transactions are idiosyncratic, property rights can still move to their highest-valued use. In this sense, Coasean bargaining is a more promising avenue for property rights in pore space than the pure market approach.

There is, of course, still the problem that parties might not have perfect information. Perhaps more important is that transaction costs are not negligible. Two main types of transaction costs arise here. First, there are the pure transaction costs associated with identifying, negotiating, and contracting with potentially large numbers of property-owners.[403] Second, there are the costs associated with the potential strategic behavior of property-owners, some of whom might hold out for payments above their reservation prices (the amount of payment needed to leave them as well-off as they would be without a transaction).[404] These payment demands are based on the owner's capacity to hold up the entire field, thereby extracting the extra benefits from the project for themselves.[405] Both of these types of transaction costs will reduce a project-developer's ability to aggregate subsurface pore-space fields for CCS, even when that is the highest-valued use.

The third, and perhaps most commonly recommended, approach to structuring private-property rights in deep-subsurface pore space is to couple private bargaining with the backstop of eminent-domain powers. As discussed above in the context of highway development, state governments have the power of eminent domain.[406] This authority allows the government to condemn property for a public use and to force its sale.[407] This power is generally used in settings where it is necessary to aggregate contiguous land for a public project. Because the sale is not voluntary, bargaining does not create an agreed-upon payment, so the government substitutes the concept of "fair market value."[408]

Arguably, eminent domain is a mechanism to overcome the tragedy of the anticommons.[409] In the classical application, a particular configuration of land is needed to pursue a public project. The project can only advance if all landowners render their property rights. In a sense, then, the collection of property is a commons that can be kept from its highest-valued use by the veto of any one of the property-owners.[410] Properly exercised, eminent domain can be an efficiency-enhancing institution.[411]

The aggregation of property rights in subsurface pore space for a CCS field could be facilitated by eminent domain. Where possible, contracts for the transfer of rights could be established by negotiation between property-owners and the state, utility, or developer. Where agreement is not possible, the property right in pore space could be condemned under eminent domain and the sale of the right forced. Under this approach, the property-owner would be compensated for the fair market value of the forfeited property rights.

However, eminent domain might not be a suitable tool for the CCS pore-space application. The eminent-domain power was developed to aggregate relatively valuable prop-

401. *See* Troy A. Rule, *Shadows on the Cathedral: Solar Access Laws in a Different Light*, 2010 U. Ill. L. Rev. 851, 859 n.56.

402. Despite the great similarity between these two important theorems, there is surprisingly little in the welfare-economics literature connecting the two directly.

403. Donald W. Hansford, Comment, *Injunction Remedy for Breach or Restrictive Covenants*, 45 Mercer L. Rev. 543, 551 n.66 (1993) (citing Richard A. Posner, Economic Analysis Of Law 35 (4th ed. 1992) ("Transaction costs include, among other things, the total costs of 'bargaining' with others to a transaction. Transaction costs include all the costs of effecting a transfer of property rights.")).

404. Rule, *supra* note 401, at 885 ("Such holdout problems can increase transaction costs and further reduce the likelihood of successful Coasean bargaining." (footnote omitted)).

405. *Id.*

406. Julius L. Sackman, 2A Nichols on Eminent Domain § 7.06[3][a] (Matthew Bender ed., 3d ed. 2010) ("The taking of private property for a public highway has long been considered a valid public use. Long before the American Revolution, this was the only use authorized by eminent domain. . . . [I]t has never been doubted that land might be taken for the purpose of laying out, extending, or widening a public highway." (footnotes omitted)).

407. Kelo v. City of New London, 545 U.S. 469, 484 (2005).

408. Boom Co. v. Patterson, 98 U.S. 403, 408 (1878) (noting that the government must pay the fair market value after using its eminent-domain powers).

409. Lee Anne Fennell, *Taking Eminent Domain Apart*, 2004 Mich. St. L. Rev. 957, 972 n.49; Amnon Lehavi & Amir N. Licht, *Eminent Domain, Inc.*, 107 Colum. L. Rev. 1704, 1709–10 (2007); Robert L. Scharff, *A Common Tragedy: Condemnation and the Anticommons*, 47 Nat. Resources J. 165, 176 (2006).

