WHO OWNS HEAT? PROPERTY RIGHTS IN GEOTHERMAL ENERGY

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Landowners can have ownership claims to oil, gas, water, and other tangible natural resources located in their subsoil. But can they also claim rights to the thermal energy found below their land? With 50,000 times more heat energy within the top 10,000 meters (around 33,000 feet) of the Earth's surface than contained in all of the world's oil and natural gas resources combined, geothermal energy is a tremendously promising, clean, and renewable energy resource. Yet, ambiguities in property rights related to the development and ownership of geothermal energy resources raise questions about who is entitled to benefit from that potential.

This Article explores questions of ownership rights and interests in geothermal energy—an incorporeal, uncontainable, natural resource that is better defined as a characteristic of underground formations rather than as a physical or tangible thing. More broadly, it looks at the effects various theoretical approaches to ownership might have on the development of geothermal energy resources.

The underlying premise of this Article is that absent clear property rules for ownership in geothermal energy, commercial and public investment in this promising, clean, renewable energy resource will remain limited. In contrast, clearly defined ownership interests could have profound implications for nearly every aspect of geothermal energy development—exploration, harvesting, conversion, and transfer of this distinct energy source—as well as for decarbonizing the economy.

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I. INTRODUCTION

Climate change has forced humanity into a desperate search to find and develop alternative sources of energy to traditional fossil fuels.[1] Over the past few decades, it has looked to the sun, winds, rivers, and oceans, and has also experimented with biomass, hydrogen, and chemical and nuclear reactions, to provide clean substitutes that might help abate the global climatic transformations that are currently underway, and that threaten humanity's very existence.[2] Yet, one of the most overlooked and underutilized sources of energy lies, in a literal sense, beneath every person's feet in every corner of the planet. This source is geothermal energy.

When most people think of geothermal energy, they envision hot springs adjacent to spas[3] and geysers, like Old Faithful in Yellowstone National Park.[4] But geothermal energy encompasses so much more than what can be seen and enjoyed on the surface. It refers to the vast trove of energy generated and stored within the Earth's interior.[5] Within the top 10,000 meters (around 33,000 feet) of the surface alone, the Earth is estimated to hold and sustain 50,000 times more heat energy than contained in all of the world's oil and natural gas resources combined.[6] More importantly, that energy is nearly limitless and continuously

1. *See generally* Nicholas J. Gardiner et al., *Geosciences and the Energy Transition*, 3 EARTH SCI. SYS. &. SOC'Y. July 5, 2023, at 1. On March 20, 2023, the International Panel on Climate Change issued its Sixth Assessment Report, the latest in a series of reports presenting assessments on the extent, causes, and future projections of climate change. In the report, the Panel asserted that "[h]uman activities, principally through emissions of greenhouse gases, have unequivocally caused global warming;" that "the largest growth in gross [greenhouse gas] emissions occurred in CO_2 from fossil fuels and industry;" and that fossil fuel combustion and industrial processes continue to contribute around 2/3 of total greenhouse gases emissions. IPCC, CORE WRITING TEAM, SECTIONS. IN: CLIMATE CHANGE 2023: SYNTHESIS REPORT 35, 42–44 (Hoesung Lee & José Romero eds., 2023) [hereinafter IPCC, 2023], https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_LongerReport.pdf [https://perma.cc/4LEF-548C]. According to the U.S. Energy Information Administration, in 2023, approximately 60% of total electricity generation in the United States was supplied by fossil fuels—coal, natural gas, petroleum, and other gases. *Frequently Asked Questions (FAQs)*, U.S. ENERGY INFO. ADMIN., https://www.eia.gov/tools/faqs/faq.php?id=427 (last visited Feb, 26, 2025) [https://perma.cc/W2HB-AQ74].

2. *See generally* Gardiner et al., *supra* note 1; Omar Ellabban, Haitham Abu-Rub & Frede Blaabjerg, *Renewable Energy Resources: Current Status, Future Prospects and Their Enabling Technology*, 39 RENEWABLE AND SUSTAINABLE ENERGY REVS. 748 (2014).

3. *See, e.g.*, Lauren Sloss, *Where to Take the Waters: A U.S. Hot Springs Guide*, N.Y. TIMES (Apr. 5, 2022), https://www.nytimes.com/2022/03/30/travel/hot-springs.html [https://perma.cc/NJD7-GW8U] (describing various hots springs and spas in the United States).

4. *Old Faithful*, NAT'L PARK SERV., https://www.nps.gov/yell/planyourvisit/exploreoldfaithful.htm (last updated July 25, 2024) [https://perma.cc/Z26N-L2LW].

5. Ellabban et al., *supra* note 2, at 750; John W. Lund, *Geothermal Energy*, ENCYC. BRITTANICA, https://www.britannica.com/science/geothermal-energy (last updated Jan. 29, 2025) [https://perma.cc/38MU-Q4ZS].

6. *How Geothermal Energy Works*, UNION OF CONCERNED SCIENTISTS, https://www.ucsusa.org/resources/how-geothermal-energy-works (Dec. 22, 2014) [https://perma.cc/M8LY-ZL63]; U.S. DEP'T OF ENERGY NAT'L RENEWABLE ENERGY LAB'Y, RENEWABLE ENERGY: AN OVERVIEW (2001), at 3 https://www.nrel.gov/docs/fy01osti/27955.pdf [https://perma.cc/R8QE-5RYW]. In addition, Bradbrook and Rønne estimate that recoverable heat energy reserves within the United States in the 90–150° C (194–302° F) range are equivalent to 900 billion barrels of oil, or twenty times the proven oil reserves of the country. Adrian J. Bradbrook & Anita Rønne, *New Advances in Geothermal Energy Law: A Comparative Analysis*, *in* THE LAW OF ENERGY UNDERGROUND: UNDERSTANDING NEW DEVELOPMENTS IN SUBSURFACE PRODUCTION, TRANSMISSION, AND STORAGE 309, 310 (Donald N. Zillman, Aileen McHarg, Adrian Bradbrook & Lila K. Barrera-Hernandez eds., 2014).

replenished, with a lifespan estimated in the billions of years,[7] and is available literally everywhere below the Earth's continental and oceanic crustal surfaces.[8] As a bonus, the production of this energy resource results in near zero carbon emissions, making it a potential leading source of clean, renewable energy globally.[9]

Despite its promise as a replenishable, green energy source, the vast majority of nations around the world have yet to adopt geothermal energy in their portfolio of renewable energy sources.[10] For example, in the United States—which is the world leader in the utilization of high-temperature geothermal resources[11]—geothermal energy production, which occurs predominantly in a few western states, accounted for only 0.4% of the total electricity generated in 2022 and 2023.[12] Globally, in 2021, total electricity production from geothermal sources amounted to about 96.5 billion kWh of electricity, or 0.34% of total electricity production worldwide.[13] Moreover, only approximately 1% of the 126 million existing buildings in the United States use geothermal energy to support their heating and cooling needs.[14]

7. U.S. DEP'T OF ENERGY, GEOVISION: HARNESSING THE HEAT BENEATH OUR FEET 11 (2019) [hereinafter GEOVISION], https://www.energy.gov/eere/geothermal/articles/geovision-full-report-0 [https://perma.cc/TYP6-DA8V] (explaining that "heat is continually replenished by the decay of naturally occurring radioactive elements in the Earth's interior and will remain available for billions of years, ensuring an essentially inexhaustible supply of energy"); *see also* A. Gando et al., *Partial Radiogenic Heat Model for Earth Revealed by Geoneutrino Measurements*, 4 NATURE GEOSCIENCE 647, 647 (2011) (concluding that "Earth's primordial heat supply has not yet been exhausted").

8. Silviu Livescu, Birol Dindiruk, Rebecca Schulz, Peter Boul, Jihoon Kim & Kan Wu, *Geothermal and Electricity Production: Scalable Geothermal Concepts*, *in* THE FUTURE OF GEOTHERMAL IN TEXAS: THE COMING CENTURY OF GROWTH & PROSPERITY IN THE LONE STAR STATE 25, 26 (Jamie C. Beard & Bryant A. Jones eds., 2023), https://doi.org/10.26153/tsw/44084 [https://perma.cc/JH2C-UZAF] (stating that "geothermal energy exists in the subsurface beneath every location on Earth"); David Roberts, *The Earth Itself Could Provide Carbon-Free Heat for Buildings*, VOX (Nov. 13, 2020, 9:00 AM), https://www.vox.com/energy-and-environment/2020/11/13/21537801/climate-change-renewable-energy-geothermal-heat-gshp-district-heating [https://perma.cc/C9VD-ZUF9] (noting that "geothermal heat is accessible almost everywhere").

9. *See generally* Jefferson W. Tester, Koenraad F. Beckers, Adam J. Hawkins & Maciej Z. Lukawski, *The Evolving Role of Geothermal Energy for Decarbonizing the United States*, 14 ENERGY & ENV'T SCI. 6211, 6217 (2021) (noting that "[c]arbon emissions are low to zero for geothermal direct-use and power generation systems").

10. For example, while solar photovoltaic power increased globally by 191 gigawatts in 2022, geothermal energy grew by a more modest 181 megawatts. Record Growth in Renewables Achieved Despite Energy Crisis, Int'l Renewable Energy Agency (Mar. 21, 2023), https://www.irena.org/News/pressreleases/2023/Mar/Record-9-point-6-Percentage-Growth-in-Renewables-Achieved-Despite-Energy-Crisis [https://perma.cc/P226-BSHA].

11. *Geothermal Explained: Use of Geothermal Energy*, U.S ENERGY INFO. ADMIN., https://www.eia.gov/energyexplained/geothermal/use-of-geothermal-energy.php (April 3, 2024) [https://perma.cc/C7LE-TNAH] (noting that the U.S. is one of 24 countries that lead the world in geothermal electricity generation, "produc[ing] about 0.4% (17 billion kilowatthours) of total U.S. utility-scale electricity generation," which "requires water or steam at high temperatures (300°F to 700°F)").

12. *See Frequently Asked Questions (FAQs)*, *supra* note 1; *Geothermal Explained: Use of Geothermal Energy*, *supra* note 11; *Electricity Explained: Electricity in the United States*, U.S ENERGY INFO. ADMIN. (Mar. 26, 2024), https://www.eia.gov/energyexplained/electricity/electricity-in-the-us.php [https://perma.cc/2KRU-3YNS].

13. Luis C.A. Gutiérrez-Negrín, *Evolution of Worldwide Geothermal Power 2020–2023*, GEOTHERMAL ENERGY (2024), Mar. 26, 2024, at 1, 2–3.

14. XIAOBING LIU ET AL., OAK RIDGE NAT'L LAB'Y, GRID COST AND TOTAL EMISSIONS REDUCTIONS THROUGH MASS DEPLOYMENT OF GEOTHERMAL HEAT PUMPS FOR BUILDING HEATING AND COOLING ELECTRIFICATION IN THE UNITED STATES 2 (2023), https://info.ornl.gov/sites/publications/Files/Pub196793.pdf [https://perma.cc/2DS6-WW26] (stating that only "[a]pproximately 1% of the 126 million existing buildings in the United States currently use GHP systems").

The challenges of expanding the use of geothermal energy, especially large scale production projects using enhanced geothermal systems,[15] are due, in part, to high upfront costs and technological limitations,[16] as well as relatively high energy production costs.[17] They are also due to a lack of public understanding about and engagement in the potential of this hidden resource and how it can be harnessed.[18] In addition to these barriers, over the past century, nations have prioritized fossil fuels over other fuel sources to drive global economic development.[19] This has constrained research into and exploration of alternative options, including geothermal resources.[20]

15. Enhanced geothermal systems are geothermal energy recovery activities that utilize fracking, open and closed loop systems, and other methodologies and technologies to extract geothermal energy where conventional methods are not available. *See* GEOVISION, *supra* note 7, at 14, 18–19; Brad Plumer, *There's a Vast Source of Clean Energy Beneath Our Feet. And a Race to Tap It*, N.Y. TIMES (Aug. 28, 2023), https://www.nytimes.com/2023/08/28/climate/geothermal-energy-projects.html [https://perma.cc/Z47C-VBX7].

16. Gregory Barber, *A Vast Untapped Green Energy Source Is Hiding Beneath Your Feet*, WIRED (July 19, 2023, 6:00 AM), https://www.wired.com/story/a-vast-untapped-green-energy-source-is-hiding-beneath-your-feet/ [https://perma.cc/M6CB-PCAN] (asserting that, "[g]eothermal happens to require a risky multimillion-dollar drilling project to get started" and that "[a] geothermal well might take 15 years to pay for itself; a natural gas rig does it in two"); Dylan Matthews, *Is the Future of Energy . . . Pouring Water on Hot Rocks in the Ground?*, VOX (Sept. 13, 2023, 6:00 AM), https://www.vox.com/future-perfect/23825844/geothermal-enhanced-fervo-demonstration-superhot [https://perma.cc/Y77U-FV7H] (discussing the high up-front costs for implementing an enhanced geothermal system as compared to solar and wind projects); Jim Robbins, *Can Geothermal Power Play a Key Role in the Energy Transition?*, YALE ENV'T 360 (Dec. 22, 2020), https://e360.yale.edu/features/can-geothermal-power-play-a-key-role-in-the-energy-transition [https://perma.cc/FQ4F-DL8U] (discussing the barriers to the development of geothermal energy).

17. Actual costs for geothermal energy production using enhanced technologies and processes are difficult to locate due largely to the dearth of enhanced geothermal energy projects in operation. Moreover, the majority of ongoing energy producing operations are located over hot springs and in geologically active areas where hot water and steam naturally rise to the surface, thereby functioning as conventional (rather than enhanced) geothermal systems. As a result, incurred costs are site specific and often depend on local geology and geothermal conditions. A recent undertaking by the U.S. Department of Energy Office of Energy Efficiency & Renewable Energy proposed to reduce the cost of enhanced geothermal energy recovery activities—extraction activities that cannot rely on the natural upflow of hot water and steam, but rather have to implement technologies and methodologies to bring the heated liquid to the surface (collectively defined as enhanced geothermal systems)—by 90% to $45 per megawatt hour by 2035. CHAD AUGUSTINE, SARAH FISHER, JONATHAN HO, IAN WARREN & ERIK WITTER, U.S. DEP'T OF ENERGY, NAT'L RENEWABLE ENERGY LAB'Y, NREL/TP-5700-84822, ENHANCED GEOTHERMAL SHOT ANALYSIS FOR THE GEOTHERMAL TECHNOLOGIES OFFICE 20 (2023), https://www.nrel.gov/docs/fy23osti/84822.pdf [https://perma.cc/QF2M-ZC89]. This suggests that the current cost of enhanced geothermal energy recovery activities may be $450 per megawatt hour. In comparison, in 2022 wholesale electricity prices in the U.S. ranged from $67.77 to $97.11 per megawatt hour, and in 2023 from $32.84 to $83.86 per megawatt hour. U.S. ENERGY INFO. ADMIN., SHORT TERM ENERGY OUTLOOK (2023), Table 7a, https://www.eia.gov/outlooks/steo/pdf/steo_full.pdf [https://perma.cc/8CUX-DL3G].

18. *See* GEOVISION, *supra* note 7, at 40 (asserting that contrary to wind, solar, and hydropower generation technologies, "the public is generally unaware that geothermal resources exist and could be used for a wide array of applications"); John W. Lund & R. Gordon Bloomquist, *Development of Geothermal Policy in the United States: What Works and What Doesn't Work*, 30 GEO-HEAT CTR. Q. BULL. 1, 8 (Feb. 2012) (identifying "[l]ack of public involvement and knowledge of geothermal energy (the 'hidden' renewable resource)" as one of the "impediments to geothermal development").

19. For example, in 2017 countries around the world provided the fossil fuel industry with direct subsidies totaling more than three-and-half times the amount provided the renewable energy sector, USD $447 billion versus USD $128 billion. MICHAEL TAYLOR, ENERGY SUBSIDIES: EVOLUTION IN THE GLOBAL ENERGY TRANSFORMATION TO 2050, INTERNATIONAL RENEWABLE ENERGY AGENCY 44 (2020), https://www.irena.org/-/media/Irena/Files/Technical-papers/IRENA_Energy_subsidies_2020.pdf?rev=4c60e02b33b54c97a4c26725a1c85e02 [https://perma.cc/2EDJ-9D94].

20. According to a report by the International Institute for Sustainable Development, subsidies paid to the fossil fuel industry "distort investment decisions in favour [*sic*] of fossil-fuel technologies" and "constitute a serious barrier to renewable energy deployment." RICHARD BRIDLE & LUCY KITSON, THE IMPACT OF FOSSIL-FUEL SUBSIDIES ON RENEWABLE ELECTRICITY GENERATION, THE INT'L INST. FOR SUSTAINABLE DEV. 18–19

Yet, a fourth and possibly more pernicious barrier to the development of geothermal energy is the lack of clarity in property rights related to the development and ownership of geothermal energy resources.[21] In a market system, as employed in the United States, property rights are an essential component of the economic system.[22] They facilitate investment by creating an environment of stability, predictability, and security in the use and exploitation of those property assets.[23] This, in turn, results in an opportunity to earn a return on that investment.[24] Yet, currently, only a small minority of states have delimited clear property and ownership rules for geothermal energy.[25] The rest have rather vague or inconsistent provisions, if any, on who owns those resources.[26] Moreover, less than half include subsurface heat or energy in the definition of geothermal resources, and some with a temperature threshold.[27]

To develop geothermal energy as both commercial and public ventures, clearly defined ownership rules for geothermal energy are necessary to facilitate investment in this promising, clean, renewable energy resource. This is not to say that geothermal energy resources must be privatized. Rather, having clear ownership rules could have profound implications for nearly every aspect of geothermal energy development, including the exploration, harvesting, conversion, and transfer of this distinct energy source. For example, given that particular

(Dec. 2014), https://www.iisd.org/system/files/publications/impact-fossil-fuel-subsidies-renewable-electricity-generation.pdf [https://perma.cc/A89K-ZZ8H]; *see also* Samantha Gross, *Why Are Fossil Fuels So Hard to Quit*, BROOKINGS (June 2020), https://www.brookings.edu/articles/why-are-fossil-fuels-so-hard-to-quit/ [https://perma.cc/PH24-2WVG] (discussing how fossil fuels have shaped the modern world and became the key for growth).

21. *See* David Percy, *Ownership Issues in the Production of Geothermal Energy*, 60 ALTA. L. REV. 523, 524 (2022) (discussing that Alberta's Geothermal Resource Development Act adequately provides clear ownership rights to geothermal energy resources). Percy asserts that "[i]f this nascent industry is to flourish, it requires a firm legal foundation consisting of at least two elements. Firstly, the legislation must establish clear ownership rights to the necessary resources, and secondly, the rights regime must not impose costs that will deter the commercial development of an industry which, at the present time, is highly marginal." *Id.*; *see also* Anna McClean & Ole W. Pedersen, *Who Owns the Heat? The Scope for Geothermal Heat to Contribute to Net Zero*, 34 J. ENV'T L. 343, 350–51 (2021) (asserting that "a lack of definition of heat in terms of who owns it and how it is regulated presents a barrier to fulfilment of this potential," and "[i]n order to encourage the investor confidence needed to expand the industry and enable geothermal heat to fulfil its potential, the issue of ownership needs to be resolved and a regime be put in place for regulation of who can extract what"); Clifton A. Squibb, *Legal Considerations for Geothermal Applications in Texas*, 60(2) FOUND. J. FOR NAT. RES. & ENERGY L. 215, 222 (2024) (noting that "confusion persisted" after the Texas Legislature declined to address the ownership of geothermal resources when it adopted in the Texas Geothermal Resources Act of 1975); A.W. OBERBECK, UNIV. OF TEX. AT AUSTIN CTR. FOR ENERGY STUDIES, THE GEOPRESSURED GEOTHERMAL RESOURCES OF TEXAS: A REPORT ON LEGAL OWNERSHIP AND ROYALTY ISSUES 45 (1977) (asserting that "[u]ntil ownership questions are resolved for geothermal resources, their development will be inhibited in some degree, wherever they are located").

22. Armen A. Alchian, *Property Rights*, ECONLIB, https://www.econlib.org/library/Enc/PropertyRights.html (last visited Feb. 26, 2025) [https://perma.cc/XC2X-PHKT]; John J. Patrick, *Market Economy*, *in* UNDERSTANDING DEMOCRACY: A HIP POCKET GUIDE, ANNENBERG CLASSROOM, https://www.annenbergclassroom.org/resource/understanding-democracy-hip-pocket-guide/market-economy/ (last visited Feb. 26, 2025) [https://perma.cc/3329-MXSX].

23. *Securing Land Tenure and Property Rights for Stability and Prosperity*, U.S. AGENCY FOR INT'L DEV., https://web.archive.org/web/20241104080432/https://www.usaid.gov/land-tenure (last visited Mar. 2, 2025) [https://perma.cc/4YEV-JT9Y].

24. *Id*.

25. *See infra* notes 185–211 and accompanying text.

26. *See infra* notes 212–33 and accompanying text.

27. *See infra* notes 224–29 and accompanying text.

subsurface geothermal resource reservoirs traverse hundreds if not thousands of property lines,[28] knowing what rights a landowner has in relation to those resources could help define the scope of extraction rights as well as cross-border impacts. It could also help set a foundation for the potential transfer of these rights, whether through easements, leases, severed estates, or other approaches. Ultimately, the willingness of investors, energy companies, and even public entities to take on the risks associated with a resource with undefined or unclear ownership traits will depend, in large part, on risk factors associated with returns on investment that are tied to property rights.[29]

Notwithstanding the benefits of defining geothermal resource ownership, there are foundational questions that must first be considered, including whether, given its unique characteristics and qualities, geothermal energy can be made subject to an ownership regime, and whether this regime should be a common pool approach, public or private ownership, or some other system. Moreover, an additional query arising from the analysis includes whether existing property notions, such as the *ad coelom* and rule of capture doctrines, and property-related tort principles like trespass and nuisance, can apply to geothermal resources. Answers to these questions could help illuminate the development opportunities available in geothermal energy and may also help generate a broader discussion on priorities for long-term energy security involving other energy sources.

Focusing on the United States, this Article explores these questions of ownership rights and interests in geothermal energy resources to develop a foundation upon which sustainable and effective extraction, management, and regulatory regimes could be established. More broadly, it looks at the effects various existing and theoretical approaches to ownership might have on the development of geothermal energy resources. Part II of this Article begins with a technical description of geothermal energy, its origins, and how the resource is harvested, used, and managed. Part III reviews the treatment of geothermal energy under existing federal and state laws. Part IV explores various ownership theories and regimes for natural resources and considers the implications that such approaches could have on the development of geothermal resources as a viable source of energy. Part V offers concluding remarks.

28. *See* Pam Boschee, *Who Holds the Rights to Geothermal Heat Sources?* J. PETROLEUM TECH. (Aug. 1, 2023), https://jpt.spe.org/who-holds-the-rights-to-geothermal-heat-sources [https://perma.cc/8H2N-6SAM]; *see, e.g.*, *The Geysers Geothermal Field*, U.S. GEOLOGICAL SURV. (Sept. 20, 2023), https://www.usgs.gov/volcanoes/clear-lake-volcanic-field/science/geysers-geothermal-field [https://perma.cc/82WU-QVKM].

29. *See generally* Boschee, *supra* note 28.

II. UNDERSTANDING GEOTHERMAL ENERGY RESOURCES

A. Defining Geothermal Energy

Geothermal energy refers to heat generated and stored within the Earth's interior.[30] That energy is a non-corporeal, non-tangible resource that cannot be broken down into smaller components.[31] In fact, energy itself has virtually no mass or weight since it is not composed of matter.[32] Rather, energy is a property or characteristic of a system or object that enables it to perform work or produce a change, and it can exist in various forms including kinetic energy,[33] potential energy,[34] electrical energy,[35] radiant energy,[36] and nuclear energy.[37] Most relevant for the discussion of geothermal energy, however, is that energy can also exist in the form of thermal energy—energy contained within an object or system that is responsible for its temperature.[38] In other words, heat is a form of energy; it is the physical manifestation of thermal energy.[39] Thus, in crude terms, the exploitation of geothermal energy means mining the Earth's heat.

30. *Geothermal Explained*, U.S. ENERGY INFO. ADMIN. (Dec. 27, 2022), https://www.eia.gov/energyexplained/geothermal/ [https://perma.cc/97XY-AD65] (referring to geothermal energy as "heat within the earth"); Samuel S. Salazar, Yecid Muñoz & Adalberto Ospino, *Analysis of Geothermal Energy as an Alternative Source for Electricity in Colombia*, 5 GEOTHERMAL ENERGY, Nov. 2017, at 1, https://geothermal-energy-journal.springeropen.com/articles/10.1186/s40517-017-0084-x [https://perma.cc/PAW6-YQK7] (asserting that "geothermal energy is the heat that is stored inside the earth").

31. *See* Éfren Paulo Porfírio & Ana Clara Ribeiro, *Energy as an Intangible Asset: A Legal Analysis in Light of Res Corporales and Res Incorporales*, 15 BEIJING L. REV. 1394, 1395 (2024).

32. According to Albert Einstein's theory of special relativity ($E=mc^2$), energy can convert into mass and *vice versa*. A. Einstein, *Does the Inertia of a Body Depend Upon Its Energy Content*, *in* THE PRINCIPLE OF RELATIVITY 69–71 (W. Perrett and G.B. Jeffery, Methuen & Co., 1923), https://www.fourmilab.ch/etexts/einstein/E_mc2/e_mc2.pdf [https://perma.cc/FQ7B-9GJG] (translating Einstein's paper, which was originally published in German, which asserts that "[t]he mass of a body is a measure of its energy-content; if the energy changes by L, the mass changes in the same sense"). This means that energy does have mass. However, although heating an object does increase its mass due to the added energy, the effect is so minuscule that it is negligible in practical terms. Stephen Hawking, A BRIEF HISTORY OF TIME 21 (1998) (noting that "[t]his effect is really only significant for objects moving at speeds close to the speed of light").

33. Kinetic energy is energy of an object that is due to that object's motion. *Kinetic Energy*, ENCYC. BRITANNICA, https://www.britannica.com/science/kinetic-energy (last visited Feb. 13, 2025) [https://perma.cc/DT7F-2V8A]. For example, a moving car and a swinging baseball bat possess kinetic energy.

34. Potential energy is energy stored within an object or system based on its position or configuration. Thus, a heavy object has more potential energy when raised above the ground than when sitting on the ground; a spring has more potential energy when it is compressed or expanded than when it is in its stable state. Examples of potential energy include gravitational potential energy, elastic potential energy, and chemical potential energy. *Potential Energy*, ENCYC. BRITANNICA, https://www.britannica.com/science/potential-energy (last visited Jan. 16, 2025) [https://perma.cc/T8CS-M4EA].

35. Electrical energy is the energy associated with the movement of electric charges, which powers electrical devices and systems. *Electrical Energy Examples*, SCI. NOTES (May 2, 2021), https://sciencenotes.org/electrical-energy-examples/ [https://perma.cc/VA3A-H46X].

36. Radiant energy is energy carried or transferred by electromagnetic waves, such as visible light, radio waves, X-rays, and other forms of electromagnetic radiation. *Radiant Energy*, ENCYC. BRITANNICA, https://www.britannica.com/science/radiant-energy (last visited Mar. 2, 2025) [https://perma.cc/VA3A-H46X].

37. Nuclear energy is the energy released during nuclear reactions, such as those occurring in nuclear power plants or in the core of the Sun. *Nuclear Energy*, ENCYC. BRITANNICA, https://www.britannica.com/science/nuclear-energy (Feb. 27, 2025) [https://perma.cc/CF3S-XHU8].

38. *Thermal Energy*, ENCYC. BRITANNICA, https://www.britannica.com/science/thermal-energy (last visited Mar. 2, 2025) [https://perma.cc/MDG8-TVNC].

39. *Id.*

B. Origin of Geothermal Energy

The Earth abounds in geothermal energy.[40] Within the bowels of our planet, various natural processes have been churning since the creation of the planet, producing incredible amounts of energy.[41] Part of that energy is residual primordial heat that originated when the planet was formed over 4.5 billion years ago (from the collision, accretion, and compression of space rocks) and continues to contribute to the Earth's internal temperature.[42] A substantial portion of that heat, however, originates from the decay of radioactive isotopes, such as uranium, thorium, rubidium, and potassium, in the Earth's crust and mantle.[43] As these isotopes decay, they release radiogenic heat energy.[44] Additional energy, albeit at comparatively much lower levels, is also produced as a result of gravitational pressure and friction.[45]

40. *See Geothermal Explained: Use of Geothermal Energy*, *supra* note 11.

41. *See Core*, NAT'L GEOGRAPHIC, https://education.nationalgeographic.org/resource/core/ (June 11, 2024) [https://perma.cc/4V6N-UFCP].

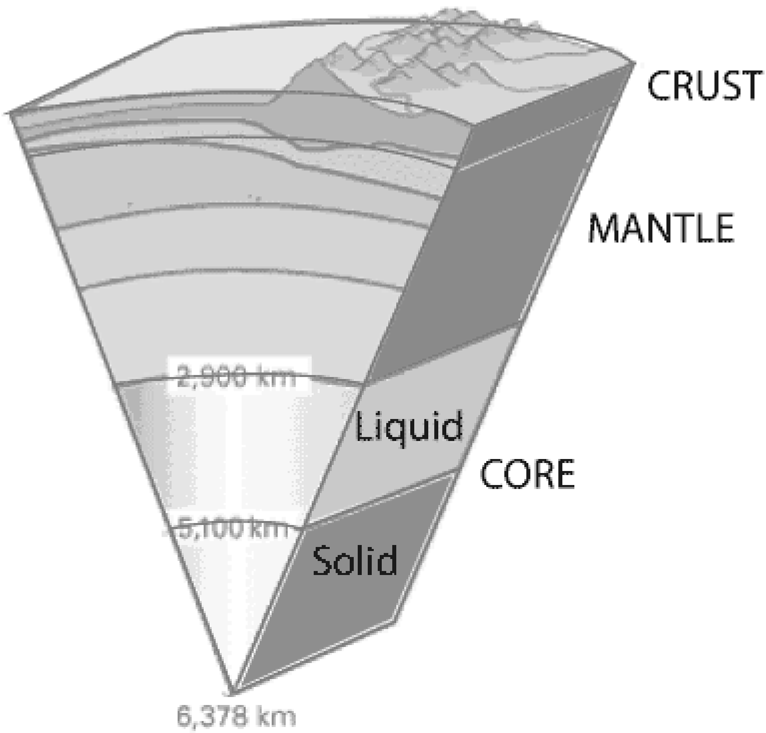
42. DAVID R. BODEN, GEOLOGIC FUNDAMENTALS OF GEOTHERMAL ENERGY 58–59 (Abbas Ghassemi ed., 2016) (identifying "residual heat left over from the formation of the planet (primordial heat) about 4.6 billion years ago" as one of the chief sources of the Earth's internal heat).

43. *Id.* at 59.

44. O. Kappelmeyer & R. Haenel, *Geothermics with Special Reference to Application*, *in* GEOEXPLORATION MONOGRAPHS, Ser. 1 – No. 4 , at 27 (Rosenbach & C. Morelli eds., 1974) (noting that "[t]he only heat sources which make a significant contribution to the heat content of the earth during a time comparable with the age of the earth and which are known with certainty are a few long-lived radioactive isotopes, namely ^{238}U, ^{235}U, ^{232}Th, and ^{40}K"); BODEN, *supra* note 42, at 59 (stating that "60% of the heat in continental crust is due to radioactive decay of" uranium, thorium, rubidium, and potassium).

45. BODEN, *supra* note 42, at 59.

FIGURE 1. CROSS SECTION SHOWING THE CRUST, MANTLE, AND CORE OF THE EARTH[46]



Within the Earth's core, heat is transferred primarily through conduction, which involves the direct transfer of heat through physical contact between particles in a solid.[47] In the mantle and crust, heat is transferred by both conduction and convection, the latter involving heat transfer that results from the fluidic movement of material caused by density differences within these materials.[48] Thus, as fluid within the mantle and crust circulates, with hotter material rising and cooler material sinking, heat is transferred outward from the mantle into the crust.[49] This process contributes to the geothermal (temperature) gradient—higher temperatures at the core, and lower at the outer crust—and also makes geothermal energy available at or near the Earth's surface.[50] Collectively, these

46. Earthquake Science Center, *Crust, Mantle, and Core of the Earth*, U.S. GEOLOGICAL SURV., https://www.usgs.gov/media/images/crust-mantle-and-core-earth (last visited Mar. 2, 2025) [https://perma.cc/JC6D-72NF].

47. BODEN, *supra* note 42, at 61.

48. *Id.* at 63.

49. *Id.*

50. *Id.* at 60–61.

energy formation and transfer mechanisms continuously generate and maintain the consistency of Earth's internal temperature.[51]

Temperatures inside the Earth are difficult to measure directly and usually are based on estimates and models.[52] The Earth's core, which extends from the center of the Earth to a depth of about 2900 km (approximately 1,800 miles), has an estimated temperature in the inner core of around 6,000° C (10,832° F), which is comparable to the temperature of the Sun's surface.[53] It is largely composed of both solid and molten iron and nickel, though the core is largely solid due to the intense pressure containing it.[54] Surrounding the inner core is a mostly molten outer core, also made up primarily of iron and nickel, where temperatures vary between 4,500 and 5,500° C (8,132 and 9,932° F) (see Figure 1).[55]

51. *Id.* at 68–69.

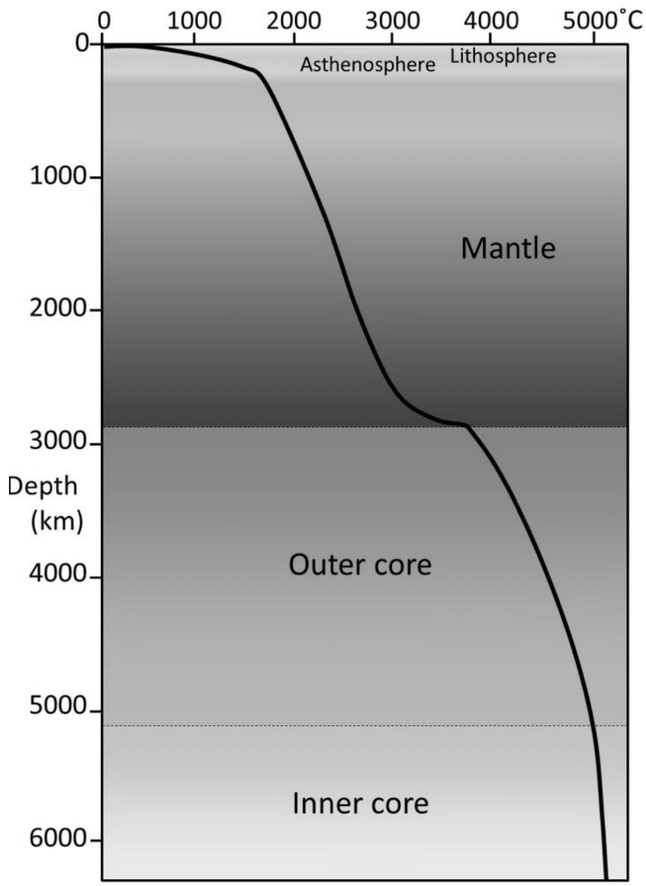
52. *Core*, *supra* note 41; *see also* David Blackwell et al., *Temperature Maps*, SMU GEOTHERMAL LAB, https://www.smu.edu/dedman/academics/departments/earth-sciences/research/geothermallab/datamaps/temperaturemaps (last visited Mar. 2, 2025) [https://perma.cc/BN35-JSH9].

53. BODEN, *supra* note 42, at 54; GEOVISION, *supra* note 7, at 10.

54. BODEN, *supra* note 42, at 57.

55. *Id.* (describing the composition of the outer core); *Core*, *supra* note 41 (describing the temperature of the outer core).

FIGURE 2. DEPICTING THE GENERALIZED RATE OF TEMPERATURE INCREASE WITH DEPTH WITHIN THE EARTH.[56]



Moving outward to the Earth's mantle, temperatures range between 1,000 and 3,700° C (1,832 and 6,692° F) in the lower mantle, and between 500 to 900° C (932 to 1652° F) in the upper mantle.[57] The mantle, which is composed of dense iron- and magnesium-rich rock, makes up the largest part of Earth's interior by volume and extends from 2900 km (approximately 1,800 miles) to less than 100 km (approximately 62 miles) below the surface.[58]

The outmost shell of the planet, the crust, varies from a few kilometers in thickness under parts of the ocean floor to 80 km (nearly 50 miles) beneath the terrestrial surface.[59] At the outer edge of the crust—on the Earth's surface—

56. STEVEN EARLE, PHYSICAL GEOLOGY 305, fig. 9.2.1 (2d ed. 2019).
57. *Mantle*, NAT'L GEOGRAPHIC (Apr. 30, 2024), https://education.nationalgeographic.org/resource/mantle/ [https://perma.cc/AJW9-LZ4Y] (describing the temperature of the mantle).
58. BODEN, *supra* note 42, at 54.
59. *Id.*

ground temperature is the same as local air temperature, which globally averages 14° C (57° F).[60] At the lower edge of the crust, temperatures can reach 400° C (752° F),[61] though ground temperature at around 9–10 meters (approximately 30 feet) below the Earth's surface throughout much of the United States is relatively constant year-round—between about 10 and 15° C (50 and 59° F).[62] Generally, the geothermal gradient between the hottest portion of the Earth, its core, and the cooler outer shell indicates an increase of approximately 25° C for each kilometer of depth, or 1° F per 70 feet.[63]

C. The Promise of Geothermal Energy

Geothermal energy resources hold tremendous promise and opportunities for expanding energy production, increasing energy access, and decarbonizing economies around the world.[64] The sheer volume of energy available in the subsurface, even in the Earth's relatively thin crust, is staggering. The amount of heat energy continuously released from the Earth at its surface (from the crust, on the outer edge of the planet) is estimated at 44 to 47 terawatts ("TW") of energy.[65] In comparison, in 2022, the total installed power capacity for all electricity generating sources worldwide was 11.825 TW,[66] and 1.16 TW for the United States.[67]

A 2019 study by the U.S. Department of Energy suggested that were the U.S. to invest in geothermal energy using existing technology,[68] electricity

60. Matt Williams, *What Is the Temperature of the Earth's Crust?*, PHYS.ORG (Sept. 19, 2016), https://phys.org/news/2016-09-temperature-earth-crust.html [https://perma.cc/EA2H-M3H9].

61. *Geothermal Explained*, *supra* note 30.

62. *Geothermal Heat Pumps*, U.S. DEP'T OF ENERGY GEOTHERMAL TECHS. OFF., https://www.energy.gov/eere/geothermal/geothermal-heat-pumps (last visited Mar. 2, 2025) [https://perma.cc/ST4V-Z33D]; *see* Hussein M. Maghrabie, Mahrousa M. Abdeltwab & Mohamed Hamam M. Tawfik, *Ground-source Heat Pumps (GSHPs): Materials, Models, Applications, and Sustainability*, 299 ENERGY & BLDGS. 1, 3 (2023) (noting that "temperature differs remarkably in the first few meters [below the surface]" and "reaches a stabilization value at the depth of 10–15 m"); *see also* ADAM ZOET, JIM BOWYER, STEVE BRATKOVICH, MATT FRANK, KATHRYN FERNHOLZ, GEOTHERMAL 101: THE BASICS AND APPLICATIONS OF GEOTHERMAL ENERGY 2 (Dovetail Partners Inc., 2011), https://dovetailinc.org/report_pdfs/2011/dovetailgeothermal0911.pdf [https://perma.cc/H5EA-SBKX].

63. Folarin Kolawole & Jonathan C. Evenick, *Global Distribution of Geothermal Gradients in Sedimentary Basins*, 14 GEOSCIENCE FRONTIERS 1, 12 (Nov. 2023) (noting that "[o]ur observations generally support the common assumption of 25 degrees C/km as 'normal' (or 'average') geothermal gradient in continental domains"); *Core*, *supra* note 41.

64. GEOVISION, *supra* note 7, at x.

65. Gando et al., *supra* note 7 (estimating total heat flux from the Earth to space is 44.2 terawatts); Jun Korenaga, *Earth's Heat Budget: Clairvoyant Geoneutrinos*, 9 NATURE GEOSCIENCE 581, 581 (2011) (suggesting that the total heat escaping the Earth is approximately 46 terawatts); J.H. Davies & D.R. Davies, *Earth's Surface Heat Flux*, 1 SOLID EARTH 5, 5, 18–23 (2010) (estimating Earth's total heat flow using updated datasets); BODEN, *supra* note 42, at 59 (concludes that "[t]he takeaway, clearly, is that Earth's internal heat energy can provide a significant contribution toward supplying the energy needs of civilization").

66. *Installed Electricity Capacity Worldwide in 2022, by Source*, STATISTA (July 16, 2024), https://www.statista.com/statistics/267358/world-installed-power-capacity/ [https://perma.cc/A97J-NWHG].

67. *Electricity Explained: Electricity Generation, Capacity, and Sales in the United States*, U.S. ENERGY INFO. ADMIN. (July 16, 2024), https://www.eia.gov/energyexplained/electricity/electricity-in-the-us-generation-capacity-and-sales.php [https://perma.cc/ZA6Q-Y6SF].