410. Lehavi & Licht, *supra* note 409, at 1710.

411. *See id.*

erty rights.[412] The procedures, which can involve lengthy and expensive court hearings, provide protection against government abuse.[413] While eminent domain could potentially be a useful tool to allow access to pore-space fields for CCS, it is a clumsy tool at best.

The final option is for the states to simply not recognize private ownership of deep-subsurface pore space. This is consistent with the current ambiguous status of the property right itself and might be the best mechanism to avoid the tragedy of the anticommons. If control of pore space rested with states rather than individual property-owners, project-developers would need to negotiate only with the responsible state agency. The cost of drawing up potentially thousands of contracts would be avoided. Perhaps more importantly, it would eliminate the holdout problem associated with aggregation of adjacent properties. Of course, this approach is based on the underlying condition that ownership in pore space has not already vested in surface- or mineral-estate owners. Jan Laitos states:

> Ownership potential is missing when the holder of the interest (the putative 'owner') cannot assert dominion over it, or cannot sell, give away, or transfer it. Additionally, an interest is not owned when it does not give its holder something of intrinsic value, which the holder could theoretically trade in the market place, use, or possess.[414]

Of course, the surface-owners could argue that they own the pore spaces because such spaces could, in theory, be traded in the marketplace, used, or possessed. However, the Supreme Court has suggested that an interest is private property only if it is a legal right that has the law behind it.[415]

The challenge, then, is to determine whether the interest at hand has the law behind it. According to Laitos, this hinges critically on whether the common law of the state in which the interest exists has always considered it to be private property.[416] If so, the Supreme Court has stated that the holder has "expectancies embodied in the concept of property."[417] In this instance, most states have *never* broadly considered the property interest of pore space. Arguably, then, the interest in the pore space is not private property.

B. *The Role of Transaction Costs*

The discussion of property rights and strategic options to address the aggregation of rights emphasized the role of transaction costs. But ultimately, the magnitude of transaction costs is an empirical matter subject to estimation and comparison with other costs.

As states consider options for developing strategies for pore-space ownership and aggregation, there are two preliminary guiding principles that could help. First, the chosen strategy should be one that promotes efficient use and management of the pore-space resource. This means that the law should not only allow ownership to move to the possession of the party that places the highest value on the use of pore space, but it should also do so in a manner that places the least burden on the state and private parties. To this end, states should seek an approach that minimizes transaction costs.

Second, the CO_2 sources, the CCS practices, the alternative uses of the pore space, and the transaction costs involved in the aggregation of pore-space rights will all vary from state to state. Geology, geography, demographics, and economic activity all affect these factors. Thus, the choice of an efficient strategy for pore-space rights and aggregation also will vary across states.

The preceding section suggested that it might be preferable to have control of pore space held by the state rather than the surface- or mineral-estate owners. The rationale was that the transaction costs associated with aggregating the property rights—contracting and dealing with strategic behavior—could be excessive, possibly even making the CCS practice itself uneconomical. That, of course, begs the question whether the transaction costs are large enough to justify the potentially unpopular decision to deny property-owners an extension of their rights to cover this element of the land.

In this section, we take Indiana as an example to examine the transaction costs that are likely to be involved if a state adopts an approach that vests pore-space property rights in the surface-estate owners—any of the first three alternatives discussed in the previous section. We address two questions. First, would the costs of recognizing private-property rights, thereby requiring project-developers to aggregate those rights, impose a large cost on implementation of the CCS technology? And second, would the transaction costs associated with aggregating property rights be large or small relative to the payments made to the rights-owners?

We start with a brief discussion of the pertinent geological, technological, and demographic factors. We then lay out a few assumptions regarding the costs of establishing contracts and the likely range of payments to landowners. These assumptions are based on experience with development of storage fields for natural gas in the Midwest, particularly in Ohio and Indiana. Finally, we provide some stylized calculations for the payments and transaction costs that are likely to occur with a CCS program in Indiana, testing the sensitivity of the results for a range of assumptions.