68. Technological assumptions include wells drilled at depths of 3–7 km and rock temperatures exceeding 150° C (302° F). *See* GEOVISION, *supra* note 7, at 10.

production capacity could reach 5.16 TW,[69] nearly five times the country's 2022 installed capacity from all energy production sources.[70] Another study, from 2023, exploring Texas' geothermal resources potential indicated that, if the state pursued an aggressive geothermal strategy of drilling as many geothermal wells as it does oil and gas wells (approximately 15,000 each year),[71] it could supplant all of the state's oil- and gas-derived energy uses within four years.[72]

In addition, and possibly more important from a utility perspective, geothermal energy systems are fully dispatchable, meaning that they can be turned on and off as needed and can adjust power output on demand.[73] They also can provide baseload power (the minimum amount of electricity needed in the electrical grid at any given time), and can supply both power and heat to a wide range of applications.[74] Finally, and critically important for global decarbonization efforts, energy security, and energy justice, they can be developed in nearly every corner of the globe.[75]

D. Harvesting Geothermal Energy

1. Past Uses of Geothermal Energy

People and communities have used geothermal energy as an energy source for millennia.[76] Paleo-Indians on the North American continent used hot springs more than 10,000 years ago for cooking and warmth, as well as medicinal purposes.[77] The world's earliest known geothermal district heating system was established in Chaudes-Aigues in France in the early 14th Century;[78] that system, which still operates today, distributes hot water to various buildings in the village for area heating.[79] The first geothermal district heating system in the United

69. GEOVISION, *supra* note 7, at 19.

70. *International: Electricity*, U.S. ENERGY INFO. ADMIN., https://www.eia.gov/international/data/world/electricity/electricity-capacity (last visited Mar. 2, 205) [https://perma.cc/B9TU-7KMU]. In January 2023, the U.S. Department of Energy released a more modest projection for geothermal energy production capacity in the United States based on technological capacity, financial resources, and other factors. It suggested that by 2050, the U.S. could reach 90 gigawatts (GW) of geothermal energy produced through enhanced geothermal systems, amounting to nearly 4% of national generation capacity and enough to power 65 million U.S. homes. AUGUSTINE ET AL., *supra* note 17, at 14–16.

71. Tim Lines, *The Geothermal Business Model & the Oil and Gas Industry Challenges and Opportunities*, *in* THE FUTURE OF GEOTHERMAL IN TEXAS: THE COMING CENTURY OF GROWTH & PROSPERITY IN THE LONE STAR STATE 218 (Jamie C. Beard & Bryant A. Jones eds., 2023) (stating that "geothermal energy exists in the subsurface beneath every location on Earth").

72. *Id.* at 218, fig.7.16.

73. Tester et. al., *supra* note 9, at 6211.

74. *Id.*

75. *Cf. supra* notes 9 and 64–65 and accompanying text.

76. *See* FRANK R. SPELLMAN, THE SCIENCE OF RENEWABLE ENERGY 403 (2d ed. 2016).

77. *Id.*; JOHN W. LUND, HISTORY, PRESENT UTILIZATION AND FUTURE PROSPECTS OF GEOTHERMAL ENERGY WORLDWIDE–2006 1–5 (ARGeo Conference 2006), https://www.geothermal-energy.org/pdf/IGAstandard/ARGeo/2006/ArGeo-Lund2.pdf [https://perma.cc/U5D8-D9AK].

78. LUND, *supra* note 77. District heating refers to a system that collects underground thermal energy in a centralized location and then distributes it as heat, in the form of hot water or steam, "to residences, businesses and industry" within a defined locale. *District Heating*, INT'L ENERGY AGENCY (July 11, 2023), https://www.iea.org/energy-system/buildings/district-heating [https://perma.cc/794R-99NK].

79. Sven Werner, *International Review of District Heating and Cooling*, 137 ENERGY 617, 619.

States was installed in 1892 in Boise, Idaho, where water piped from hot springs was used to heat several town buildings.[80] Within a few years, more than 200 homes and 40 downtown Boise businesses were supplied by the system;[81] today, the system serves over 5,000,000 square feet of residential homes, commercial space, and governmental offices.[82]

The first use of geothermal energy to produce electricity occurred in Italy in 1904 where a conventional geothermal steam-driven piston engine lit five light bulbs; by the early 1940s, the installed capacity of that system grew to 132 megawatts ("MWs").[83] In the United States, the first conventional geothermal electricity-generating plant went into operation in 1922 at The Geysers in California, though, it was discontinued soon after due to costs.[84] In 1960, The Geysers became the site of the country's first large-scale conventional geothermal electricity-generating plant,[85] which currently produces approximately 800 MW of electricity per hour.[86]

All of these examples of conventional geothermal energy production are a proverbial drop in the bucket. All have occurred in tectonically active regions, or where the Earth's crust is fractured and the heated rocks interact with native groundwater to produce hot springs and geysers used to heat homes and power electricity-generating turbines.[87] Geographically, these regions amount to a tiny proportion of the Earth's terrestrial area and contain only a fraction of a percentage of the energy potential contained within the Earth.[88] In the United States, these sources are responsible for a scant 0.4% of the country's electricity production[89] and supply barely 1% of buildings in the United States with cost-effective and clean geothermal heating and cooling.[90] The real opportunity lies in mining the heat everywhere else.

2. *Harvesting the Heat*

The process for harvesting Earth's internal heat and converting it into usable forms of energy encompasses various technologies and processes. Generally, it requires accessing subsurface thermal energy in one of three ways.[91] The first two require accessing underground reservoirs of steam or hot water, or the heated

80. Kevin Rafferty, *A Century of Service: The Boise Warm Springs Water District System*, 14 GEO-HEAT CTR. BULL., Aug. 1992, at 1.

81. *Id.* at 2.

82. *Id.* at 3; SPELLMAN, *supra* note 76, at 404.

83. John W. Lund, *100 Years of Geothermal Power Production*, 25(3) GEO-HEAT CTR. BULL. 11, 11–12 (2004).

84. SPELLMAN, *supra* note 76, at 404.

85. *Id*. at 405.

86. *Opportunities and Challenges for Advanced Geothermal Energy in the United States: Hearing Before the S. Comm. on Energy and Natural Resources*, 116th Cong. (2019) (statement of Tim Spisak, State Director for New Mexico, Oklahoma, Texas and Kansas, Bureau of Land Management, U.S. Department of the Interior).

87. Barber, *supra* note 16.

88. *See id.*

89. *Frequently Asked Questions (FAQs)*, *supra* note 1.

90. *See* LIU ET AL., *supra* note 14, at 2.

91. *See infra* notes 95–142 and accompanying text.

subsurface formations, and then using the heat energy: 1) to generate electricity, or 2) to provide direct heat for structures, industrial processes, and other purposes.[92] In both scenarios, the heat is extracted from the subsurface for use on the surface, although for the second one, the use of heat exchangers also may come into play.[93] The third equally important process utilizes the relatively lower and constant ground temperature close to the Earth's surface to heat and cool buildings through the use of heat exchangers.[94]

a. Harvesting the Heat to Generate Electricity

Conventional approaches for using geothermal energy resources to generate electricity take advantage of natural forces that circulate and make hot water, native to the formation, available at or near the surface.[95] This approach is only possible where these natural forces are active (*e.g.*, in tectonically and volcanically active regions of the world), the forces create a system of fractures in the rock that allow native water to flow through hot rock at depth as well as reach shallower depths that are economically accessible, and the economically accessible water temperatures are adequate for energy production.[96] Where native water is present in the heated subsurface formation, there also needs to be a relatively impermeable caprock overlying the formation that traps that water.[97] Drilling into the formation allows the water to escape under pressure through the well bore and toward the turbine.[98] Where native water is not present in sufficient quantity, or if the formation contains water but lacks sufficient permeability and connectivity for adequate and sustained heat extraction using that water, modern energy recovery technologies and methodologies—often categorized as

92. *See generally* Tester et al., *supra* note 9, at 6217.

93. A heat exchanger is a system or devise that transfers thermal energy (heat) between two or more fluids at different temperatures, or between a fluid and a source. *See generally* SADIK KAKAÇ, HOGTAN LIU & ANCHASA PRAMUANJAROENKJI, HEAT EXCHANGERS: SELECTION, RATING, AND THERMAL DESIGN (4th ed. 2020). The heat is transferred from the hotter substance to the cooler substance as a result of the second law of thermodynamics, which posits that heat always moves from hotter to cooler objects. Richard Webb, *Second Law of Thermodynamics*, NEWSCIENTIST, https://www.newscientist.com/definition/second-law-thermodynamics/ (last visited Mar. 2, 2025) [https://perma.cc/CN9W-5GBG]. For a video diagram explaining how a heat exchanger works, see Advanced Thermal Solutions, Inc., *What Is a Heat Exchanger?*, YOUTUBE (June 9, 2017), https://www.youtube.com/watch?v=WYJ9BsCrifQ [https://perma.cc/ZS2V-EH5P]. Such transfers are used for heating and cooling purposes. Heat exchangers are widely used in power generation, space heating, refrigeration, air conditioning, and various manufacturing and industrial applications. *See generally* KAKAÇ ET AL., *supra* note 93.

94. *See infra* notes 129–42 and accompanying text.

95. *See* Livescu et al., *supra* note 8, at 27 (discussing conventional hydrothermal systems, which "comprise[] nearly all geothermal electrical power generation existing today").

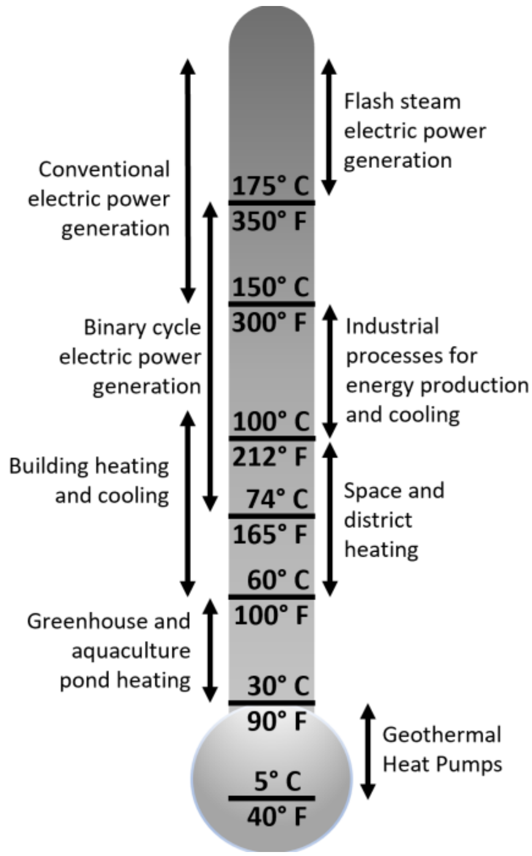
96. *Id.* at 27–28 (noting that the conventional approach is "largely confined to areas with active basaltic volcanism, or continental plate boundaries . . . [including] those along major tectonic plates, such as the western United States, Turkey, Iceland, Kenya, Philippines, and Indonesia. As such, a very limited part of the world has accessible CHS potential," and that exploration for conventional geothermal reservoirs "tend to rely on the presence of surface expressions indicative of a geothermal resource, such as geysers, steam vents, or other thermal features").

97. *See* GEOVISION, *supra* note 7, at 15.

98. *Id.* at 23; Eli Dourado, *Harnessing the Heat Beneath Our Feet*, 40 PERCREPORTS 26, 29 (2021).

enhanced geothermal systems that include hydraulic fracturing[99]—can be used to stimulate and facilitate the abstraction of the Earth's heat energy.[100]

FIGURE 3. COMMON USES OF GEOTHERMAL ENERGY RESOURCES AT DIFFERENT TEMPERATURES.[101]



To generate sustained, commercial electricity production, underground temperatures typically need to be at least 150° C (302° F) for the vapor to propel turbines.[102] Binary cycle power plants, however, can operate with temperatures as low as 74° C (165° F) by taking the hot water through a heat exchanger to boil a "working fluid" with a lower boiling point (typically an organic compound like isobutane) that can then drive the turbines.[103]

99. *See infra* note 105 and accompanying text.
100. *See* Coastal Oil & Gas Corp. v. Garza Energy Tr., 268 S.W.3d 1, 7 (2008).
101. Adapted, in part, from Lund & Bloomquist, *supra* note 18, at 1–2 and figure 1.
102. *See* GEOVISION, *supra* note 7.
103. *See* TOM WILLIAMS, NEIL SNYDER & WILL GOSNOLD, NAT'L RENEWABLE ENERGY LAB'Y, LOW-TEMPERATURE PROJECTS OF THE DEPARTMENT OF ENERGY'S GEOTHERMAL TECHNOLOGIES PROGRAM: EVALUATION AND LESSONS LEARNED 2 (2016), https://www.nrel.gov/docs/fy17osti/67403.pdf [https://perma.cc/R9FT-BSFP].

When using enhanced geothermal systems, the heat can be captured through either an open or closed loop system.[104] In an open loop system, mechanisms to enhance permeability, including hydraulic fracturing (more commonly known as "fracking") technology,[105] can be used to maximize the flow of fluids through the formation and, thereby, capture the heat.[106] Thereafter, the heated fluids can be channeled through another well and directed into turbines or heat exchangers to generate electricity.[107] Such systems, however, often require injection of water (or other working fluid) from an external source (such as a nearby lake or aquifer) in order to maintain the formation's pressure and ensure the continuous production of vapor.[108] In a closed loop system, boreholes drilled into the hot, dry rock formations are lined with pipes and water or other fluid is circulated through the tube system.[109] The heat in the deeper formation increases the temperature of the water or working fluid, which is channeled back to the surface where it is used to drive turbines.[110] Once the fluid releases its energy, the vapor condenses and is reinjected into the reservoir to be heated again.[111] The system, which effectively functions as a large underground radiator operating in reverse, eliminates the need for a substantial external source of water since the fluid used in the system is continuously reinjected into the formation to maintain pressure.[112]

104. *See* GEOVISION, *supra* note 7, at 26.

105. In the context of oil and gas recovery, the Texas Supreme Court in *Coastal Oil v. Garza Energy Trust* concisely explained the hydraulic fracturing process as:

> [P]umping fluid down a well at high pressure so that it is forced out into the formation. The pressure creates cracks in the rock that propagate along the azimuth of natural fault lines in an elongated elliptical pattern in opposite directions from the well. Behind the fluid comes a slurry containing small granules called proppants—sand, ceramic beads, or bauxite are used—that lodge themselves in the cracks, propping them open against the enormous subsurface pressure that would force them shut as soon as the fluid was gone. The fluid is then drained, leaving the cracks open for gas or oil to flow to the wellbore. Fracing (sic) in effect increases the well's exposure to the formation, allowing greater production.

Coastal Oil, 268 S.W.3d, at 6–7.

106. *See* Livescu at el., *supra* note 8, at 29 (describing a "traditional" enhanced geothermal system configuration, which effectively is an open loop system).

107. *See id.*; ZOET ET AL., *supra* note 62, at 3–4.

108. Radovan Cernak, *MUSE—Open-Loop Systems Requirements & Advantages*, GEOERA (Oct. 5, 2020), https://geoera.eu/blog/muse-open-loop-systems-requirements-advantages/ [https://perma.cc/5ZYP-L4RD] (describing how open loop geothermal systems operate); *Geothermal Heat Pumps*, U.S. DEP'T OF ENERGY, OFF. OF ENERGY SAVER, https://www.energy.gov/energysaver/geothermal-heat-pumps (last visited Mar. 2, 2025) [https://perma.cc/672D-QKBX].

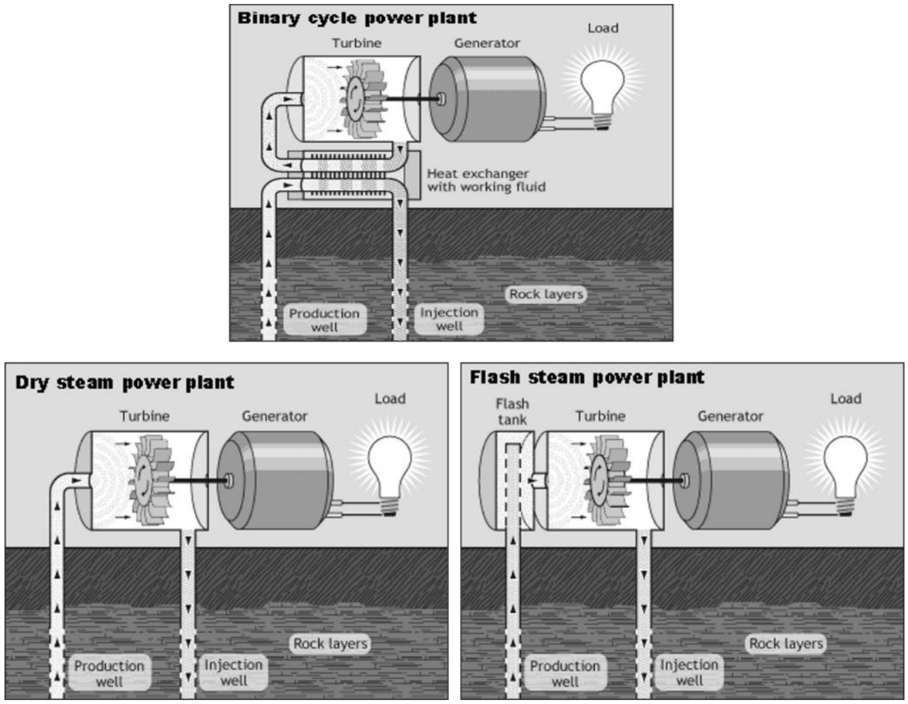
109. *See* Livescu et al., *supra* note 8, at 32.

110. Barber, *supra* note 16.

111. *See* Livescu et al., *supra* note 8, at 32–33 (describing closed loop geothermal systems); KOENRAAD BECKERS ET AL., NAT'L RENEWABLE ENERGY LAB'Y, TABULATED DATABASE OF CLOSED-LOOP GEOTHERMAL SYSTEMS PERFORMANCE FOR CLOUD-BASED TECHNICAL AND ECONOMIC MODELING OF HEAT PRODUCTION AND ELECTRICITY GENERATION 1 (2023), https://www.nrel.gov/docs/fy23osti/84979.pdf [https://perma.cc/WPG7-P3MZ] (describing closed loop systems).

112. *See* GEOVISION, *supra* note 7, at 23; Plumer, *supra* note 15.

FIGURE 4. TYPES OF GEOTHERMAL POWER PLANTS[113]



While the depth at which the necessary temperatures can be found varies with the local geology, in principle, "[i]f you can drill deep enough, you will find heat, guaranteed."[114] According to the U.S. Department of Energy, at seven kilometers (4.35 miles) below the surface, temperatures exceed 100° C (212° F) underneath nearly the entire U.S. mainland.[115] Importantly, geothermal temperatures at these depths are accessible with existing drilling technology, which has been used widely in the oil and gas sector.[116] The long term goal, however, is to drill down to around 9.5 kilometers (nearly six miles) where temperatures

113. *Geothermal Explained: Geothermal Power Plants*, U.S. ENERGY INFO. ADMIN., https://www.eia.gov/energyexplained/geothermal/geothermal-power-plants.php (last updated Dec. 21, 2022) [https://perma.cc/9EMQ-MRHW].

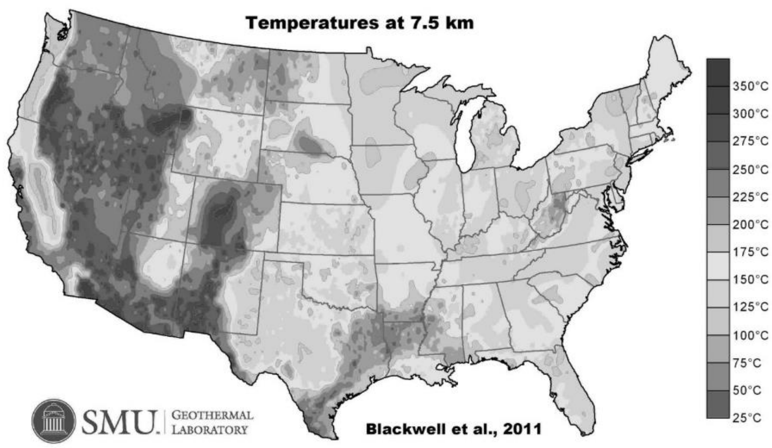
114. Dourado, *supra* note 98, at 30.

115. *See* GEOVISION, *supra* note 7; *see also* Tester et al., *supra* note 9, at 6218 (referencing a study suggesting that temperatures of 60–120° C (140° F–248° F) can be found throughout the U.S. at depths of less than 3km).