1. Background Information and Assumptions for the Cost Analysis

To perform even a stylized cost calculation, as is undertaken here, it is important to establish reasonable ranges of estimates for the important parameters. As discussed below, there are a number of important assumptions and estimates that are

412. *See, e.g.*, Steven J. Eagle, *Public Use in the Dirigiste Tradition: Private and Public Benefit in an Era of Agglomeration*, 38 Fordham Urb. L.J. 1023, 1076 (2011).
413. *See, e.g.*, D. Zachary Hudson, Note, *Eminent Domain Due Process*, 119 Yale L.J. 1280, 1287 (2010).
414. Jan G. Laitos, Law of Property Rights Protection: Limitations on Governmental Powers § 6.02, at 6-5 (1998) (footnote omitted).
415. *Id.* (citing Phillips v. Wash. Legal Found., 524 U.S. 156, 164 (1998); United States v. Gen. Motors Corp., 323 U.S. 373, 377–78 (1945)).
416. *Id.*
417. *Id.* at 6-5 to -6 (quoting Kaiser Aetna v. United States, 444 U.S. 164, 179 (1979)).

important factors in the transaction cost analysis. We start with a basic hypothetical: suppose that rights to deep pore space are held by the surface-estate owners. Further suppose that the state or an authorized private developer were to set out to aggregate property rights in pore space across a storage field sufficient to store CO_2 emissions from a planned electricity plant. What can we deduce about the magnitude and relative importance of the payments and transaction costs?

To provide an initial crude analysis, we employ transaction-cost and easement-payment estimates drawn on experience from the aggregation of natural-gas-storage fields in Indiana. Although the specific costs may be different in other states, the approach is broadly applicable across contexts.

In general, the larger the average landholding size, the fewer the number of parties involved in negotiations for pore-space rights. Unfortunately, data on average landholding size is not readily available for Indiana. As a proxy, we might consider the acres per household. For Indiana, in the 2000 census, that figure is approximately nine acres per household.[418] However, CCS-developers might favor projects in less densely populated areas. In Knox County, for example, where Duke Energy is building a new IGCC power plant, there were twenty-one acres per household.[419]

The primary sources of CO_2 injectate in Indiana will almost certainly be power plants.[420] The plant sizes and amount of CO_2 generated will vary substantially.

As discussed above, the precise size and shape of a CO_2 injectate plume is difficult to anticipate precisely.[421] At a minimum, there will be significant uncertainty regarding the ultimate path and mode in which the CO_2 will exist in the reservoir.

As a starting point for this analysis we assume that there will be 2,417 tons of CO_2 per acre of surface area, reflecting a single reservoir with moderate physical characteristics of thickness and porosity. Therefore, rights to significantly large amounts of acreage will need to be aggregated to account for the uncertainty and the large volumes that will need to be accommodated.

It is unclear what the magnitude of payments might be, if any, for a permanent easement or annual lease of the pore space used in CCS. As discussed above, cycled storage of natural gas—that is, injection during the summer months and draw-down in the winter—provides a useful analog to CCS injection. There is no established market price for leasing natural-gas-storage fields, but at least one source suggests that the figure for Ohio, Pennsylvania, New York, and West Virginia is approximately $50 per acre for a permanent easement.[422] That figure might be higher where there are natural-gas wells on the property, because storage activities can interfere with production.

The natural-gas analogy is not perfect, of course. First, natural gas storage tends to take place at shallower depths than CCS.[423] Second, re-injection of natural gas for seasonal storage generally most commonly involves carefully selected geological structures that once contained natural gas or oil; they are naturally well-suited for the purpose.[424] Finally, natural-gas storage involves a more dangerous substance; while natural gas is flammable, CO_2 is not.[425] Hence, the payments for natural-gas storage may be substantially higher than what we could expect to pay for CCS storage in Indiana. As a starting point for our analysis, we will assume that CCS-developers will pay as much per acre for pore space as do developers of natural-gas-storage fields, but we will also test the sensitivity of our results to that assumption.

Some of the costs of acquiring pore-space property rights are the payments to landowners. Where the payments made to landowners are generally proportional to the number of acres under contract, the transaction costs are more like fixed costs—nearly the same cost per contract regardless of size. The costs of acquiring pore-space property rights are not limited to the payments made to landowners, however. There also are the costs of completing the transaction itself. The storage-field-developer, or lease "landman," reviews courthouse records to verify ownership, conducts negotiations, educates landowners, records the lease in the courthouse, and adds the new lease to the lessee company's databases.[426] There are also costs associated with attorneys and administrative support. A rough estimate of the cost of negotiating a typical contract might be $3,100.[427] This cost would, of course, be far higher if the process had to be resolved with a condemnation trial.

2. Estimates of Payments and Transaction Costs

Based on the background information and assumptions outlined above, it is possible to conduct some simple calculations to provide rough estimates of the likely level of payments and transaction costs associated with a CCS operation.

Table 1 shows the results for four scenarios. The base case assumes a 652-megawatt plant producing 4.5 million tons of CO_2 per year with a capture rate of 50%. With a storage rate of 2,417 tons of CO_2 per acre, this suggests that after 30

418. During the period from 2005 to 2009, there were nearly 2.5 million households in Indiana with a land area of 35,826 square miles (9.3 acres per household). The corresponding figures for Knox County, Indiana are 15,466 households and 516 square miles (21.3 acres per household). *See State & County QuickFacts: Indiana*, *supra* note 230.

419. *Id.*

420. Some industrial processes produce substantial CO_2 emissions, but those sources are relatively small compared to the CO_2 emissions from electricity generation. For example, in 2009, electricity generation in the United States generated 2.15 billion metric tons of CO_2, while industrial processes generated only 0.12 billion tons. EPA, EPA 430-R-11-005, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2009, at 2-8 tbl.2-4, 2-11 tbl.2-6 (2011), *available at* http://epa.gov/climatechange/emissions/downloads11/US-GHG-Inventory-2011-Complete_Report.pdf.

421. *See supra* Part I.B.

422. E-mail from Andrew Theodos, Dir., Gas Storage Dev., NiSource Gas and Transmission, to author (May 21, 2009) (on file with author).

423. Benson, *supra* note 356, at 21.

424. *See supra* notes 214–15 and accompanying text.

425. *See supra* note 240 and accompanying text.

426. *See About AAPL*, Am. Ass'n Prof. Landmen, http://www.landman.org/WCM/AAPL/ABOUT_AAPL/AAPL/About_AAPL/About_AAPL.aspx?hkey=04c0535f-d6bd-4e38-a29f-39f11a4764c8 (last visited Nov. 18, 2011).

427. This is based on experience that suggests a typical contract might take 70 hours of a land man's time at $30 per hour and 20 hours of legal support at $50 per hour, for a total of $3,100 per contract.

years of production, the CCS facility would cover 27,933 acres.[428] While the discussion above suggests that there are about 9 acres per household in Indiana and 21 acres per household in rural Knox County, to provide a lower bound on the transaction costs, we start our base case with the optimistic assumption that the average landholding over the CCS field is 125 acres. This means that it would require 223 contracts to acquire rights to the pore space. At an average transaction (fixed cost) of $3,100 per contract,[429] the transaction costs of aggregating the property rights would be nearly $700,000.

Table 1: Estimates of Payments and Transaction Costs for CCS Pore-Space Property Rights

	Base Case	Alternative 1	Alternative 2	Alternative 3
Plant Size (MW)	632	632	632	632
Tons CO_2/year	4,500,000	4,500,000	4,500,000	4,500,000
Capture rate	50%	100%	100%	100%
Operation life (years)	30	30	30	30
Total lifetime tons captured	67,500,000	135,000,000	135,000,000	135,000,000
Total area (acres)	27,933	55,866	55,866	55,866
Tons per acre	2,417	2,417	2,417	2,417
Acres per landowner	125	125	10	10
Number of landowners	223	447	5,587	5,587
Transaction cost/landowner ($)	3,100	3,100	3,100	3,100
Total transaction cost	692,733	1,385,467	17,318,331	17,318,331
Payment per acre ($)	50	50	50	10
Total Payment ($)	1,396,640	2,793,279	2,793,279	558,656
Transaction cost + payment ($)	2,089,373	4,178,746	20,111,610	17,876,987
Transaction cost/payment ($)	0.50	0.50	6.20	31.00
Unit cost ($/ton of $C0_2$)	0.06	0.06	0.29	0.26

Assuming that landowners are compensated $50 per acre for a permanent easement on the pore space,[430] the total payment to landowners would be nearly $1.4 million. The total cost of aggregating the property rights for this hypothetical plant is just over $2 million.