116. Jamie C. Beard, *Introduction*, *in* THE FUTURE OF GEOTHERMAL IN TEXAS: CONTEMPORARY PROSPECTS AND PERSPECTIVES 19, 19 (Jamie C. Beard & Bryant Jones eds., 2023) (discussing the oil- and gas-related technologies, such as horizontal drilling, multi-stage fracturing, and managed pressure drilling, that could be applicable to geothermal energy extraction); Jamie C. Beard, *Roadmap for Action*, *in* THE FUTURE OF GEOTHERMAL IN TEXAS: CONTEMPORARY PROSPECTS AND PERSPECTIVES 351 (Jamie C. Beard & Bryant Jones eds., 2023), (discussing the "nexus between the oil and gas industry, and the potential for fast, global deployment and scale of geothermal energy").

surpass 374° C (705° F) and pressures exceed 217 times atmospheric pressure.[117] This is the point at which water becomes supercritical[118] and can store five to ten times as much energy as lower temperature steam.[119]

FIGURE 5. TEMPERATURES AT 7.5 KM BELOW THE EARTH'S SURFACE IN THE UNITED STATES.[120]



b. Harvesting the Heat for Direct Use

The second method for exploiting subsurface heat is through direct use. This approach typically uses low to moderate temperature resources of 20 to 150° C (68 to 302° F) to heat buildings, facilitate industrial processes, maintain greenhouses, and melt snow on roads and sidewalks.[121] In most cases, the heat source contains native water, which is channeled to the surface and then distributed for

117. *See* Bryn Huxley-Reicher, *Drilling for Heat: The Future of Geothermal*, FRONTIER GRP. (May 4, 2021), https://frontiergroup.org/resources/drilling-heat-future-geothermal/ [https://perma.cc/D68E-EMN4]; Thomas Reinsch et al., *Utilizing Supercritical Geothermal Systems: A Review of Past Ventures and Ongoing Research Activities*, 5 GEOTHERMAL ENERGY, no. 16, 2017, at 16.

118. Water becomes supercritical when it is heated to a temperature and pressure where it is no longer possible to differentiate between the liquid and vapor phase of the substance. *Supercritical Fluid*, U. CALGARY: ENERGY EDUC., https://energyeducation.ca/encyclopedia/Supercritical_fluid (last visited Mar. 2, 2025) [https://perma.cc/R3DB-ZE4L].

119. Plumer, *supra* note 15.

120. Blackwell et al., *supra* note 52 (7.5 km temperature-at-depth map).

121. ZOET ET AL., *supra* note 62, at 4; S. Kapusta, S. Livescu, B. Dindoruk, R. Schulz & M. Webber, *Direct Use Applications: Decarbonization of Industrial Processes, and Heating and Cooling Scenarios*, *in* THE FUTURE OF GEOTHERMAL IN TEXAS: THE COMING CENTURY OF GROWTH & PROSPERITY IN THE LONE STAR STATE 48–49 (Jamie C. Beard & Bryant A. Jones eds., 2023) (describing direct use geothermal systems). Depending on the depth of the wells and the subsurface temperatures, direct heating can be used to provide heat to individual buildings as well as to entire communities. The latter is termed "district heating" and refers to the provision of heat to a group of buildings and facilities that comprise the district. *What Is Geothermal District Heating?*, EUR. GEOTHERMAL ENERGY COUNCIL, http://geodh.eu/about-geothermal-district-heating/ (last visited Mar. 2, 2025) [https://perma.cc/CSV2-XNE8].

direct use through pipes that crisscross the community.[122] In some cases, the hot water is processed through heat exchangers to maximize efficiency.[123] It is noteworthy that this process does not generate electricity.[124] Rather, it is used to supplement and vastly reduce dependence on heating from other sources (*e.g.*, electric, gas, coal, oil, etc.).[125] Regardless, as compared to conventional fossil fuels, cost savings from direct geothermal heating are estimated to be as high as 80%.[126] Again, given the ubiquity of high temperatures everywhere beneath the Earth's surface,[127] exploitation becomes a matter of drilling depth and economic efficiency in each particular region.[128]

c. Harvesting the Heat Through Heat Exchangers

The third chief approach for harnessing subsurface temperatures, also a form of direct use, utilizes heat exchangers.[129] As noted earlier, ground temperatures at 9–10 meters (approximately 30 feet) below the surface of much of the United States is relatively stable—between about 50°F and 59°F (10°C and 15°C).[130] Heat exchangers used in geothermal heat pumps[131] can utilize these relatively constant temperatures both to heat and cool buildings by circulating a fluid through pipes buried underground.[132] The fluid, which typically is a refrigerant with a low boiling point (though, water can also be used in some climates)[133] allows heat to be transferred to and from the ground to maintain a comfortable indoor climate.[134] During the summer, the liquid transfers heat from buildings into the cooler ground, while in winter, it does the opposite, supplying warmed air to the structure.[135] As a result, systems using heat exchangers are

122. OFF. OF ENERGY EFFICIENCY AND RENEWABLE ENERGY, U.S. DEP'T OF ENERGY, GEOTHERMAL TECHNOLOGIES PROGRAM: DIRECT USE 3 (2004), https://www.nrel.gov/docs/fy04osti/36316.pdf [https://perma.cc/2262-8VDA] [hereinafter DIRECT USE]; *What Is Geothermal District Heating*, *supra* note 121.

123. DIRECT USE, *supra* note 122, at 4–5.

124. *See* ZOET ET AL., *supra* note 62, at 4.

125. *See id.*

126. DIRECT USE, *supra* note 122, at 3.

127. *See supra* note 8 and accompanying text.

128. *See* Tester et al., *supra* note 9, at 6232.

129. *See supra* note 93 and accompanying text (explaining how a heat exchanger functions).

130. *See supra* note 62 and accompanying text.

131. A geothermal heat pump, also called a ground source heat pump, is a heating and cooling system that takes advantage of the naturally occurring difference in temperature above and below the ground surface to heat buildings, greenhouses, and frozen sidewalks, as well to cool buildings and industrial operations. Geothermal heat pumps circulate water or other fluids through a series of underground pipes and use heat exchangers to transfer the heat in the preferred direction—to the surface during winter and into the ground during summer. *Renewable Heating and Cooling: Geothermal Heating and Cooling Technologies*, U.S. ENV'T PROT. AGENCY, https://19january2017snapshot.epa.gov/rhc/geothermal-heating-and-cooling-technologies_.html (last visited Mar. 2, 2025) [https://perma.cc/8NVE-PP9Z]. *See also Geothermal Heat Pumps*, *supra* note 62. For a video diagram explaining how a geothermal heat pump functions, see New York State Energy Research and Development Authority, *How It Works: Ground Source (Geothermal) Heat Pumps (GSHP)*, YOUTUBE (Dec. 9, 2022), https://www.youtube.com/watch?v=uhXUV2Xm5fQ [https://perma.cc/M57N-G7U8].

132. GEOVISION, *supra* note 7, at 21.

133. *See Geothermal Energy*, ENV'T PROT. AGENCY, https://archive.epa.gov/climatechange/kids/solutions/technologies/geothermal.html (last updated May 9, 2017) [https://perma.cc/FG4Y-MT9E].

134. GEOVISION, *supra* note 7, at 26.

135. *How Geothermal Energy Works*, *supra* note 6. According to the second law of thermodynamics, heat always moves from hotter objects to colder objects. Webb, *supra* note 93. Thus, during the summer, the system

differentiated from geothermal energy production in that the former uses the ground both as a source of renewable heat during cold weather and a heat sink during summertime;[136] the latter only extracts the heat from the subsurface.[137] District heating systems, when coupled with heat exchangers, can also be used for heating and cooling purposes.[138]

Since these systems produce warmer and cooler heat flows, but do not generate electricity, they are used to supplement or replace traditional sources of heating and cooling, most often electricity-based systems.[139] However, because they operate on such low amounts of electrical energy, they are exceptionally economical and can achieve efficiencies of 300–600 % during cold winters and hot summers.[140] In addition to heating and cooling buildings, systems using heat exchangers can also be used to dry grain, maintain temperatures in greenhouses, melt ice on streets and airport runways,[141] and even heat and cool entire college campuses.[142]

TABLE 1. ENERGY EFFICIENCY OF VARIOUS SOURCES OF HOME HEATING AND COOLING[143]

Energy Source for Typical Homes	**Energy Efficiency (heat output as a percent of energy input)**
Oil or gas furnace	70% – 90%
Electric resistance heating (baseboard heaters, wall heaters, space heaters)	100%
Air source heat pumps	<300%
Geothermal heat pumps	300% – 600% (depending on climate)

E. The Availability of Geothermal Energy

One of the most notable characteristics of geothermal energy is its renewability. Renewability of a natural resource refers to the capacity of the resource to be replenished at some consistent rate, usually measured in relation to human

transfers the heat energy from inside a building through the heat exchanger and into the ground; in winter, the energy from the warmer ground is transferred through the heat exchanger into the building. *See* Kapusta et al., *supra* note 121, at 50–51 (describing how a geothermal heat pump functions).

136. ZOET ET AL., *supra* note 62, at 5.

137. *See* Tester et al., *supra* note 9, at 6225.

138. DIRECT USE, *supra* note 122, at 4–5.

139. *See id.*

140. U.S. DEP'T OF ENERGY, DOE/EE-0385, GUIDE TO GEOTHERMAL HEAT PUMPS, (2011), https://www.energy.gov/sites/prod/files/guide_to_geothermal_heat_pumps.pdf [https://perma.cc/7U34-NQ2N].

141. Roberts, *supra* note 8.

142. Carleton College in Minnesota, for example, installed a district heating system combined with heat exchangers that has cut the school's annual natural gas use by 70%. Similar systems are currently being installed at Cornell, Princeton, Smith, Oberlin, Dartmouth, William & Mary, and others. *See* Cara Buckley, *To Slash Carbon Emissions, Colleges Are Digging Really Deep*, N.Y. TIMES (Jan. 23, 2024), https://www.nytimes.com/2024/01/23/climate/geoexchange-climate-colleges-heat.html [https://perma.cc/R4KG-8PQX].

143. Roberts, *supra* note 8; ZOET ET AL., *supra* note 62, at 5.

lifespans.[144] Given that geothermal energy originates from residual primordial heat in combination with the decay of radioactive isotopes, it is constantly being produced and replenished.[145]

Renewability, however, does not equate with sustainability.[146] Sustainability pertains to how much of the resource is used over a period of time.[147] In other words, it is possible for a resource to be deemed renewable, but be used in an unsustainable manner.[148] Thus, depending on various factors, such as rate of extraction, rate of replenishment, and pressure declines, the exploitation of geothermal resources must be carefully managed to ensure that they are used sustainably.[149]

For example, commercial production of electricity at The Geysers geothermal field in California began in 1960 and peaked at 1,605 MW in 1987.[150] By the mid-2000s, production had dropped by nearly one-half as a result of pressure declines in the system caused by overexploitation and insufficient fluid recharge.[151] In another example of unsustainable use, the energy extracted at the Wairakei-Tauhara geothermal system in New Zealand, which has been used to produce electricity since the late 1950s,[152] is currently extracting nearly five times the amount of heat energy that is being replaced through natural recharge.[153] As a result, the resource is expected to reach economic exhaustion by the 2050s.[154] Scientists project that if the system is shut down in 2053, it would recover to its pre-production levels in approximately 300 years.[155] In contrast, the Matsukawa geothermal system in Japan has been operating sustainably,

144. *See* Phebe Asantewaa Owusu & Samuel Asumada-Sarkodie, *A Review of Renewable Energy Sources, Sustainability Issues and Climate Change Mitigation*, 3 COGENT ENGINEERING, no. 1167990, 2016, at 1, 4 (stating that "[r]enewable energy sources replenish themselves naturally without being depleted by the earth"); Shae v. Boston Edison Co., 431 Mass. 251, 255 (2000) (noting that renewable energy is energy generated from resources whose common characteristic is that they are nondepletable or are naturally replenishable but flow-limited) (internal citations omitted).

145. *See* GEOVISION, *supra* note 7.

146. McClean & Pedersen, *supra* note 21, at 348 (noting that "whilst geothermal heat is a renewable resource, it is not necessarily sustainable" and that "rates of extraction have the potential to impact on the productivity of a reservoir"); Ladislaus Rybach, *Geothermal Sustainability or Heat Mining?*, 4 INT'L J. TERRESTRIAL HEAT FLOW & APPLIED GEOTHERMICS 15, 16 (2021) (discussing renewability and sustainability in the context of geothermal energy resources).

147. *See* Rybach, *supra* note 146.

148. *See* Gudni Axelsson, *Sustainable Geothermal Utilization—Case Histories; Definitions; Research Issues and Modelling*, 39 GEOTHERMICS 283, 283–84 (2010).

149. *See id.* at 286 (noting that "[d]uring long-term use, some pressure or temperature interference effects may be observed between adjacent geothermal fields. These possible effects could be significant even over distances of tens of kilometres, and should be taken into consideration when planning or modelling regional development strategies").

150. Ben Barker, *The Geysers: Past and Future*, GEOTHERMAL RES. COUNCIL BULL., Sept./Oct. 2000, at 163, 164, https://publications.mygeoenergynow.org/grc/7003706.pdf [https://perma.cc/CL9B-QL92].

151. Axelsson, *supra* note 148, at 284.

152. *Wairakei Geothermal System*, N.Z. GEOTHERMAL ASS'N, https://www.nzgeothermal.org.nz/geothermal-in-nz/nz-geothermal-fields/wairakei/ (last visited Mar. 2, 2025) [https://perma.cc/RD6Z-JJQZ].

153. Michael O'Sullivan & Warren Mannington, *Renewability of the Wairakei-Tauhara Geothermal Resource*, 2005 PROC. WORLD GEOTHERMAL CONG. 1, 1, https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2005/0508.pdf [https://perma.cc/7B36-DYDJ] (asserting that "[t]he current production of geothermal fluid from the Wairakei-Tauhara system exceeds the natural recharge of heat by a factor of 4.75").

154. *Id.*

155. *Id.* at 8.

producing electricity (9,500 kW at the start, and 23.5 MW since 1993) on a relatively constant basis since the mid-1960s.[156] Likewise, the Laugarnes geothermal system in Reykjavík, Iceland, has continuously provided the same level of district heating since the 1930s, currently supplying energy to nearly 200,000 residents.[157]

Geothermal energy is an incredibly promising source of renewable energy.[158] However, its extraction and use must be carefully managed to avoid overexploitation, interference amongst adjacent users, and other avoidable externalities.[159] If employed sustainably, it could be used to support the move to a clean-energy economy, not only in the United States, but on a global scale.[160] In order for that transition to take hold, an appropriate management and regulatory regime for its exploitation is necessary to ensure sustainability and economic efficiency as well as minimize negative impacts on people and the environment.

One of the core components of that regime must be a clear understanding of how geothermal energy is or can be owned.[161] Yet, because geothermal resources are underground,[162] the relevant property system will need to have a vertical reach into physical spaces that cannot be easily seen or accessed. As a result, the system necessarily would have to be premised on the availability of remote sensing information and analytical inferences, which in the case of geothermal energy resources often are imperfect or non-existent.[163] Moreover, because of the mobility and renewability of geothermal energy,[164] it would have to recognize the spatial and temporal aspects of exploiting the resource.

The next two Sections explore how geothermal energy is treated under various property regimes. The first reviews the existing mechanisms in place under federal and state laws. The second explores how various property and ownership regimes might relate to geothermal energy, and what implications they may have on the sustainable exploitation of the resource. Admittedly, the regimes reviewed here are based on the conventional typology of property systems best articulated in the Justinian compilation of Roman law—*res privatae* (private property), *res*

156. *Mechanical Engineering Heritage No. 77: Matsukawa Geothermal Power Plant*, JAPAN SOC'Y MECH. ENG'RS, https://www.jsme.or.jp/kikaiisan/heritage_077_en.html (last visited Mar. 2, 2025) [https://perma.cc/8RB7-YEMF] (noting that the plant, now operating for nearly 60 years, continues to produce 23.5 MW of electricity and is open for tours); Mineyuki Hanano, *Sustainable Steam Production in the Matsukawa Geothermal Field, Japan*, 32 GEOTHERMICS 311, 316–18 (2003) (describing the history of the Matsukawa geothermal system). Hanano asserts that the main reasons that the Matsukawa project has been successfully maintained as sustainable is because of: (1) appropriate station sizing; (2) adequate operational criteria; (3) no additional development; and (4) wider reservoir than the drilling area. *Id.* at 320–21.

157. *See* Axelsson, *supra* note 148, at 284–85; Reykjavík Travel Guide, GUIDE TO ICELAND, https://guidetoiceland.is/travel-iceland/drive/Reykjavik (last visited Mar. 2, 2025) [https://perma.cc/8FQS-HFDW].

158. *See generally* Tester et al., *supra* note 9.

159. McClean & Pedersen, *supra* note 21, at 348 (asserting that the "potential for interference and over-exploitation arguably supports the adoption of a central coherent framework for regulating and governing extraction of geothermal heat which maintains a balance between different users and maximises [*sic*] the economic use of geothermal resources").

160. *See generally id.*

161. *See supra* note 21 and accompanying text.

162. *See* Squibb, *supra* note 21, at 273.

163. *See, e.g.*, *id.* at 238.

164. *See* McClean & Pedersen, *supra* note 21, at 345.

publicae (public property), *res communes* (common property), and *res nullius* (nonproperty)—and "[f]ew, if any, real-existing property arrangements fit within a single category."[165] Nevertheless, the discussion provides a foundation upon which a functional and effective property regime for geothermal energy can be constructed and tailored to this distinct natural resource, taking into account all of its idiosyncrasies.

III. OWNERSHIP STATUS OF GEOTHERMAL ENERGY UNDER CURRENT LAW

The legal landscape in the United States for geothermal energy is still nascent and rather chaotic. Only a handful of laws and regulations at the federal and state levels address access to, use of, and rights to the resource, and those that exist provide only a patchwork of rules and policies, which have not facilitated or incentivized much investment or growth in the sector.[166]

A. Federal Law and Geothermal Energy

As a general matter, the federal government owns natural resources on and under federal lands. That ownership status is derived from the Property Clause of the U.S. Constitution (Article IV, Section 3, Clause 2), which permits the federal government to acquire, dispose of, and manage federal property.[167] The U.S. Supreme Court has interpreted this clause as "without limitation" on Congressional powers,[168] thereby authorizing Congress to regulate the use of federal lands as well as transfer rights to minerals found on these lands.[169]

Prior to 1970, thermal springs and other waters emanating from geothermal formations on federal lands were, as a matter of law, treated as a type of groundwater resource.[170] Since groundwater (and most freshwater resources for that matter) have long been relegated to the authority of the several states, these heated waters were therefore subject to state groundwater legal regimes rather than to any federal rules.[171] As a result, their ownership status depended on the state in which the federal lands were located.[172]

Passage of the federal Geothermal Steam Act of 1970[173] resulted in all geothermal energy resources found on federal land being treated as mineral

165. *See* Daniel H. Cole & Elinor Ostrom, *The Variety of Property Systems and Rights in Natural Resources*, *in* PROPERTY IN LAND AND OTHER RESOURCES, 37, 41–42 (Daniel H. Cole & Elinor Ostrom eds., 2014), https://www.lincolninst.edu/app/uploads/legacy-files/pubfiles/property-systems-and-rights-in-natural-resources_0.pdf [https://perma.cc/6X35-CFYT] (discussing the simplicity of Justinian typology of property systems).

166. *See* discussion *infra* Sections III.A–B.

167. *See* U.S. CONST. art. IV, § 3, cl. 2.

168. Kleppe v. New Mexico, 426 U.S. 529, 539 (1976).

169. KRISTINA ALEXANDER & ROSS W. GORTE, CONG. RSCH. SERV., FEDERAL LAND OWNERSHIP: CONSTITUTIONAL AUTHORITY AND THE HISTORY OF ACQUISITION, DISPOSAL, AND RETENTION 2 (2007), https://sgp.fas.org/crs/misc/RL34267.pdf [https://perma.cc/YG2Z-ASQS].

170. *Opportunities and Challenges for Advancement of Geothermal Energy in the United States*, *supra* note 86.

171. *See id.*

172. *See* discussion *infra* Section IV.B.

173. 30 U.S.C. §§ 1001–27.

reserves and subject to federal jurisdiction.[174] The Act authorized the Secretary of the Interior to issue leases in exchange for royalties for the development and utilization of geothermal resources on lands managed by the Department of the Interior and the U.S. Forest Service.[175] Effectively, these resources are now recognized as "owned" by the federal government.[176]

Subsequent amendments to the Act predominantly focused on incentivizing the development of geothermal energy. For example, various amendments reduced royalty payments, modified how land is leased, expanded the time available to bring leaseholds into production, provided tax incentives and loan guarantees for geothermal energy ventures, and modified how federal income from geothermal development is distributed.[177] Other federal actions sought to encourage development by funding demonstration projects,[178] providing tax incentives for drilling and energy production, offering tax credits for homeowners installing geothermal energy-based systems,[179] and reducing risk through loan and grant programs.[180] The most recent federal act addressing geothermal energy—the Energy Act of 2020[181]—authorized research, development, demonstration, and commercialization of various energy technologies, including geothermal energy.[182]

174. Aaron Levine, Faith Martinez Smith & Heather Buchanan, NAT'L RENEWABLE ENERGY LAB'Y, NREL/TP-6A20-86985, TOPICS AND CONSIDERATIONS FOR DEVELOPING STATE GEOTHERMAL REGULATIONS 3 (Sept. 2023), https://www.nrel.gov/docs/fy23osti/86985.pdf [https://perma.cc/WPG7-P3MZ].

175. 30 U.S.C. § 1002. Federal law defines geothermal steam and associated geothermal resources as:

> (1) All products of geothermal processes, including indigenous steam, hot water, and hot brines; (2) Steam and other gases, hot water, and hot brines resulting from water, gas, or other fluids artificially introduced into geothermal formations; (3) Heat or other associated energy found in geothermal formations; and (4) Any byproducts. 43 C.F.R. § 3200.1 (2023). In exchange for these leases, the government receives royalty payments on the electricity generated, as well as any mineral "byproduct" produced through the geothermal production process. 30 U.S.C. § 1004.

176. *See* Levine et al., *supra* note 174, at 3.

177. *See* George D. Wilson, *The Geothermal Steam Act Amendments of 1988*, 19 INDEP. ENERGY, no. 4, Apr. 1989, at 64, https://web.stanford.edu/~gwilson/19.Independent.Energy.64.Apr.1989.pdf [https://perma.cc/4NE6-TFPP] (discussing 1988 amendments to the federal Geothermal Steam Act); *Energy Saver History Timeline: Geothermal Energy*, OFF. OF ENERGY SAVER, U.S. DEP'T OF ENERGY, https://www.energy.gov/energysaver/energy-saver-history-timeline-geothermal-energy (last visited Mar. 2, 2025) [https://perma.cc/79YX-FCNV] (discussing 2005 amendments to the federal Geothermal Steam Act).

178. For example, under the Geothermal Energy Research, Development, and Demonstration Act of 1974, the Federal Government is obligated to encourage and assist the private sector to develop and demonstrate practicable means of producing useful energy from geothermal resources with environmentally acceptable processes. 30 U.S.C. § 1101.

179. *See* Lund & Bloomquist, *supra* note 18, at 3–4 (referencing, among others, Investment Tax Credits enacted in 1978, the Public Utilities Regulatory Act of 1979, and the Federal Production Tax Credit that was first applied to geothermal resources in 2004).

180. *See id.* at 4–6 (referencing the Geothermal Loan Guarantee Program initiated in 1975, Program Research Development Announcement initiated in 1976, Program Opportunity Notice initiated in 1979, User Coupled Confirmation Drilling Program initiated in 1980, and the American Recovery and Reinvestment Act which began in 2009).

181. Energy Act of 2020, Pub. L. No. 116–260, §§ 3101–3106 (codified at 43 U.S.C. §§ 3001–05).

182. The main provisions of the Act pertaining to geothermal energy set aside funds for research and development of a range of geothermal-related activities, including hydrothermal resources, enhanced geothermal systems, and low-temperature applications, as well as work on thermal energy storage and integrated energy systems. *Id.* at § 3002; *see also* SEAN PORSE, JEFFREY WINICK, CORYNE TASCA & DOUGLAS BLANKENSHIP, GEOTHERMAL TECHNOLOGIES OFFICE FISCAL YEARS 2022–2026 MULTI-YEAR PROGRAM PLAN 1 (2022), https://www.energy.gov/sites/default/files/2022-02/GTO%20Multi-Year%20Program%20Plan%20FY%202022-2026.pdf [https://perma.cc/935X-Q3AL] (discussing some of the geothermal resources-related amendments of the

B. State Law and Geothermal Energy

In contrast to federal law, state law treatment of geothermal resources underlying private property is diverse and disparate; to call it a patchwork would be generous.[183] It ranges from states that have no rules on the topic, to those with extensive acts containing detailed definitions and regulations that address the ownership, use, extraction, and management of the subsurface energy.[184]

Among the states of the United States, seventeen have either legislation or case law that clearly identifies the owner of geothermal resources on privately owned land.[185] In seven states, the owner of the surface estate owns the underlying geothermal resources and retains title to those resources when the mineral estate is severed, unless the underlying geothermal resources are explicitly reserved or conveyed to another person.[186] These seven states include: Nevada,[187] Oregon,[188] Texas,[189] Utah,[190] Virginia,[191] Washington,[192] and West Virginia.[193] In California,[194] Nebraska,[195] and New Mexico,[196] the owner of the mineral

Energy Act of 2020). It also facilitated coproduction of geothermal energy on oil and gas leases, reserved funding to establish a cross-cutting energy storage research and development program that includes geothermal energy as one of the potential sources of thermal energy storage, and requires the Secretary of the Interior to establish national goals for geothermal energy production on federal lands. *See* Energy Act of 2020, *supra* note 181, at §§ 3104, 3105, 3201.

183. Peter Mostow & Andrew Braff, *Geothermal Site Acquisition and Early Development: Key Legal Issues and Emerging Strategies*, 32 GRC TRANSACTIONS 113, 116 (2008) (describing the state legal regimes as a "patchwork" and asserting that "[a]lthough these legal definitions of the nature of geothermal rights are central to determining ownership, they often are frustratingly unclear").

184. *See* discussion *infra* Section IV.B.

185. *See infra* note 205–10 and accompanying text.

186. *See infra* notes 187–93 and accompanying text.

187. NEV. REV. STAT. ANN. § 534A.050 (West 2023).

188. OR. REV. STAT. ANN. § 522.035 (West 2023).

189. *See* S.B. 785, 88th Leg. (Tex. 2023) (providing that, unless expressly severed, geothermal energy and associated resources below the surface of the land are owned as real property by the landowner); *see also* Lightning Oil Co. v. Anadarko E&P Onshore, L.L.C., 520 S.W.3d 39, 43 (Tex. 2017) (holding that the surface owner owns everything not severed); Benjamin Sebree, *Who Owns Heat? Ownership of Geothermal Energy and Associated Resources Under Texas Law*, *in* THE FUTURE OF GEOTHERMAL IN TEXAS: CONTEMPORARY PROSPECTS AND PERSPECTIVES at 332, 333 (Jamie C. Beard & Bryant A. Jones eds., 2023) (interpreting Texas jurisprudence as assigning geothermal energy resources, absent a separate and explicit contrary provision, to the surface estate in the event of a severance of the mineral and surface estates).

190. *See* UTAH CODE ANN. § 73-22-4(1) (West 2024) (asserting that ownership of geothermal resources "derives from an interest in land and not from an appropriative right to geothermal fluids"), UTAH CODE ANN. § 73-22-9 (West 2024) (stating that the "rights to geothermal resources and to geothermal fluids to be extracted in the course of production of geothermal resources . . . is based on the principal of correlative rights"), and UTAH CODE ANN. § 73-22-3(1) (West 2024) (explaining that every landowner overlying geothermal resources has the right "to produce without waste his just and equitable share of the geothermal resource").

191. VA. CODE ANN. § 45.2-2002 (West 2024).

192. WASH. REV. CODE ANN. § RCW 78.60.040 (West 2024).

193. W. VA. CODE ANN. § 22-33-4(a) (West 2024).

194. *See* Geothermal Kinetics, Inc. v. Union Oil Co., 75 Cal. App. 3d 56, 58 (Cal. Ct. App. 1977) (concluding that "the general grant of minerals in, on or under the property includes a grant of geothermal resources, including steam therefrom"); *see also* Pariani v. State, 105 Cal. App. 3d 923, 937 (Cal. Ct. App. 1980) (ruling that "the trial court properly concluded that the geothermal resources were 'mineral deposits' and 'mineral water'").

195. NEB. REV. STAT. ANN. § 66-1103 (West 2024).

196. Boschee, *supra* note 28. Under federal law, geothermal energy resources on federal lands in New Mexico are reserved to the United States as the mineral interest holder under the federal Stock Raising Homestead Act. Rosette Inc. v. United States, 277 F.3d 1222, 1234–35 (10th Cir. 2002), *cert. denied*, 537 U.S. 878 (2002).

estate has ownership rights to geothermal resources, though neither California nor Nebraska explicitly defines "mineral" to include geothermal resources,[197] while New Mexico's Mining Act explicitly excludes geothermal resources from the definition of mineral.[198] This means that if the mineral estate is severed, geothermal resources would be held by the mineral estate owner.[199] Alaska is singular in the nation as having retained the ownership rights to all mineral and geothermal resources in the state.[200] Wyoming is also unique in subjecting geothermal resources containing native water to the state's usufructuary groundwater allocation regime of prior appropriation.[201] Colorado employs two types of ownership regimes for geothermal resources.[202] Those associated with "tributary groundwater"[203] are subject to the state's usufructuary groundwater law of prior appropriation; those associated with non-tributary groundwater or not containing any fluid are owned by the overlying landowner, unless severed or reserved.[204]

In addition, four states—Idaho,[205] Montana,[206] Virginia,[207] and Washington[208]—treat geothermal resources as *sui generis*, meaning the resource has an independent legal classification from minerals, water and all other resources. This suggests that where ownership of the mineral estate is severed from the surface, geothermal resources would remain with the surface estate.[209] This is

197. *See infra* note 213 and accompanying text.

198. New Mexico Mining Act, N.M. STAT. ANN. § 69-36-3(G) (West 2024).

199. Presumably, though yet untested, geothermal resources in these three states could be reserved or assigned separately from the remaining mineral estate if done so explicitly and intentionally.

200. Under section 6(i) of the Alaska Statehood Act, 72 Stat. 339, Alaska retains the rights to all minerals in the state but is obligated to allow the lease of such resources. Alaska Statehood Act, Pub. L. No. 85-508, § 6(i), 72 Stat. 339, 342 (1958). The state also expressly included "geothermal resources" as part of its reservation when disposing of state land. ALASKA STAT. § 38.05.125(a) (West 2024). Additionally, Alaska recognized a "preferential right" in landowners to a geothermal prospecting permit or lease for the area underlying their land. ALASKA STAT. § 38.05.181(a) (West 2024).

201. Per Wyoming Statute section 41-3-901(a)(ii), Wyoming defines "underground water" as any "water, *including hot water and geothermal steam*, under the surface of the land or the bed of any stream, lake reservoir, or other body of surface water." WYO. STAT. ANN. § 41-3-901(a)(ii) (West 2024). According to Wyoming Statute section 41-3-101 and section 41-3-906, "underground water" is subject to the state's prior appropriation regime. WYO. STAT. ANN. §§ 41-3-101, 41-3-906 (West 2024). Under the prior appropriation system, the first person to put water to beneficial use secures the prioritized right to that volume of water. When water supplies are scarce, those with senior rights are entitled to their full allotment before more junior rights holders. *See infra* note 363.

202. *See infra* notes 203–04 and accompanying text.

203. In Colorado, tributary groundwater refers to groundwater that is hydrologically connected to a natural stream system either through surface or subsurface flows. All groundwater in Colorado is presumed to be tributary unless it is determined to be non-tributary through a judicial or administrative process. *Colorado Water Knowledge: Groundwater Rights*, COLO. STATE UNIV., https://waterknowledge.colostate.edu/water-management-administration/water-rights/groundwater-rights/ (last visited Mar. 4, 2025) [https://perma.cc/AVH6-9CXD].

204. In Colorado, if a geothermal resource is found to be associated with geothermal fluid that is deemed to be tributary groundwater, that geothermal resource is regarded as a public resource subject to usufructuary, prior appropriation water rights. COLO. REV. STAT. § 37-90.5-104(1) (West 2025). Where a geothermal resource is not associated with any subsurface fluid (just hot dry rock), or if the resource is associated with non-tributary groundwater, it is subject to ownership of the overlying surface, unless severed or reserved. COLO. REV. STAT. ANN. § 37-90.5-104(1)-(2) (West 2024).

205. Geothermal Resources Act, IDAHO CODE ANN. § 42-4002(c) (West 2022).

206. MONT. CODE ANN. § 77-4-104 (West 2022).

207. VA. CODE ANN. § 45.2-2003 (West 2021).

208. WASH. REV. CODE § 78.60.040 (West 2013).

209. Curiously, Idaho defines "mineral" to include geothermal resources. IDAHO CODE ANN. § 47-701 (West 2022) (asserting that "[t]he terms 'mineral lands,' 'mineral,' 'mineral deposits,' 'deposit,' and 'mineral right,' as used in this chapter, and amendments thereto shall be construed to mean and include all . . . geothermal

affirmed in legislation in Virginia and Washington, which explicitly assign ownership of the geothermal resource to the owner of the surface estate;[210] Idaho and Montana do not offer any additional clarification.[211]

Ownership rights to geothermal resources is considerably less clear in the remaining thirty-three states. In some of these, ownership appears to be a function of how each state defines these resources under state law. For example, fifteen of the thirty-three states define "mineral" to include geothermal resources, thereby suggesting indirectly that such resources may be assigned to the owner of the mineral estate.[212]

While the ownership status of geothermal resources varies across the country, so do the definitions and characterizations of these resources. For example, twenty-two states have definitions for the term "geothermal" or "geothermal resources,"[213] albeit with extensive permutations. They differ considerably and include a variety of characteristics and components of geothermal formations—

resources"). While this suggest that these resources might be within the domain of a mineral estate owner, it is unclear how this definition relates to their proclaimed *sui generis* character. *See also supra* note 205 and accompanying text.

210. *See supra* notes 207–08 and accompanying text.

211. *See supra* notes 205–06 and accompanying text.

212. These fifteen states are Alabama, Arkansas, Connecticut, Delaware, Illinois, Indiana, Iowa, Kentucky, Louisiana, Maine, Maryland, New Jersey, North Carolina, Vermont, and Wisconsin. ALA. CODE ANN. § 35-12-71(7) (West 2022); ARK. CODE ANN. § 18-28-201(8) (West 2020); CONN. GEN. STAT. §47-33o(2) (West 2022); DEL. CODE ANN. tit. 12, § 1130(13) (West 2022); 765 ILL. COMP. STAT. ANN. 1026/15-102(15) (West 2022); IND. CODE ANN. § 32-34-1.5-3(16) (West 2023); IOWA CODE ANN § 556.1(8) (West 2023); KY. REV. STAT. ANN. § 393A.10(15) (West 2018); LA. STAT. ANN. § 9:153(8) (West 2022); ME. STAT. ANN. tit. 33 § 2052(15) (2019); MD. CODE ANN., ENV'T § 15-1201(b) (West 2023); N.J. STAT. ANN. § 46:30B-6(o) (West 2023); N.C. GEN. STAT. ANN. § 116B-52(7) (West 2023); VT. STAT. tit. 27 § 1452(15) (West 2024); WIS. STAT. § 177.01 (West 2024).

213. These twenty-two states are Alabama, Alaska, Arizona, California, Colorado, Hawaii, Idaho, Louisiana, Maryland, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oregon, South Carolina, South Dakota, Texas, Utah, Virginia, Washington, and West Virginia. ALA. CODE ANN. § 40-18-1(14) (West 2022); ALASKA STAT. ANN. § 41.06.060(5) (West 2022); ARIZ. REV. STAT. ANN. § 27-651(6) (West 2022); CAL. PUB. RES. CODE § 6903 (West 2023); COLO. REV. STAT. ANN. § 37-90.5-103(9) (West 2023); HAW. CODE R. ANN. § 13-184-2 (West 2023); IDAHO CODE ANN. § 42-4002(c) (West 2022); LA. STAT. ANN. § 30:801(1) (West 2022); MD. CODE ANN., ENV'T § 5-601(e) (West 2023); MONT. CODE ANN. § 77-41-102(2) (West 2022); NEB. REV. STAT. ANN. § 66-1102(1) (West 2023); NEV. REV. STAT. ANN. § 534A.010 (West 2023); N.M. STAT. ANN. § 19-13-2(A) (West 2021); N.D. CENT. CODE ANN. § 38-19-02(4) (West 2022); OR. REV. STAT. ANN. § 522.005(11) (West 2021); S.C. CODE ANN. § 10-9-310 (West 2015); S.D. CODIFIED LAWS § 5-1-2(2) (West 2023); TEX. NAT. RES. CODE ANN. § 141.003(4) (West 2023); UTAH CODE ANN. § 73-22-3(5) (West 2023); VA. CODE ANN. § 45.2-2000 (West 2021); WASH. REV. CODE ANN. § 78.60.030(7) (West 2022); W. VA. CODE ANN. § 22-33-5(C) (West 2022).

such as the natural heat,[214] energy,[215] mineral content,[216] water or fluids,[217] brine,[218] indigenous vapor or steam,[219] gas,[220] and byproducts of the production

214. All of the states with definitions for geothermal resources include the natural heat contained in the subsurface formation. ALA. CODE ANN. § 40-18-1(14) (West 2022); ALASKA STAT. ANN. § 41.06.060(5) (West 2022); ARIZ. REV. STAT. ANN. § 27-651(6) (West 2022); CAL. PUB. RES. CODE ANN. § 6903 (West 2023); COLO. REV. STAT. ANN. § 37-90.5-103(9) (West 2023); HAW. CODE R. ANN. § 13-184-2 (West 2023); IDAHO CODE ANN. § 42-4002(c) (West 2022); LA. STAT. ANN. § 30:801(1) (West 2022); MD. CODE ANN., ENV'T § 5-601(e) (West 2023); MONT. CODE ANN § 77-41-102(2) (West 2022); NEB. REV. STAT. ANN. § 66-1102(1) (West 2023); NEV. REV. STAT. ANN. § 534A.010 (West 2023); N.M. STAT. ANN. § 19-13-2(A) (West 2021); N.D. CENT. CODE ANN. § 38-19-02(4) (West 2022); OR. REV. STAT. ANN. § 522.005(11) (West 2021); S.C. CODE ANN. § 10-9-310 (West 2015); S.D. CODIFIED LAWS § 5-1-2(2) (West 2023); TEX. NAT. RES. CODE ANN. § 141.003(4) (West 2023); UTAH CODE ANN. § 73-22-3(5) (West 2023); VA. CODE ANN. § 45.2-2000 (West 2021); WASH. REV. CODE ANN. § 78.60.030(7) (West 2022); W. VA. CODE § 22-33-5(c) (West 2022).

215. All of the states with definitions for geothermal resources include the energy contained in the subsurface formation except for Alabama and Louisiana. *Compare* ALASKA STAT. ANN. § 41.06.060(5) (West 2022); ARIZ. REV. STAT. ANN. § 27-651(6) (West 2022); CAL. PUB. RES. CODE ANN. § 6903 (West 2023); COLO. REV. STAT. ANN. § 37-90.5-103(9) (West 2023); HAW. CODE R. ANN. § 13-184-2 (West 2023); IDAHO CODE ANN. § 42-4002(c) (West 2022); MD. CODE ANN., ENV'T § 5-601(e) (West 2023); MONT. CODE ANN § 77-41-102(2) (West 2022); NEB. REV. STAT. ANN. § 66-1102(1) (West 2023); NEV. REV. STAT. ANN. § 534A.010 (West 2023); N.M. STAT. ANN. § 19-13-2(A) (West 2021); N.D. CENT. CODE ANN. § 38-19-02(4) (West 2022); OR. REV. STAT. ANN. § 522.005(11) (West 2021); S.C. CODE ANN. § 10-9-310 (West 2015); S.D. CODIFIED LAWS § 5-1-2(2) (West 2023); TEX. NAT. RES. CODE ANN. § 141.003(4) (West 2023); UTAH CODE ANN. § 73-22-3(5) (West 2023); VA. CODE ANN. § 45.2-2000 (West 2021); WASH. REV. CODE ANN. § 78.60.030(7) (West 2022); W. VA. CODE § 22-33-5(c) (West 2022) *with* ALA. CODE ANN. § 40-18-1(14) (West 2022); LA. STAT. ANN. § 30:801(1) (West 2022).

216. All of the states with definitions for geothermal resources include minerals in the definition except for Nebraska, New Jersey, Ohio, Pennsylvania, South Dakota, Texas, Utah, Virginia, and West Virginia. *Compare* ALA. CODE ANN. § 40-18-1(14) (West 2022); ALASKA STAT. ANN. § 41.06.060(5) (West 2022); ARIZ. REV. STAT. ANN. § 27-651(6) (West 2022); CAL. PUB. RES. CODE ANN. § 6903 (West 2023); COLO. REV. STAT. ANN. § 37-90.5-103(9) (West 2023); HAW. CODE R. ANN. § 13-184-2 (West 2023); IDAHO CODE ANN. § 42-4002(c) (West 2022); LA. STAT. ANN. § 30:801(1) (West 2022); MD. CODE ANN., ENV'T § 5-601(e) (West 2023); MONT. CODE ANN § 77-41-102(2) (West 2022); NEV. REV. STAT. ANN. § 534A.010 (West 2023); N.M. STAT. ANN. § 19-13-2(A) (West 2021); N.D. CENT. CODE ANN. § 38-19-02(4) (West 2022); OR. REV. STAT. ANN. § 522.005(11) (West 2021); S.C. CODE ANN. § 10-9-310 (West 2015); WASH. REV. CODE ANN. § 78.60.030(7) (West 2022) *with* NEB. REV. STAT. ANN. § 66-1102(1) (West 2023); N.J. ADMIN. CODE § 14:8-2.2 (West 2024); OHIO ADMIN. CODE 4901:1-40-01(O) (West 2023); PA. STAT. AND CONS. STATS § 1648.2 (WEST 2022); S.D. CODIFIED LAWS § 5-1-2(2) (West 2023); TEX. NAT. RES. CODE ANN. § 141.003(4) (West 2023); UTAH CODE ANN. § 73-22-3(5) (West 2023); VA. CODE ANN. § 45.2-2000 (West 2021); W. VA. CODE § 22-33-5(c) (West 2022).