From this analysis, a few important points emerge. First, the total pore-space property-rights cost (transaction costs and landowner payment) is just $0.06 per ton of CO_2 injected. This figure is extremely small relative to the total incremental cost of CCS, which has been estimated in the range of $35 to $70 per ton of CO_2 emissions avoided.[431] In other words, the cost of acquiring the property rights is mere noise in the CCS cost calculation.

However, this cost does not reflect the potentially disruptive effect that a holdout property-owner might have on the project costs. If a landowner forces the acquisition to go through the eminent-domain process, the legal costs could be much greater. More importantly, the process associated with the typical exercise of eminent domain could lead to extraordinarily high delay costs. These delay costs are generally not incurred in the natural-gas development process because of the "quick-take" provisions generally available in that application.[432]

Finally, the transaction costs of arranging the payment to the landowners is half as much as the payment itself.[433] That means that for every dollar the state or the developer pays to the landowners, they are incurring another $0.50 of cost just to organize the payment.

Now consider how the results change as the underlying assumptions are adjusted. In the Alternative 1 case, the only change relative to the Base case is that, rather than capturing and injecting 50% of the CO_2 emissions, the project injects 100%.[434] This change doubles all of the important impacts—twice as many tons per year of CO_2, twice as many acres, and twice as many landowners.[435] The unit costs and the ratio of transaction costs to payment, however, are unchanged.[436] Thus, the size of the CCS operation alone is not the most important factor.

In Alternative 2, it is assumed that the average landholding is 10 acres rather than 125.[437] While the total payments to landowners remain the same, the payments are made to many more landowners.[438] This substantially increases the transaction costs associated with aggregating the pore-space property rights;[439] the cost rises to $0.29 per ton of carbon.[440]

428. Compare this figure to the average size of a natural-gas-storage field in Indiana, which is 4,500 acres. *See supra* note 229 and accompanying text. Even this relatively small facility with only a fifty percent capture rate will require a storage field that is a factor of six larger than the average natural-gas field.
429. *See supra* note 427 and accompanying text. This figure assumes that there are no cases involving the exercise of eminent domain and the legal proceedings that generally attend the exercise of that power.
430. *See supra* note 422 and accompanying text.
431. Estimates vary substantially. *See, e.g*, Int'l Energy Agency, ETE01, IEA Energy Technology Essentials: CO_2 Capture & Storage 1 (2008), *available at* http://www.iea.org/techno/essentials1.pdf (typical cost of CCS plants range from $30 to $90 per metric ton of CO_2); *Carbon Capture and Storage*, 238 U.K. Parliamentary Office of Sci. &Tech.Postnote 3 (2005), *available at* http://www.parliament.uk/documents/post/postpn238.pdf (costs of CCS range from £30 to £90 per metric ton of CO_2); Emily Giovanni & Kenneth R. Richards, *Determinants of the Costs of Carbon Capture and Sequestration for Expanding Electricity Generation Capacity*, 38 Energy Pol'y 6026, 6031 fig.7 (2010), *available at* http://classwebs.spea.indiana.edu/kenricha/Research/Giovanni%20and%20Richards%202010%20article.pdf (cost of CCS is sensitive to underlying natural-gas price, ranging from $35 to $60 per ton of CO_2); Michael R. Hamilton et al., *Cost and U.S. Public Policy for New Coal Power Plants with Carbon Capture and Sequestration*, 1 Energy Procedia 4487, 4489 tbl.1 (2009), *available at* http://sequestration.mit.edu/pdf/GHGT9_Hamilton_Herzog_Parsons.pdf (cost of CCS with supercritical pulverized coal is $52.20 per ton of CO_2).
432. *See supra* note 233 and accompanying text.
433. *See supra* Table 1 and Part IV.B.1.
434. *See supra* Table 1.
435. *Id.*
436. *Id.*
437. *Id.*
438. *Id.*
439. *Id.*
440. *Id.*

More importantly, in this scenario, the transaction costs are nearly seven times as large as the payments themselves.[441] In other words, the state or the project-developer would incur costs of seven dollars for each dollar it moved from the state treasury or the developer's funds to the landowners' pockets.