217. All of the states with definitions for geothermal resources include water or fluids in the definition except for Montana, Nevada, South Dakota, Utah, Virginia, West Virginia. *Compare* ALA. CODE ANN. § 40-18-1(14) (West 2022); ALASKA STAT. ANN. § 41.06.060(5) (West 2022); ARIZ. REV. STAT. ANN. § 27-651(6) (West 2022); CAL. PUB. RES. CODE ANN. § 6903 (West 2023); HAW. CODE R. ANN. § 13-184-2 (West 2023); IDAHO CODE ANN. § 42-4002(c) (West 2022); LA. STAT. ANN. § 30:801(1) (West 2022); MD. CODE ANN., ENV'T § 5-601(e) (West 2023); NEB. REV. STAT. ANN. § 66-1102(1) (West 2023); N.M. STAT. ANN. § 19-13-2 (West 2021)(A); N.D. CENT. CODE ANN. § 38-19-02(4) (West 2022); OR. REV. STAT. § 522.005(11) (West 2021); S.C. CODE ANN. § 10-9-310 (West 2015); TEX. NAT. RES. CODE ANN. § 141.003(4) (West 2023); WASH. REV. CODE ANN. § 78.60.030(7) (West 2022) *with* MONT. CODE ANN § 77-41-102(2) (West 2022); NEV. REV. STAT. ANN. § 534A.010 (West 2023); S.D. CODIFIED LAWS § 5-1-2(2) (West 2023); UTAH CODE ANN. § 73-22-3(5) (West 2023); VA. CODE ANN. § 45.2-2000 (West 2021); W. VA. CODE § 22-33-5(c) (West 2022). While Colorado does not include water or fluids in its definition of geothermal resources, it does include water in its definition of "allocated geothermal resources." COLO. REV. STAT. ANN. § 37-90.5-103(3)(a)(I) (West 2023).

218. 12 of the 22 states that define geothermal resources include brine in that definition: Alaska, Arizona, California, Colorado (in geothermal fluid definition), Hawaii, Louisiana, Maryland, New Mexico, Oregon, South Carolina, Texas, and Washington. ALASKA STAT. ANN. § 41.06.060(5) (West 2022); ARIZ. REV. STAT. ANN. § 27-651(6) (West 2022); CAL. PUB. RES. CODE ANN. § 6903 (West 2023); COLO. REV. STAT. § 37-90.5-103(8) (West 2023); HAW. CODE R. ANN. § 13-184-2 (West 2023); LA. STAT. ANN. § 30:801(1) (West 2022); MD. CODE ANN., ENV'T § 5-601(e) (West 2023); N.M. STAT. ANN. § 19-13-2(A) (West 2021); OR. REV. STAT. ANN. § 522.005(11) (West 2021); S.C. CODE ANN. § 10-9-310 (West 2015); TEX. NAT. RES. CODE ANN. § 141.003(4) (West 2023); WASH. REV. CODE ANN. § 78.60.030(7) (West 2022).

219. All of the states with definitions for geothermal resources include the indigenous vapor or steam in the definition except for Idaho, Montana, Nebraska, Nevada, North Dakota, Utah, Virginia, and West Virginia. *Compare* ALA. CODE ANN. § 40-18-1(14) (West 2022); ALASKA STAT. ANN. § 41.06.060(5) (West 2022); ARIZ. REV.

of geothermal energy[221]—as well as substances that are artificially introduced into a geothermal formation.[222] Moreover, the definition in one of these states—Alabama—applies solely for taxation purposes.[223]

Taking a different approach, six states offer definitions for geothermal energy, albeit with distinct nuances. New Jersey, Pennsylvania, and Virginia, for example, focus their definitions on the energy or electricity generated from hot water, steam turbines, or geothermal resources.[224] In contrast, Ohio's and Texas'

STAT. ANN. § 27-651(6) (West 2022); CAL. PUB. RES. CODE ANN. § 6903 (West 2023); COLO. REV. STAT. ANN. § 37-90.5-103(9) (West 2023); HAW. CODE R. ANN. § 13-184-2 (West 2023); LA. STAT. ANN. § 30:801(1) (West 2022); MD. CODE ANN., ENV'T § 5-601(e) (West 2023); N.M. STAT. ANN. § 19-13-2(A) (West 2021); OR. REV. STAT. ANN. § 522.005(11) (West 2021); S.C. CODE ANN. § 10-9-310 (West 2015); S.D. CODIFIED LAWS § 5-1-2(2) (West 2023); TEX. NAT. RES. CODE ANN. § 141.003(4) (West 2023); WASH. REV. CODE ANN. § 78.60.030(7) (West 2022) *with* IDAHO CODE ANN. § 42-4002(c) (West 2022); MONT. CODE ANN. § 77-41-102(2) (West 2022); NEB. REV. STAT. ANN. § 66-1102 (1) (West 2023); NEV. REV. STAT. ANN § 534A.010 (West 2023); N.D. CENT. CODE ANN. § 38-19-02(4) (West 2022); UTAH CODE ANN. § 73-22-3(5) (West 2023); VA. CODE ANN. § 45.2-2000 (West 2021); W. VA. CODE ANN. § 22-33-5(c) (West 2022). Separately, Colorado uses indigenous vapor/steam in its definition of geothermal fluid. COLO. REV. STAT. ANN. § 37-90.5-103(8) (West 2023).

220. 12 of the 22 states that define geothermal resources include gas in that definition: Alaska, Arizona, California, Colorado, Hawaii, Louisiana, Maryland, New Mexico, Oregon, South Carolina, Texas, and Washington. ALASKA STAT. ANN. § 41.06.060(5) (West 2022); ARIZ. REV. STAT. ANN. § 27-651(6) (West 2022); CAL. PUB. RES. CODE ANN. § 6903 (West 2023); COLO. REV. STAT. ANN. § 37-90.5-103(9) (West 2023); HAW. CODE R. ANN. § 13-184-2 (West 2023); LA. STAT. ANN. § 30:801(1) (West 2022); MD. CODE ANN., ENV'T § 5-601(e) (West 2023); N.M. STAT. ANN. § 19-13-2(A) (West 2021); OR. REV. STAT. ANN. § 522.005(11) (West 2021); S.C. CODE ANN. § 10-9-310 (West 2015); TEX. NAT. RES. CODE ANN. § 141.003(4) (West 2023); WASH. REV. CODE ANN. § 78.60.030(7) (West 2022).

221. Four states—Colorado, Louisiana, Oregon, and Texas—explicitly include "by-products" in their definition of geothermal resources. COLO. REV. STAT. ANN. § 37-90.5-103(9)(c) (West 2023); LA. STAT. ANN. § 30:801(1)(d) (West 2022); OR. REV. STAT. ANN. § 522.005(11)(d) (West 2021); TEX. NAT. RES. CODE ANN. § 141.003(4)(D) (West 2023). By-products generally refers to any mineral, gas, or other substance, but not hydrocarbons (in Colorado, also excluding carbon dioxide; in Oregon, also excluding helium), that may be obtained through the process of extracting or generating geothermal heat or energy. COLO. REV. STAT. ANN. § 37-90.5-103(7) (West 2023); LA. STAT. ANN. § 30:801(2) (West 2022); OR. REV. STAT. ANN. § 522.005(2) (West 2021); TEX. NAT. RES. CODE ANN. § 141.003(5) (West 2023). However, many of states appear to include such "by-products" when including "other products" resulting from the geothermal process within the definition of geothermal resources. Thus, for example, California law provides that "'Geothermal resources' shall mean . . . all minerals in solution or other products obtained from naturally heated fluids, brines, associated gases, and steam, in whatever form, found below the surface of the earth." CAL. PUB. RES. CODE ANN. § 6903 (West 2023), while Montana law provides that "'Geothermal resources' means . . . all minerals in solution or other products obtained from the material medium of any geothermal resource." MONT. CODE ANN. § 77-4-102 (West 2022).

222. Of the 22 states with definitions for geothermal resources, eight include introduced or artificial substances in their definition: Alaska, Arizona, Louisiana, Maryland, Oregon, South Carolina, Texas, and Washington. ALASKA STAT. ANN. § 41.06.060(5) (West 2022); ARIZ. REV. STAT. ANN. § 27-651(6) (West 2022); LA. REV. STAT. ANN. § 30:801(1) (West 2022); MD. CODE ANN., ENV'T § 5-601(e) (West 2023); OR. REV. STAT. ANN. § 522.005(11) (West 2021); S.C. CODE ANN. § 10-9-310 (West 2015); TEX. NAT. RES. CODE ANN. § 141.003(4) (West 2023); WASH. REV. CODE § 78.60.030(7) (West 2022). In the context of geothermal energy production, introduced and artificial substances generally include fluids and gases artificially injected into the geothermal formation or the geothermal wells that serve as a medium for transferring the heat. *See, e.g.*, *supra* and accompanying text.

223. Section 40-18-1 of the Code of Alabama, which is focused on income tax, is preceded by the introductory "[f]or the purpose of this chapter, the following terms shall have the respective meanings ascribed by this section." ALA. CODE ANN. § 40-18-1 (West 2022). Alabama does not define geothermal in any other context. It is noteworthy that Rhode Island's definition for "geothermal system," which also is solely applicable in the context of taxation, is not included here because the definition refers to the functions of the system ("a system that *produces and stores* energy to heat buildings, cool buildings or produces hot water") and does not define geothermal itself. 44 R.I. GEN. LAWS ANN. § 44-57-2(37) (West 2024) (emphasis added).

224. *See* N.J. ADMIN. CODE § 14:8-2.2 (West 2024) (defining geothermal energy as "energy generated by a steam turbine, driven by hot water or steam extracted from geothermal reservoirs in the earth's crust"); 73 PA. STAT. AND CONS. STAT. ANN. § 1648.2 (West 2024) (defining geothermal energy as "electricity produced by extracting hot water or steam from geothermal reserves in the earth's crust and supplied to steam turbines that

definitions center on the products of the geothermal process, including hot water, steam, and brines extracted from a geothermal reservoir and used to produce electricity,[225] though Texas' definition also extends to these products when resulting from "water, gas and fluid artificially introduced in the geothermal formation."[226] In further contrast, and in possibly the most basic and clear designation, North Dakota's definition of geothermal energy refers solely to "the internal energy of the earth, available to man as heat from rocks or liquids."[227]

Of the 22 states that define the term "geothermal" or "geothermal resources," all specifically include the natural heat of the Earth in their definition.[228] However, five states have a temperature threshold that must be met for the resource to qualify as a geothermal resource. Alaska and Utah set that threshold at 120° C (248° F), New Mexico at 250° F, Maryland at 120° F, and South Carolina at 40° C (104° F).[229]

Further, thirteen of the same twenty-two states exclude hydrocarbons in certain forms. Some do so narrowly by excepting oil and natural gas, while others

drive generators to produce electricity), and VA. CODE ANN. § 45.2-2000 (West 2021) (defining geothermal energy as "the usable energy that is produced or that can be produced from a geothermal resource").

225. *See* OHIO ADMIN CODE 4901-1-40-01 (West 2023) (defining geothermal energy as "hot water or steam extracted from geothermal reservoirs in the earth's crust and used for electricity generation"), and TEXAS NAT. RES. CODE ANN. § 141.003 (West 2023) (defining geothermal energy as "products of geothermal processes, embracing indigenous steam, hot water and hot brines, and geopressured water").

226. *See* TEXAS NAT. RES. CODE ANN. § 141.003 (West 2023).

227. *See* N.D. CENT. CODE ANN. § 38-19-02 (West 2022).

228. *See supra* note 214 and accompanying text.

229. *See* ALASKA STAT. ANN. § 41.06.060(4)–(5) (West 2022); UTAH CODE ANN. § 73-22-3(4)–(5) (West 2023); N.M. STAT. ANN. § 19-13-2(A) (West 2021); MD. CODE ANN., ENV'T §5-601(e)(1) (West 2023); and S.C. CODE ANN. § 10-9-310 (West 2015).

Curiously, Utah excludes heat below 120° C from the definition of geothermal resources. *See* UTAH CODE ANN. § 73-22-3 (West 2023). However, it also excludes subsurface water and steam greater that 120°C from the scope of geothermal resources. Under Utah's Geothermal Resource Conservation Act, 73-22-3(4), it states that "'[g]eothermal fluid' means water and steam at temperatures greater than 120 degrees centigrade naturally present in a geothermal system." UTAH CODE ANN. § 73-22-3(4) (West 2023). Then, in section 73-22-3(5)(b), it asserts that "'[g]eothermal resource' does not include geothermal fluids." UTAH CODE ANN. § 73-22-3(5)(b) (West 2023). As a result, in Utah, "geothermal resources" encompass natural subsurface heat that exceeds 120° C as well as the native water below that temperature, but not native water hotter than 120° C. *See* UTAH CODE ANN. § 73-22-3 (West 2023).

In another curiosity, Idaho does not have a heat temperature threshold for purposes of the scope of geothermal resources. *See* IDAHO CODE ANN. § 42-4002(c) (West 2022). However, it does provide that "[g]round water having a temperature of two hundred twelve (212) degrees Fahrenheit or more in the bottom of a well shall be classified as a geothermal resource," thereby excluding hot groundwater below 212°F. IDAHO CODE ANN. § 42-4002(c) (West 2022).

exclude hydrocarbons more broadly.[230] In addition, six states exclude naturally occurring helium from the definition of geothermal resources.[231]

Finally, of the twenty-two states, twelve states specifically include "dissolved or entrained . . . gases," "other gas," or "associated gas" in their definition of geothermal resources or geothermal energy.[232] While none of the states define these phrases, in the context of geothermal formation, gas usually refers to ammonia and methane, as well as non-hydrocarbon gases, such as carbon dioxide, argon, ammonia, boron, hydrogen, hydrogen sulfide, and nitrogen, which can be found in geothermal reservoirs.[233]

As can be seen, the definitions for geothermal, geothermal resources, and geothermal energy vary considerably among the states. Some regard it as a mineral, others as water, and a few *sui generis*.[234] Only seventeen states—the thirteen that have legally defined the ownership status of geothermal resources,[235] and the four states categorizing such resources as *sui generis*[236]—offer a somewhat clear articulation of ownership rights in geothermal resources on privately held property. Conceivably, development of and investment in geothermal resources would be more prone to occur in these states than in the states where ownership rules are unclear or lacking. Yet, the disparate rules and definitions that do exist make the market less enticing for investors with the resources

230. California, Louisiana, Maryland, New Mexico, Oregon and Washington specifically exclude oil and gas, CAL. PUB. RES. CODE ANN. § 6903 (West 2023); LA. REV. STAT. ANN. § 30:801(1) (West 2022); MD. CODE ANN., ENV'T § 5-601(e)(2) (West 2023); N.M. STAT. ANN. § 19-13-2(A) (West 2021); OR. REV. STAT. ANN. §§ 522.005(2), 522.005(11) (West 2021); WASH. REV. CODE ANN. §§ 78.60.030(1), 78.60.030 (7) (West 2022), while Texas excludes oil and gas and any product of oil or gas. TEX. NAT. RES. CODE ANN. §§ 141.003(4)–(5)(B) (West 2023). Alaska, California, Colorado, Maryland, Nevada, New Mexico, Oregon, South Carolina, and Washington exclude hydrocarbon, ALASKA STAT. ANN. § 41.06.060(5)(B)(iii) (West 2022); CAL. PUB. RES. CODE ANN. § 6903 (West 2023); COLO. REV. STAT. ANN §§ 37-90.5-103(7), 37-90.5-103(9) (West 2023); MD. CODE ANN., ENV'T § 5-601(e)(2) (West 2023); NEV. REV. STAT. ANN. § 534A.010 (West 2023); N.M. STAT. ANN. § 19-13-2(A) (West 2021); OR. REV. STAT. ANN. §§ 522.005(2), 522.005(11) (West 2021); S.C. CODE ANN. § 10-9-310(3) (West 2015); WASH. REV. CODE §§ 78.60.030(1), 78.60.030(7)(a) (West 2022), and Arizona excludes fossil fuels. ARIZ. REV. STAT. ANN. § 27-651(6)(d) (West 2022).

231. Alaska, Arizona, Nevada, Oregon, South Carolina, and Washington exclude helium. ALASKA STAT. ANN. § 41.06.060(5)(B)(iii) (West 2022); ARIZ. REV. STAT. ANN. § 27-651(6)(d) (West 2022); NEV. REV. STAT. ANN. § 534A.010 (West 2023); OR. REV. STAT. ANN. §§ 522.005(2), 522.005(11) (West 2021); S.C. CODE ANN. § 10-9-310(3) (West 2015); WASH. REV. CODE ANN. §§ 78.60.030(1), 78.60.030(7)(a) (West 2022).

232. Alaska, Arizona, California, Colorado, Hawaii, Louisiana, Maryland, New Mexico, Oregon, South Carolina, Texas, and Washington. ALASKA STAT. ANN. §§ 41.06.060(5)(ii)–(iii) (West 2022); ARIZ. REV. STAT. ANN. § 27-651(6)(b) (West 2022); CAL. PUB. RES. CODE ANN. § 6903 (West 2023); COLO. REV. STAT. ANN. § 37-90.5-103(7) (West 2023); HAW. CODE R. ANN. § 13-184-2 (West 2023); LA. STAT. ANN. § 30:801(1)(b) (West 2022); MD. CODE ANN., ENV'T § 5-601(e) (West 2023); N.M. STAT. ANN. § 19-13-2(A) (West 2021); OR. REV. STAT. ANN. § 522.005(11) (West 2021); S.C. CODE ANN. § 10-9-310(3) (West 2015); TEX. NAT. RES. CODE ANN. § 141.003(4)(B) (West 2023); WASH. REV. CODE ANN. § 78.60.030(7)(a) (West 2022).

233. *See Geothermal Energy*, NAT'L GEOGRAPHIC (May 10, 2024), https://education.nationalgeographic.org/resource/geothermal-energy/ [https://perma.cc/Q4WK-NZM6]; ALISON HOLM, DAN JENNEJOHN & LESLIE BLODGETT, GEOTHERMAL ENERGY ASSOCIATION, GEOTHERMAL ENERGY AND GREENHOUSE GAS EMISSIONS 4 (Nov. 2012), https://geothermal.org/sites/default/files/2021-02/Geothermal_Greenhouse_Emissions_2012_0.pdf [https://perma.cc/LL6W-TD2F].

234. To make the situation more disjointed, the United States Court of Appeals for the Ninth Circuit held in *Reich v. Commissioner of Internal Revenue* that geothermal resources should be classified as gases for purposes of taking a depletion deduction under Internal Revenue Code §§ 263(c), 611(a), and 613(b) "for the intangible costs of drilling and developing oil and gas wells." 454 F.2d 1157, 1158–59 (9th Cir. 1972).

235. *Supra* notes 185–204 and accompanying text.

236. *Supra* notes 205–10 and accompanying text.

needed to engage in such projects.[237] Moreover, in states where questions of ownership have not been addressed, disputes over rights, market access, and interference are left to the vagaries of courts and judges who often have little experience in or understanding of this nascent industry.[238]

IV. OWNERSHIP THEORIES AND GEOTHERMAL ENERGY

A. The Importance of Ownership

In societies grounded in capitalism and the market system, ownership of things, both real and personal, is indispensable for their effective functioning and underpins the highly interrelated systems of modern property law and economics.[239] Moreover, since natural resources are the building blocks of the economy, ownership is typically considered a crucial aspect of governance regimes for such resources.[240]

In order to manage and regulate a resource within a market system, it is helpful, if not necessary, first to establish who has what ownership rights in that particular resource.[241] Where ownership can be clearly identified in the market system, owners will have patent incentives to secure and develop their property. It will also allow them to see a more direct relationship between their investment and efforts and the benefits that can arise from owned property.[242] Furthermore, where ownership is easily identifiable, owners can be made accountable and responsible for the use, management, and even non-use of the resource, and can be held liable for any related obligations or ensuing consequences.[243] Ultimately, since regulations often define the rights and responsibilities of owners, including those related to the use and transfer of such resources, ownership provides the legal framework on which a regulatory system can be constructed.[244]

In addition, in the context of natural resources, ownership plays a crucial role in the allocation, conservation, and management of those resources "because

237. *Supra* note 21 and accompanying text.

238. *See* OBERBECK, *supra* note 21, at 40–41.

239. John D. Sullivan, Jean Rogers & Kim Eric Bettcher, *The Importance of Property Rights to Development*, 27 SAIS REV. INT'L AFFS., Summer–Fall 2007, at 31. Coase posits that:

> [I]f no property rights were created in land, so that everyone could use a tract of land, it is clear that there would be considerable confusion and that the price mechanism could not work because there would not be any property rights that could be acquired . . . system. A private-enterprise system cannot function properly unless property rights are created in resources, and, when this is done, someone wishing to use a resource has to pay the owner to obtain it.

R. H. Coase, *The Federal Communications Commission*, 2 J. L. & ECON. 1, 14 (1959).

240. *See* Donald N. Zillman, Aileen McHarg, Lila K. Barrera-Hernández & Adrian Bradbrook, *Introduction* to THE LAW OF ENERGY UNDERGROUND: UNDERSTANDING NEW DEVELOPMENTS IN SUBSURFACE PRODUCTION, TRANSMISSION, AND STORAGE 1, 14–15 (Donald N. Zillman, Aileen McHarg, Adrian Bradbrook & Lila K. Barrera-Hernández eds., 2014).

241. Ownership can lie in the nation, government, public, people, community, an individual or group of people, or one or more companies. It can also be unowned by anyone. *See* discussion *supra* Part I.

242. Elinor Ostrom & Charlotte Hess, *Private and Common Property Rights*, *in* PROPERTY LAW AND ECONOMICS: ENCYCLOPEDIA OF LAW AND ECONOMICS 53, 54 (Boudewijn Bouchaert, ed., 2010); *see also* Bradbrook & Rønne, *supra* note 6, at 311.

243. *See* Bradbrook & Rønne, *supra* note 6, at 311, 315.

244. *Cf.* Sullivan et al., *supra* note 239, at 35.

property owners have a substantial incentive to maximize the value of the resource in question."[245] Clear ownership rights to natural resources provide market-based private financiers with critical information necessary to assess whether or not a given proposal to exploit that resource is viable.[246] Few investors would take a risk on the exploitation of a resource if they did not have some assurances that the company exploiting the resource has legal rights both to implement its operations and to enjoy the financial benefits derived from such work.[247]

In contrast, where an ownership regime is absent in a market system, regulations can become difficult to implement and enforce, resulting in conflicts among those raising claims of right to a resource.[248] Moreover, the absence of an ownership regime creates the dilemma whereby no one is identified as accountable or responsible for the use, management, or exploitation of the resource, or for any negative consequences that might ensue as a result of such activities.[249] That, in turn, would complicate any disputes over the use, enjoyment, or protection of a resource as therewould be little basis for cooperation, concession, or dispute resolution.[250]

Of particular note, unclear ownership interests can also impact the ability of project proponents to attract and maintain private sector financing in the market since the right to develop, exploit, and profit from the investment are all directly linked to the rights to exploit the resource that are held by the company seeking the investment.[251] As a result, there is a predilection in property law and the law of natural resources, especially in the market-oriented system of the United States, for there to be an identifiable owner for most things in society, both tangible and intangible.[252] This is especially true under the common law, but also in many statutory and regulatory regimes, as they pertain to the rights to and use of land and underlying geologic formations.[253]

245. Jonathan H. Adler, *Conservation Through Collusion: Antitrust as an Obstacle to Marine Resource Conservation*, 61 WASH. & LEE L. REV. 3, 11 (2004); *but see* Keith H. Hirokawa, *The New Law of Geology: Rights, Responsibilities, and Geosystem Services*, 52 ENV'T L. REP. 10380, 10406 (2022) (arguing for adoption of more holistic approach to property rights through a prism of a geosystem services that would value resources in relation to their broader geological context).

246. Bradbrook & Rønne, *supra* note 6, at 311.

247. *See* Matthews, *supra* note 16 (discussing the current financial disincentives for private equity and start-ups to invest in geothermal energy resources). This is especially true for geothermal energy development, which will require large-scale and long-term capital investment. OBERBECK, *supra* note 21, at 46. "The risks for such investment must be reduced from present unfavorable levels to attract private capital. An initial deterrent to investment is the unresolved question of resource ownership." *Id.*

248. *See, e.g.*, Gulf Prod. Co. v. Cont'l Oil Co., 164 S.W.2d 488 (Tex. 1942).

249. *Cf.* Jeremy Waldron, *Property and Ownership*, STAN. ENCYC. PHIL. https://plato.stanford.edu/entries/property/ (Mar. 21, 2020) [https://perma.cc/YGW9-PHVJ]; Sullivan et al., *supra* note 239, at 35.

250. *Cf.* Sullivan et al., *supra* note 239, at 33.

251. *See id.* at 37 (asserting that "[p]roperty rights, not credit, play a crucial role in determining entrepreneurs' levels of investment").

252. *See, e.g.*, Sullivan et al., *supra* note 239, at 31.

253. *See generally* Barry Barton, *The Common Law of Subsurface Activity: General Principles and Current Problems*, *in* THE LAW OF ENERGY UNDERGROUND: UNDERSTANDING NEW DEVELOPMENTS IN SUBSURFACE PRODUCTION, TRANSMISSION, AND STORAGE 21, 21–22 (Donald N. Zillman, Aileen McHarg, Adrian Bradbrook & Lila K. Barrera-Hernández eds., 2014).

Ownership, as a practical concept, is often styled as a dichotomy with property being held either by government or privately.[254] Government typically refers to a national, state, or local representative body, or even "the people," though, in some countries it also could be styled as the monarchy.[255] When property is held by the government, the notion is that it is held in trust, on behalf of, or for the benefit of the populace of that jurisdiction.[256] In contrast, private ownership denotes concentration of title or rights in an individual, collective, or entity like a corporation, and where the broader public is excluded from the benefits of that proprietorship.[257]

Despite this dichotomy, not everything that we regulate is subject to ownership; and not all regulated natural resources have an identifiable owner. Fish stock and fisheries, for example, have not been privatized or subjected to any form of ownership.[258] In fact, fishing unions that sought to limit entry and establish harvesting limits during the 1950s were prosecuted by the U.S. Department of Justice and found in violation of the Sherman Antitrust Act.[259] Thus, wild fish in the United States have been treated as a part of the commons and treated as either a broadly shared or open access resource.[260] Still, these fisheries are commonly regulated to prevent a tragedy of the commons effect[261]—to avoid overfishing and promote sustainability.[262] More recent conservation innovations include individual transferable quotas in which the quotas function as transferable property rights, albeit maintaining the non-ownership status of the fish.[263] Other examples of natural resources that are regulated but unowned include air, wind, solar energy, migratory birds, and the atmosphere.[264]

To better understand whether and how ownership and regulation might apply to geothermal energy resources, the following Section reviews various ownership principles and approaches and explores their relevance to such resources.

254. *See, e.g.*, *id.*

255. *See, e.g.*, James L. Huffman, *Why Liberating the Public Trust Doctrine Is Bad for the Public*, 45 ENV'T L. 337, 361 (2015).

256. *See* Alexandra Klass, *Renewable Energy and the Public Trust Doctrine*, 45 U.C.D. L. REV. 1021, 1023 (2012).

257. Waldron, *supra* note 249.

258. *See generally* Adler, *supra* note 245.

259. *See, e.g.*, Manaka v. Monterey Sardine Indus., Inc., 41 F. Supp. 531, 536 (N.D. Cal. 1941); Gulf Coast Shrimpers & Oystermans Ass'n v. United States, 236 F.2d 658–59 (5th Cir. 1956); *see generally* Adler, *supra* note 245, at 4.

260. *See infra* notes 426–34 for a discussion of common pool and open access resources.

261. *See infra* notes 432–36 for a discussion of the tragedy of the commons.

262. For example, governments and regulatory bodies often designate maximum harvest quotas and fish size limits, restrictions on allowable types of fishing gear and fishing seasons, protected zones, and other constraints in order to maintain healthy fisheries and habitats. *See* Adler, *supra* note 245, at 14 (asserting that "the dominant management approach of the past several decades has been the use of government regulation" and referencing the Magnuson Fishery Conservation and Management Act, 16 U.S.C. §§ 1801–82, as the "primary federal statute governing fishery management" in the United States). The success rates of such restrictions, however, have been challenged. *See, e.g.*, Alison Rieser, *Property Rights and Ecosystem Management in U.S. Fisheries: Contracting for the Commons?*, 24 ECOLOGY L.Q. 813, 813 (1997) (asserting that government-led regulations have been a "spectacular failure"). *See also* Jonathan H. Adler & Nathaniel Stewart, *Learning How to Fish: Catch Shares and the Future of Fishery Conservation*, 31 UCLA J. ENV'T L. & POL. 150, 162 (2013).

263. Adler, *supra* note 245, at 17.

264. *See, e.g.*, Clean Air Act, 42 U.S.C. § 7401; Migratory Bird Act, 42 U.S.C. §§ 703–12.

B. Private Property Rights in Geothermal Energy

Under basic market theory, markets work most effectively when private actors own and control property in accordance with their interests.[265] Thus, the ability to recognize private ownership rights in natural resources is regarded as essential for the system to function properly.[266] Ascribing property rights in land and subsurface minerals has become a mainstay of the American economic system.[267] Yet, ownership in natural resources, as well as other property interests, are not absolute. In most cases, ownership rights in a thing are constrained when their exercise interferes with the correlative rights of others, or of the competing interests of the public at large.[268] Thus, even in market-based regimes, ownership rights have often been diminished to recognize and accommodate the rights of others.[269]

In addition, not all natural resources can be easily subjected to private ownership due to their unique qualities and characteristics. Solar energy and wind, for example, are incapable of being owned directly due to the practical inability to cordon off these resources or control their movement.[270] Like solar and wind, the physical characteristics of geothermal energy challenges efforts at privatization.[271]

Geothermal energy manifests as an invisible and intangible characteristic or quality of subsurface formations in the form of heat.[272] Unlike coal, timber, oil, or water, all of which are physical and tangible natural resources that can be extracted in their physical form, extracting geothermal energy requires either a physical medium that can contain and transport the heat, like water, or technology that will convert the resource into another, more readily useable energy form, like electrical energy.[273]

265. *See* Sullivan et al., *supra* note 239, at 34.

266. *See* SAFIA AGGARWAL & KENT ELBOW, U.S. AGENCY FOR INT'L DEV., THE ROLE OF PROPERTY RIGHTS IN NATURAL RESOURCE MANAGEMENT, GOOD GOVERNANCE AND EMPOWERMENT OF THE RURAL POOR 2 (2006), https://www.land-links.org/wp-content/uploads/2016/09/USAID_Land_Tenure_Property_Rights_and_NRM_Report.pdf [https://perma.cc/2LUG-D8B9].

267. *See, e.g.*, Joseph E. Pogue, *The Economic Structure of the American Petroleum Industry*, 21 BULL. AM. ASS'N PETROLEUM GEOLOGISTS 149, 151 (1937).

268. *See, e.g.*, Ryan C. Moore, *What Is The Correlative Rights Doctrine and How Is It Related to the Rule of Capture?*, PHEASANT ENERGY, https://www.pheasantenergy.com/correlative-rights-doctrine/ (Oct. 17, 2024) [https://perma.cc/HL59-2LMK].

269. *See id.*

270. *See* Cole & Ostrom, *supra* note 165, at 45–46

271. *Cf.* CORINNA ABESSER, DAVID SCHOFIELD, JON BUSBY, HELEN BONSOR & ROB WARD, BRITISH GEOLOGICAL SURVEY, WHO OWNS (GEOTHERMAL) HEAT? 2 (November 2018).

272. *Id.* at 2–3.

273. *See* Bradbrook & Rønne, *supra* note 6, at 313 (asserting that "minerals, oil, and gas can be utilized directly, while the geothermal resource can only be exploited indirectly by means of steam or water which conveys the heat energy to the land surface"); *see also Electricity Generation*, U.S. DEP'T OF ENERGY, https://www.energy.gov/eere/geothermal/electricity-generation (last visited Mar. 5, 2025) [https://perma.cc/THG7-NDPA] (discussing various approaches for converting geothermal energy into electricity); *Geothermal Electricity Production Basics*, NAT'L RENEWABLE ENERGY LAB'Y, U.S. DEP'T OF ENERGY, https://www.nrel.gov/research/re-geo-elec-production.html (last visited Mar. 5, 2025) [https://perma.cc/B6H6-ZGA4] (discussing various approaches for converting geothermal energy into electricity).

The following Section explores various aspects of private ownership rights applied to various natural resources. It discusses a number of ownership approaches and their practical application, while considering their relevance and applicability to geothermal energy.

1. Private Property and Tort Law

Private ownership is traditionally defined in terms of property rights and interests. Yet, liability for interfering with such rights and interests is typically expressed through tort law, which is used to provide redress for the wrongful conduct of others.[274] Two of the more common tort actions used to ensure property rights, and especially in the context of land and natural resources, are trespass and nuisance.

a. Trespass

i. Overview of Trespass Law

A trespass to land is the wrongful interference with another person's real property rights committed by entering the property without permission.[275] With few exceptions, a trespass can occur on, beneath, or above the surface of the land,[276] as well as on any structure found on the property.[277]

Trespass is actionable so long as the trespasser deliberately enters the land or knows that there is a high probability that the intrusion will occur, regardless of whether or not the trespasser wants to intrude onto the property or to cause a wrongful or harmful outcome.[278] In other words, even an innocent or accidental entry onto someone's property can be an actionable trespass where someone crosses onto a private domain.[279] Moreover, an unlawful trespass can be found

274. *See, e.g.*, RESTATEMENT (SECOND) OF TORTS § 158 (AM. L. INST. 1965).

275. Under the Restatement (Second) of Torts § 158, a trespass occurs where someone "intentionally (a) enters land in the possession of the other, or causes a thing or a third person to do so, or (b) remains on the land, or (c) fails to remove from the land a thing which he is under a duty to remove." *Id.* A trespass is subject to liability "irrespective of whether [the trespasser] thereby causes harm to any legally protected interest of the other." *Id.*; s*ee also* RESTATEMENT (SECOND) OF TORTS § 163 (AM. L. INST. 1965) (discussing "Intended Intrusions Causing No Harm").

276. RESTATEMENT (SECOND) OF TORTS § 159 (AM. L. INST. 1965) (asserting that a trespass can occur "on, beneath, or above the surface of the earth").

277. *Id.* at cmt. b (noting that "[t]he phrase 'surface of the earth' includes soil, water, trees, and other growths, and any structures on the land or affixed to it").

278. Watson v. Brazos Elec. Power Co-op., Inc., 918 S.W.2d 639, 646 (Tex. App. Ct. 1996), *writ denied*, (stating "unauthorized entry upon land of another is a trespass and the intent or motive prompting the trespass is immaterial"); RESTATEMENT (SECOND) OF TORTS § 163 cmt. b (AM. L. INST. 1965) (providing that "[t]he intention which is required to make the actor liable under the rule stated in this Section is an intention to enter upon the particular piece of land in question, irrespective of whether the actor knows or should know that he is not entitled to enter. It is, therefore, immaterial whether or not he honestly and reasonably believes that the land is his own, or that he has the consent of the possessor or of a third person having power to give consent on his behalf, or that he has a mistaken belief that he has some other privilege to enter").

279. *Watson*, 918 S.W.2d at 646.

where the trespass occurred negligently or as a result of an abnormally dangerous activity.[280]

The entry, however, does not need to be achieved by the person accused of the trespass.[281] It can also occur as a result of an activity or thing managed or controlled by that person.[282] Thus, for example, rocks blown onto a neighboring property as a result of nearby blasting could be deemed a trespass.[283] Similarly, concussion and vibration damage caused by the use of explosives on a neighboring property, even absent a showing of negligence, may constitute an actionable trespass.[284] Interestingly, in a case involving alleged migration of injected wastewater, the Texas Supreme Court held that a permit from a state agency authorizing the defendant to inject wastewater on his property did not immunize the defendant from civil tort liability if the injected wastewater were to migrate underneath the plaintiff's adjacent property.[285]

ii. Trespass and Geothermal Energy Resources

In the context of geothermal energy production, a trespass could occur where components of the energy project's extraction or conversion processes intrude onto or under a neighboring property. For example, chemicals, non-native water, and other fluids could migrate across a boundary line and underneath a non-target adjacent property.[286] This could occur when these components are used in either the heat harvesting processes or in the context of enhanced geothermal energy recovery activities, which often use techniques developed in the oil and gas industry.[287] One of these techniques, hydraulic fracturing,[288] can cause fractures to traverse property boundaries.

280. RESTATEMENT (SECOND) OF TORTS § 165 (AM. L. INST. 1965) (asserting that "[o]ne who recklessly or negligently, or as a result of an abnormally dangerous activity, enters land in the possession of another or causes a thing or third person so to enter is subject to liability to the possessor if, but only if, his presence or the presence of the thing or the third person upon the land causes harm to the land, to the possessor, or to a thing or a third person in whose security the possessor has a legally protected interest").

281. *Id.* § 158 cmt. b (AM. L. INST. 1965) (stating that trespass may include "the presence upon the land of a third person or thing which the actor has caused to be or to remain there").

282. *Id.* at cmt. i (AM. L. INST. 1965) (stating that a trespass may include "throwing, propelling, or placing" a thing on, above, or below the land).

283. Asheville Constr. Co. v. Southern Ry. Co., 19 F.2d 32, 34 (4th Cir. 1927); *see also* Smith v. Lockheed Propulsion Co., 56 Cal. Rep. 2d 128, 132 (Cal. Ct. App. 1967) (stating "[a]ctionable trespass may be committed indirectly through concussions or vibrations activated by defendant's conduct").

284. Wallace v. A.H. Guion & Co., 117 S.E.2d 3359, 356 (S.C. 1960).

285. FPL Farming Ltd. v. Env't Processing Sys., L.C., 351 S.W.3d 306, 310–11 (Tex. 2011). In a follow up case on the same matter, the Texas Supreme Court declined "to decide whether Texas law recognizes a trespass cause of action for deep subsurface water migration," Env't Processing Sys., L.C. v. FPL Farming Ltd., 457 S.W.3d 414, 425 (Tex. 2015), but reaffirmed its prior ruling in *Coastal Oil & Gas Corp. v. Garza Energy Trust* that "[e]very unauthorized entry upon land of another is a trespass even if no damage is done or injury is slight, and gives a cause of action to the injured party." 268 S.W.3d 1, 12 n.36 (Tex. 2008).

286. *See* Squibb, *supra* note 21, at 229–30 (discussing the possibility of geothermal energy production-related fluids flowing across a property through fractures).

287. *Id.* at 222.

288. *See supra* note 105 and accompanying text; *see also* Rafal Moska, Krzysztof Labus & Piotr Kasza, *Hydraulic Fracturing in Enhanced Geothermal Systems—Field, Tectonic and Rock Mechanics Conditions—A Review*, 14 ENERGIES 5725 (2021).

Heat harvesting can not only cause fluids and fractures to migrate across property lines, but can also affect temperatures and thermal energy content in portions of the formation that lay across a property boundary.[289] This is possible because, as heat is extracted through a geothermal well, the temperature of the formation in the immediate vicinity of the well reduces in proportion to the heat that is being extracted plus the rate of natural replenishment.[290] While geothermal energy is constantly replenished,[291] if the extraction rate exceeds natural replenishment, the area surrounding the well's heat extraction zone will have a lower temperature than further afield.[292] This is more likely in shallow geothermal activities, such as occurs with direct use and geothermal heat pumps, where heat replenishment rates are much lower than in deeper locations and temperature fluctuations are more likely.[293] If the heat extraction zone of the well runs along the length of the well, or along pipes installed underground specifically to exploit the temperature differentials, the reduced heat area will extend radially from the well and pipes for some distance.[294] Whether any of these scenarios might result in an actionable trespass if they traversed a neighbor's property boundary has yet to be considered by any court or legislature in the United States.[295]

In comparison, instances of uninvited cross-border migration of fluids and fractures have occurred in the processes of extracting oil and gas resources. For example, waterflooding is a widely used technique in the secondary recovery process for stubborn oil and gas deposits.[296] In 1962, the Texas Supreme Court concluded in *Railroad Commission of Texas v. Manziel* that where the relevant state agency authorized waterflooding as a means to prevent waste and protect correlative rights, "or in the exercise of other powers within its jurisdiction," no trespass can occur if the lawfully injected material crosses into a neighboring tract.[297] The court concluded that "[t]he technical rules of trespass have no place in the consideration of the validity of the orders of the Commission."[298] In contrast, the Supreme Court of New Mexico reached the opposite conclusion in *Snyder Ranches, Inc. v. Oil Conservation Com'n of the State of N.M.*, albeit while

289. *See* M.K. Woodward, *Ownership of Interests in Oil and Gas*, 26 OHIO ST. L.J. 353, 355 (1965).

290. *See, e.g.*, *How Geothermal Energy Works*, *supra* note 6.

291. *See supra* note 7 and accompanying text.

292. *See* LADISLAUS RYBACH, GEOTHERMAL SUSTAINABILITY 2 (European Geothermal Congress, 2007), https://www.researchgate.net/profile/Ladislaus-Rybach/publication/228467384_Geothermal_Sustainability/links/004635278193a68013000000/Geothermal-Sustainability.pdf [https://perma.cc/S5YJ-2KA2].

293. *See* Alejandro García-Gil et al., *Governance of Shallow Geothermal Energy Resources*, 138 ENERGY POL'Y, Jan. 2020, at 3 (discussing "negative thermal interference" in shallow geothermal energy extraction activities, including ground source heat pumps); RYBACH, *supra* note 292 (describing and calculating temperature changes in the ground around borehole heat exchangers used in geothermal heat pumps).