For reasons discussed above, a payment of $50 per acre, which is typical for natural-gas-field development in nearby eastern states, is arguably much higher than should be required for CCS.[442] Alternative 3 demonstrates the effect of lowering the payment to $10 per acre.[443] The cost of acquiring property rights CO_2 drops to $0.26 per ton of CO_2.[444] However, the transaction costs in this scenario are $31 for each dollar of payment made to landowners.[445]

C. *Practical Approaches to Pore-Space Ownership*

Given the results of the transaction-cost analysis, we can now consider two modifications to the four options outlined above. The rudimentary transaction-cost analysis suggests that the costs of aggregating pore-space property rights will not be large relative to the overall costs of CCS, at least in the context of a state like Indiana. However, that analysis does not consider the transaction costs associated with overcoming strategic behavior, particularly the holdout problem.

It is significant that for the aggregation of natural-gas storage fields, at least some jurisdictions include a "quick-take" provision that allows developers to occupy the property as soon as the court papers are filed.[446] This represents a different balance between the potential loss of low-value rights in pore space against the cost delay of developments with important public-interest implications. Arguably, at least, the property rights in saline-aquifer pore space for CCS will be much less valuable than those in natural-gas storage.[447]

To minimize the costs associated with holdouts and other strategic behavior, a state legislature that opts to recognize private property rights in deep-subsurface pore space, and to deal with aggregation through exercise of the eminent-domain power, should also adopt a quick-take provision.

Even if a state legislature decided to establish a policy stating that property rights in pore space do not lie with private citizens, there might be considerable political resistance to such a statute. It might be more feasible to make the lack of property rights implicit in a small "proximity payment" that offers fixed payments to surface-owners whose land overlays the affected pore space.[448] This approach might have two primary elements. First, developers could be required to publish a map of the expected location and area of the plume at *X* years after first injection. Developers could then be required to make a $*Y*-per-acre payment to any surface-owner that fills out an application and provides proof of title within the relevant area.

As a benchmark, it might be reasonable to require that *X* be 15 years and *Y* be $10 per acre. These provisions for "proximity payments" do several things. First, they provide some compensation to landowners as a way of diffusing political resistance to a perceived loss of one of the sticks in the property-rights bundle.[449] Second, this approach substantially reduces the transaction costs—including negotiation costs, legal costs, and potential delay—associated with the aggregation of property rights.[450] Third, it shifts the responsibility for initiating the compensation process to the landowners. It is unlikely that the majority of owners of small properties would take the initiative to process the paperwork and provide the required documentation. This means that only those landowners with a substantial stake, who also are likely to be the most politically resistant, would make a claim. Finally, if a court were to determine that some compensation is due to landowners, this proximity payment would likely satisfy that requirement.[451]

This approach has two benefits. First, by shifting the responsibility for making the claim to landowners, the majority of small landowners—the ones for whom transaction costs are greater than the value of the payment—would not make claims. This is an improvement to a system under which the state or developer has a positive obligation to identify and pay landowners. Second, it mitigates the impression that surface-owners have "lost" a right they once enjoyed.[452]

The real argument against recognizing private rights in deep-subsurface pore space is that those rights only have value when they are aggregated, and the costs of aggregation might be far greater than the value of the rights themselves.[453] In other words, vesting those rights in private landowners could be extremely inefficient.

This analysis demonstrates two other important results. First, even if property rights in pore space do rest with individual landowners, in absolute terms the costs of acquiring those rights are likely to be a very small part of the total costs of CCS-project development.[454] Second, landowners who engage in strategic holdout behavior have the potential to inflict sizable costs of project development due to delays, even if the eminent-domain power is available to the developer.[455]

The four options for addressing and managing property rights in pore space range from vesting the property rights in private parties and trading the pore-space rights in the marketplace, to vesting the rights in the public and using them for public purposes, particularly for CCS.[456] Now that several states have enacted laws related to pore-space property

441. *Id.*
442. *See supra* Part IV.B.1.
443. *See supra* Table 1.
444. *Id.*
445. *Id.*
446. *See, e.g.*, Moorhead Econ. Dev. Auth. v. Anda, 789 N.W.2d 860, 868 (Minn. 2010).
447. *See supra* Part IV.B.1 (discussing the differences between CCS and natural-gas storage; the depth at which CCS takes place makes it unlikely to interfere with other land uses, at least in some regions of the country).
448. *See, e.g.*, Flatt, *supra* note 16, at 234; Wilson & de Figueiredo, *supra* note 145, at 10,123.
449. *See* Marston & Moore, *supra* note 78, at 477.
450. *See supra* Part IV.B.1.
451. *See, e.g.*, Flatt *supra* note 16, at 234.
452. *See* Marston & Moore, *supra* note 78, at 477.
453. *See supra* Table 1.
454. *Id.*
455. *See* Rule, *supra* note 401, at 885.
456. *See* Johnson, Midwestern Governors Ass'n, *supra* note 397 at 33.

rights, it is interesting to consider where on the spectrum of approaches they seem to land.

Perhaps the state with the clearest approach is Montana, which has stated that the pore space belongs to the party that has the right to drill and extract oil and natural gas.[457] Where there is ambiguity regarding ownership of the pore space, it rests with the surface-owner.[458] Moreover, the state has clearly invoked a form of the police power in authorizing forced unitization.[459] Thus, Montana has adopted a variation of Option 3, replacing the exercise of eminent-domain authority with forced unitization.

The North Dakota approach is very similar to the Montana law. North Dakota has vested ownership of pore space in surface-owners and prohibits future severing of the two rights, with the exception of leasing.[460] Like Montana, North Dakota has authorized use of forced unitization with a requirement that pore-space owners receive "equitable compensation."[461] This latter requirement sounds just a little more like eminent domain than the forced-unitization process authorized by Montana.

For the other states, it is more difficult to discern a clear strategy. While Louisiana's explicit provisions for the use of eminent domain suggest that it is tracking the Option 3 approach, it has not taken the important first step of clearly vesting ownership of the pore space.[462]

Wyoming has employed an approach that vests pore-space ownership in surface-owners, but does not stipulate provisions for unitization, eminent domain, or other approaches to aggregate the rights into a usable unit.[463] In this sense, the state seems to be relying on an approach similar to Option 2, which relies on pure bargaining and contracting to aggregate property rights.

The Oklahoma process might be interpreted as approaching Option 4. The law emphasizes the protection of mineral rights.[464] It also requires CCS-permit applicants to notify surface- and mineral-owners within the boundary of the facility.[465] The notification provision would be redundant if the permit applicant also had to acquire pore-space property rights, suggesting that aggregation of the rights is not necessary in Oklahoma. If that is the case, the state will have essentially reserved the property rights for public use, to be managed through the permitting process.

The processes established by Kansas and Illinois do not address ownership directly.[466] Utah and West Virginia have established working groups to study and recommend strategies for managing pore-space property rights.[467]

There is no single strategy that emerges from the states' actions. Rather, they seem to fall in the range of Options 2 to 4. Many more states are still trying to identify and develop viable approaches.

457. Mont. Code Ann. § 82-11-180(2)(a) (2011).
458. *Id.* § 82-11-180(3).
459. *Id.* §82-11-104.
460. N.D. Cent. Code §§ 47-31-01 to -08 (2011).
461. *Id.* § 38-08-08(1) (2011).
462. *See State CCS Policy*, *supra* note 4.
463. *See* Wyo. Stat. Ann. § 34-1-152(a)–(b) (2011).
464. Okla. Stat. tit. 27A, § 3-5-101(C)(2) (2011).
465. *Id.* § 3-5-104(D).
466. *See supra* note 4 and accompanying text.
467. *See supra* notes 4, 6.

V. Conclusions

The analysis of transaction costs suggests that, at least for some states, adoption of an approach based largely on negotiation would not unduly burden the CCS technology unless strategic behavior on the part of surface- or mineral-owners becomes a significant obstacle.[468] In the absence of strategic behavior, the additional costs of aggregating rights to pore-space fields would likely be less than one percent of the total costs per ton of CO_2 stored.[469]

That does not mean, however, that states should necessarily follow the lead of Montana and other states that have legislatively declared that rights to deep-subsurface pore space reside with surface-owners. The discussion of the function of property rights demonstrates that establishing property rights is beneficial when a resource has multiple uses. Prices and payments function to move resources to their highest-value use.

But, at least in states where the pore space suitable for CCS is almost entirely below the depth at which other viable economic activities occur, payments for pore-space use would likely be quite small based on analogous payments for natural-gas-storage fields, and the average surface estate is smaller than ten acres.[470] Given these conditions, pore space has virtually no alternative use,[471] so establishing property rights will not serve the basic function of allocating the resource among competing uses. And making payments—essentially just moving money—from the state or its authorized CCS-developer to surface-owners comes at a substantial economic cost for society.[472] Moreover, the transaction costs associated with organizing the transfer of property rights and negotiating payments could well be greater than the payments themselves, leading to gross economic efficiencies.[473]

The examples of Wyoming, Montana, and North Dakota notwithstanding, for at least some states it is inefficient to start a CCS regulatory process by first declaring that surface-owners also control the deep-subsurface pore space.[474] To do so would essentially scatter the rights to the wind, only to have to collect them again to develop CCS. It would be a self-inflicted tragedy of the anticommons.[475]

468. *See supra* Part IV.A.
469. *See supra* Table 1.
470. *See supra* Part IV.B.1.
471. To borrow a phrase from economics, we would say that the pore space-resource in Indiana has no "opportunity cost"—that is, there is no reasonable, foreseeable alternative use. *See* Jerry Brito, *Sending Out an S.O.S.: Public Safety Communications Interoperability as a Collective Action Problem*, 59 Fed. Comm. L.J. 457 (2007) (defining "opportunity cost" as "the loss of a potential benefit from other alternative uses of [a good]"); *supra* notes 347–348 and accompanying text.
472. Given the underlying inefficiencies inherent in taxation—what economists call "deadweight loss"—there is a substantial social cost associated with revenue-raising that would be required for the state government to make payments. *See* Brian H. Jenn, *The Case for Tax Credits*, 61 Tax Law. 549, 567–68 (2008).
473. *See supra* Table 1.
474. *See supra* Part III.B.
475. *See id.*

Rather, the legislatures in midwestern (and similarly situated) states should recognize that the most valuable spatial arrangement of property rights in pore space in no way resembles the most valuable spatial arrangement of surface-estate rights. The state legislation should be designed with three primary goals in mind. First, do not inefficiently disaggregate property rights in deep-subsurface pore space. Second, provide legal grounds for courts to support the efficient use and management of pore-space resources. Third, develop an approach that is politically viable.

As discussed above, the surest legal foundation for establishing state control over pore space is to incorporate that provision into the state constitution; for example, establishing that rights to deep-subsurface pore space are held in public trust for the benefit of state citizens.[476] Unfortunately, most state constitutions do not contain such a provision. Moreover, constitutional amendments generally move at a glacial pace—not particularly conducive to addressing an immediate policy challenge.

However, state courts have consistently recognized the public-trust doctrine.[477] As an alternative to a constitutional amendment, then, the state legislature could codify the application of the public-trust doctrine and common property to the pore space. Similar to New Mexico's approach to groundwater, states could statutorily declare that all pore spaces are public and subject to appropriation for beneficial use. The state legislature could reinforce its intent by establishing that any rights to deep-subsurface pore space held by private parties are under a public servitude that allows the state or its authorized agents to store CO_2 at depths great enough to avoid interference with activities that are currently economically viable. Finally, the legislation could establish that, should there be any remaining subsurface-property rights that are not covered by the legislation because of omission or court ruling, state agencies are authorized to use eminent domain with a "quick-take" provision and their police powers to aggregate the rights required to assemble an injection field.

Note, however, that providing legal cover does not assure political viability. If the political environment is such that it is prudent to assuage the concerns of landowners, the legislature could include a proximity payment, as discussed above,[478] a provision that provides compensation in a form that does not admit to any compromise on property rights.

476. *See supra* Part II.B.3.a.
477. *See supra* Part II.B.3.
478. *See supra* Part IV.C.