294. RYBACH, *supra* note 292, at 2 (discussing the "cylindrically shaped heat sink in the ground' in the area immediately surrounding borehole heat exchangers).

295. *Cf.* Squibb, *supra* note 21, at 229.

296. Secondary recovery mechanisms for oil and gas deposits are designed to "extend a field's productive life generally by injecting water or gas to displace oil and drive it to a production wellbore, resulting in the recovery of 20 to 40 percent of the original oil in place." *Enhanced Oil Recovery*, OFF. OF FOSSIL ENERGY AND CARBON MGMT., U.S. DEP'T OF ENERGY, https://www.energy.gov/fecm/enhanced-oil-recovery (last visited Mar. 5, 2025) [https://perma.cc/XU34-7VQV].

297. R.R. Comm'n of Tex. v. Manziel, 361 S.W.2d 560, 568 (Tex. 1962).

298. *Id.* at 568–69.

using a hypothetical situation, when it concluded in 1990 that "[t]he issuance of a license by the State does not authorize trespass or other tortious conduct by the licensee, nor does such license immunize the licensee from liability for negligence or nuisance which flows from the licensed activity.[299]

In the context of hydraulic fracturing, the Texas Supreme Court suggested in dicta that oil and gas disputes are precluded from trespass claims because the resource extraction process is subject to the rule of capture.[300] In its 2008 case of *Coastal Oil v. Garza Energy Trust*, the court concluded that the owner of a neighboring property, whose subsurface was breached both by fracking fluid and fractures, was disallowed from raising a trespass claim by the rule of capture.[301] The court argued that so long as the extraction process was not deliberately designed to exploit the resources underlying a neighboring tract (*e.g.*, through use of a slant well) or otherwise "illegal, malicious, reckless, or intended to harm another without commercial justification," any fracking fluid or fractures appearing underneath a neighboring tract were not actionable.[302] In contrast, in *Stone v. Chesapeake Appalachia, LLC*, a 2013 case from the U.S. District Court in West Virginia, the court found the exact opposite.[303] In denying a summary judgment motion, that court held that hydraulic fracturing that reaches a neighboring property without that owner's consent constitutes an actionable trespass that is not protected by the rule of capture.[304] In its decision, the U.S. District Court severely criticized the reasoning of the Texas Supreme Court's *Garza* decision asserting that "[t]he *Garza* opinion gives oil and gas operators a blank check to steal from the small landowner."[305] That court concluded that, in applying West Virginia law to the matter, it believed "that the West Virginia Supreme Court of Appeals would find, that hydraulic fracturing under the land of a neighboring property without that party's consent is not protected by the 'rule of capture,' but rather constitutes an actionable trespass."[306] While that decision was vacated upon a joint motion filed by the parties,[307] in 2020 in *Briggs v. Southwestern Energy Production Company*, the Pennsylvania Supreme Court adopted most of the reasoning of the West Virginia U.S. District Court, but only where the aggrieved party could prove that the hydraulic fracturing process caused an actual physical intrusion onto the landowner's property,[308] a hurdle that, even with today's technology, is not insignificant.

As a result of these few and inconsistent examples, it is difficult to reach any conclusion regarding whether a subsurface trespass claim in the oil and gas

299. Snyder Ranches, Inc. v. Oil Conservation Comm'n, 798 P.2d N.M. 587, 590 (N.M. 1990).
300. *See infra* notes 390–99 and accompanying text (describing the rule of capture).
301. Coastal Oil & Gas Corp. v. Garza Energy Trust, 268 S.W.3d. 1, 17 (Tex 2008) (asserting that "damages for drainage by hydraulic fracturing are precluded by the rule of capture").
302. *Id.*
303. Stone v. Chesapeake Appalachia, LLC, No. 5:12-CV-102, 2013 U.S. Dist. LEXIS 71121, at *23 (N.D. W. Va. Apr. 10, 2013).
304. *Id.*
305. *Id.* at *17–18.
306. *Id.* at *23.
307. Ord. Granting Joint Motion, Stone v. Chesapeake Appalachia, LLC, (No. 5:12-CV-102), 2013 U.S. Dist. LEXIS 185857, at *1 (N.D.W. Va. July 30, 2013).
308. Briggs v. Sw. Energy Prod. Co., 224 A.3d 334, 348 (Pa. 2020).

sector could or should be actionable. Too few court decisions have addressed the issues, and the few that have done so have reached diverging opinions. Moreover, no court has addressed a trespass involving a cross-border change in temperature.[309] As a result, it remains to be seen whether any of these cases may be instructive or influential in cases involving the extraction and development of geothermal energy.

b. Private Nuisance[310]

i. Overview of Private Nuisance Law

Nuisance refers to a conduct or activity occurring on one property that unreasonably interferes with the use or enjoyment of another's property.[311] Under contemporary American law, a private nuisance occurs where the external interference, most often by an incorporeal or non-trespassory invasion,[312] substantially affects the utility function of a particular property owner to the extent that it is unreasonable for the plaintiff to bear the harm without compensation.[313] The more common private nuisance cases usually involve activities that result in the "pollution of air, water, or land from dust, smoke, odors, chemicals, or noise."[314]

For a private nuisance to be actionable, it must be unreasonable and substantial, and either be intentional or the result of negligence or a strict liability activity.[315] For a nuisance to be unreasonable and substantial, it must be judged in relation to the reasonable expectations of an average person in the plaintiff's position.[316] Thus, not all interference with a neighboring property is unlawful. Rather, it depends on the circumstances, which include the nature of the activity causing the alleged nuisance, the frequency of the activity and resulting impact, the motive of the defendant, the plaintiff's level of sensitivity to such interference, and the character of the neighborhood in which the properties are found.[317]

In addition, in order for a plaintiff to sue on a private nuisance claim, the plaintiff must show that the defendant caused the nuisance intentionally, as a

309. *Cf.* Squibb, *supra* note 21, at 229.

310. For the purpose of this analysis, the focus is on private nuisance because the nuances between a private and public nuisance will likely be of little import for the purpose of assessing what property regime might be better suited to geothermal energy resources.

311. Timothy Swanson & Andreas Kontoleon, *Nuisance*, *in* 5 PROPERTY LAW AND ECONOMICS: ENCYCLOPEDIA OF LAW AND ECONOMICS 161, 161 (Boudewijn Bouchaert ed., 2010) (reviewing the meaning and definition of nuisance); *see also* Morgan v. High Penn Oil Co., 77 S.E.2d 682, 689 (N.C. 1953) (defining nuisance as "any substantial nontrespassory invasion of another's interest in the private use and enjoyment of land by any type of liability forming conduct is a private nuisance").

312. RESTATEMENT (SECOND) OF TORTS § 821D (AM. L. INST. 1979)

313. DAN B. DOBBS, PAUL T. HAYDEN & ELLEN M. BUBLICK, THE LAW OF TORTS § 399 (2d ed. 2023). In contrast, a public nuisance arises where the externality interferes with a right held in common by the general public, such as in public health and safety or in the use of public facilities. RESTATEMENT (SECOND) OF TORTS § 821B (AM. L. INST. 1979).

314. DOBBS ET AL., *supra* note 313, § 399.

315. *See id.*

316. *See id.*

317. *See* Swanson & Kontoleon, *supra* note 311, at 162; DOBBS ET AL., *supra* note 313, § 401.

result of negligence, or as a strict liability activity.[318] Intentional conduct can be established either where the evidence shows that the defendant deliberately caused the nuisance to impact the plaintiff's land, or that they were substantially certain that their activities would result in that outcome.[319] Negligence by a defendant in the context of a nuisance claim requires similar evidence and analysis as would apply in a standard negligence case, namely showing that the defendant had a duty to act in a certain manner and failed to do so, that the defendant's conduct was the proximate cause of the nuisance, and that the nuisance resulted in damages to the plaintiff.[320] As a result, nuisance claims based on negligence might be characterized as negligence claims that result in harm to the use and enjoyment of land rather than to a person.[321] Finally, strict liability for nuisance may be applied only where the evidence shows that the defendant's conduct, which resulted in the nuisance, was an abnormally dangerous condition or activity.[322]

For example, in *Scribner v. Summers*, the Second Circuit concluded that a metal treatment business that caused high levels of barium to contaminate an adjacent property constituted a private nuisance.[323] The court specifically referenced the company's knowledge: that the neighboring tract was contaminated with high levels of barium; that the contamination of the neighboring tract was substantially certain to result from its operations; of the unreasonableness of processing barium on its property while knowing that barium is a hazardous waste; that the contamination interfered with the adjacent landowners' use and enjoyment of their land; and that the business' conduct was the cause of the barium invasion of the plaintiff's property.[324]

Similarly, in *West v. Jewett and Noonan Transportation, Inc.*, the Supreme Judicial Court of Maine concluded that oil and kerosene spilled from an overturned tanker onto plaintiff's land constituted an unlawful private nuisance.[325] The court noted that because the spill affected the physical condition of the plaintiff's land, the impact was more than "mere physical discomfort or mental annoyance."[326] Moreover, it stated that because interest by third parties in developing the property disappeared after the spill, there was no question about the substantial or significant character of the interference.[327] Notably, the Maine court also held that a landowner was not required to establish a specific

318. RESTATEMENT (SECOND) OF TORTS § 822 (AM. L. INST. 1979) (defining:

[L]iability for a private nuisance if, but only if, [one's] conduct is a legal cause of an invasion of another's interest in the private use and enjoyment of land, and the invasion is either (a) intentional and unreasonable, or (b) unintentional and otherwise actionable under the rules controlling liability for negligent or reckless conduct, or for abnormally dangerous conditions or activities).

319. DOBBS ET AL., *supra* note 313, § 400.

320. *See id.*

321. *Id.*

322. *Id.*; RESTATEMENT (SECOND) OF TORTS § 822 (AM. L. INST. 1979).

323. 84 F.3d 554, 559 (2d Cir. 1996).

324. *Id*.

325. 189 A.3d 277, 282 (Me. 2018).

326. *Id.* (internal quotation omitted).

327. *Id.*

diminution in market value of their property in order to successfully prosecute a nuisance claim.[328]

In a unique example, in *Vogel v. Grant-Lafayette Elec. Co-op.*, the Supreme Court of Wisconsin held that nuisance law can apply to stray voltage claims because unwarranted levels of stray voltage can constitute an interference with the use and enjoyment of private property.[329] Thus, the court held that a private nuisance action can be maintained for injuries to cows on a dairy farm caused by stray voltage originating from a local electricity distributor.[330]

ii. Private Nuisance and Geothermal Energy Resources

In the case of geothermal energy resources, many of the same scenarios discussed above under trespass also might be relevant for a private nuisance claim—hydraulic fractures, as well as chemicals, non-native water, and other fluids used in the heat harvesting, conversion, or storage processes, could migrate to an adjacent property. Where such an invasion, directly or indirectly, interferes with the use and enjoyment of the neighboring tract, it could be the basis for a private nuisance claim. A nuisance claim, however, could be more challenging to sustain than a trespass claim given that the claimant must show that interference is unreasonable and substantial, and is either intentional or the result of negligence or a strict liability activity. None are insubstantial thresholds.

As noted above, not all interferences with a neighboring property rise to the level of unreasonable and substantial.[331] Rather, the adjudicator of the facts would be asked to evaluate the circumstances of the specific instance—such as the nature of the geothermal extraction, conversion, or storage activity; the frequency and impact of the interference, such as cross-border, subsurface temperature fluctuation, or cross-border leakage of fluids used in the activity; defendant's motives in operating the geothermal energy activity; plaintiff's sensitivity to the interference from the geothermal operation; and the character of the neighborhood in which the geothermal operation takes place—in order to determine whether the interference is unreasonable and substantial.[332]

Similarly, determining whether the defendant's conduct was intentional or the result of negligence or strict liability-related conduct also requires an assessment of the facts and conditions.[333] While it is probably unlikely that a geothermal extraction, conversion, or storage operator would deliberately wish to cause

328. *Id.* at 281–82.

329. 548 N.W.2d 829, 834 (Wis. 1996). The Wisconsin court, however, ruled that not all scenarios of excessive levels of stray voltage constitute a nuisance. Rather, "[t]he determination of whether stray voltage unreasonably interferes with a person's interest in the private use and enjoyment of land is reserved for the trier of fact." *Id.*

330. *Id.*; *see also* Martins v. Interstate Power Co., 652 N.W.2d 657, 663 (Iowa 2002).

331. *See supra* notes 315–17 and accompanying text.

332. *See* RESTATEMENT (SECOND) OF TORTS § 821F cmts. c, g (AM. L. INST. 1979) (discussing the assessment of significant harm and duration or frequency of the invasion for purposes of determining a nuisance); RESTATEMENT (SECOND) OF TORTS § 826 cmts. b, d, e (AM. L. INST. 1979) (discussing the assessment of unreasonableness, gravity of the harm, and utility of the conduct).

333. *See supra* notes 318–20 and accompanying text.

a nuisance to a nearby landowner, were it possible to show that the defendant was substantially certain that the activities would result in the claimed nuisance, or that the defendant operated the geothermal energy project negligently, this element could be fulfilled. Whether the implementation of a geothermal energy harvesting, conversion, or storage operation constitutes a strict liability activity, however, has not been judicially decided.[334] It is noteworthy, though, that the California Court of Appeals in the Second District declined to rule, as a matter of law, that oil drilling is an ultrahazardous activity that requires application of strict liability.[335] Similarly, the U.S. District Court for the Middle District of Pennsylvania ruled that natural gas drilling, including through the use of hydraulic fracturing, neither constitutes an abnormally dangerous activity nor requires application of strict liability.[336]

In the only case found in which a private nuisance claim was raised against a geothermal power plant, *Layton v. Yankee Caithness Joint Venture, L.P.*, the U.S. District Court for the District of Nevada concluded that the plaintiff failed to meet their burden of proof to support the allegations.[337] Thus, no court has ruled on the merits of a private nuisance claim involving geothermal energy resources, making any conclusion a matter of prognostication.

c. Conclusion

Property-based, common law torts rules can be used to resolve certain disputes related to the ownership, use, and exploitation of privately held land.[338] Trespass can help resolve interference with the use and enjoyment of real property resulting from wrongful invasion by another, while nuisance can provide a cause of action for non-trespassory, unreasonable interference with such property.[339]

To protect one's property rights from unwanted interference, these rules can certainly be useful mechanisms. As a practical matter, however, they rely on the existence of property rights in geothermal energy resources. Moreover, they may be difficult to implement in the context of geothermal energy, in part, because of the complexities associated with establishing liability for violations that occur far below the surface. At depths of miles or even dozens of yards below the surface, securing the evidence needed to support claims of violations may be economically or technologically challenging.[340] In addition, because such a

334. *Cf.* A. Dan Tarlock & Richard L. Waller, *An Environmental Overview of Geothermal Resources Development*, 13 LAND & WATER L. REV. 289, 312 (1977).

335. Travelers Indem. Co. v. City of Redondo Beach, 34 Cal. Rptr. 2d 337, 344 (1994). Referencing Section 520 of the Restatement (Second) of Torts, the court asserted that the determination of whether an activity is ultrahazardous for purposes of strict liability was question of fact. *Id.*

336. Ely v. Cabot Oil & Gas Corp., 38 F. Supp. 3d 518, 534 (M.D. Pa. 2014).

337. Layton v. Yankee Caithness Joint Venture, L.P., 774 F. Supp. 576, 577 (D. Nev. 1991). In the case, plaintiff homeowners claimed that noise and hydrogen sulfide odor emanating from the geothermal power plant constituted a private nuisance affecting human health, drinking water quality, and property values, and was "offensive to the senses." *Id.*

338. *See, e.g.*, Martins v. Interstate Power Co., 652 N.W.2d 657, 663 (Iowa 2002).

339. *See, e.g.*, *id.*; Briggs v. Sw. Energy Prod. Co., 224 A.3d 334, 341 (2020).

340. *See, e.g.*, *supra* note 308 and accompanying text.

regime is grounded in state common law,[341] these rules may not be ideal for the development or exploitation of geothermal resources as they could result in fifty variations that could constrain the private sector's ability to expand operations and investments across state lines. Thus, property-based tort regimes may not be ideal for geothermal resources.

2. *The* Ad Coelum *Doctrine*

a. Overview of the *Ad Coelum* Doctrine

The *ad coelum* doctrine asserts that landowners have property rights extending indefinitely above and below their land.[342] In its purest form, its bounds were said to extend "to the periphery of the universe,"[343] meaning it encompassed the area above the land up to the sky and beyond, and the space below the land down to the earth's core, including all minerals and other substances that may be found there.[344] Thus, the doctrine has been used to support ownership of all valuable substances found in the subsurface, especially immovable minerals, like coal and ore.[345] The doctrine even extends to pore spaces within the Earth—the empty space between the grains of sand, dirt, and other material comprising a geologic formation.[346]

One of the better known applications of this doctrine occurred in *Edwards v. Sims*[347] involving ownership of the Great Onyx Cave, now part of Mammoth Cave National Park in Kentucky.[348] In that case, Kentucky's Supreme Court ruled that the portion of an underground cave system located below a

341. *See, e.g.*, Terence Daintith, *The Common Law of Underground Energy Resources in the United States*, *in* THE LAW OF ENERGY UNDERGROUND: UNDERSTANDING NEW DEVELOPMENTS IN SUBSURFACE PRODUCTION, TRANSMISSION, AND STORAGE 37–58, 46. (Donald N. Zillman, Aileen McHarg, Adrian Bradbrook & Lila K. Barrera-Hernández eds., 2014).

342. Barton, *supra* note 253, at 22. The phrase *ad coelum* is an abbreviation of a Latin maxim that scholars have developed to encapsulate the notion that the doctrine espouses. The full Latin phrase is *cujus est solum, ejus est usque ad coelum et ad inferos*, which translates to "to whom the soil belongs, to that person it belongs all the way to the skies and the depths." *Id.* The *ad coelum* doctrine is occasionally referred to as the *cujus est solum* doctrine. *See, e.g.*, Sho Sato, Thomas D. Crocker & L.J.P. Muffler, *Property Rights to Geothermal Resources—Part I*, 6 ECOLOGY L.Q. 247, 309 (1977).

343. United States v. Causby, 328 U.S. 256, 260 (1946). A decade prior to the *Causby* case, in a trespass claim involving private airplane overflights, the U.S. Court of Appeals for the Ninth Circuit asserted in *Hinman v. Pacific Air Transport* that the *ad coelum* doctrine did not literally extend to the heavens, but rather "simply meant that the owner of the land could use the overlying space to such an extent as he was able." 84 F.2d 755, 757 (9th Cir. 1936), *cert. denied*, 300 U.S. 654 (1937). Thus, airplanes flying over private property do not constitute a trespass unless the property owner was already using the airspace in a way that is "necessary or convenient to the enjoyment of the land." *Id.*

344. Barton, *supra* note 253, at 23.

345. Blake Grow, *A Modern Approach to the Ad Coelum Doctrine and Trespass-by-Fracture*, 11 GEO. WASH. J. ENERGY & ENV'T L. 78, 80 (2021).

346. Trae Gray, *A 2015 Analysis and Update on U.S. Pore Space Law—The Necessity of Proceeding Cautiously with Respect to the "Stick" Known as Pore Space*, 1 OIL & GAS, NAT. RES. & ENERGY J. 277, 279, 337 (2015).

347. 24 S.W.2d 619 (Ky. 1929).

348. *Mammoth Cave: Timeline*, NAT'L PARK SERV., https://www.nps.gov/maca/learn/historyculture/timeline.htm (last visited Oct 17, 2024) [https://perma.cc/AP72-VGMX].

landowner's tract is owned by that landowner, regardless of where the entrance to the cave may be found:

> *It is that the owner of realty, unless there has been a division of the estate, is entitled to the free and unfettered control of his own land above, upon and beneath the surface. So whatever is in a direct line between the surface of the land and the center of the earth belongs to the owner of the surface.*[349]

Although the doctrine has long been a part of U.S. common law jurisprudence,[350] its scope has been whittled down in response to changes in societal priorities and emerging technologies.[351] Already in 1937, as air traffic became a mainstay of national transportation, the 9th Circuit Court of Appeals ruled that landowners have an ownership right to the air space overlying their property only to the extent that they actually used the space for the enjoyment of land.[352] A decade later, in response to a takings claim raised against the U.S. government for military flights using an airport located adjacent to the plaintiff's home, the U.S. Supreme Court asserted that the *ad coelum* doctrine only afforded the landowner "as much of the space above the ground as they can occupy or use in connection with the land."[353]

Defining these height limits further, regulations adopted by the Secretary of Commerce following adoption of the 1926 Air Commerce Act established a required minimum flying elevation of 1,000 feet over cities, towns, and settlements, and 500 feet over all other land.[354] More recently, under the FAA Reauthorization Act of 2018, the federal government restricted recreational drones to no more than 400 feet above ground level.[355] As these federal regulations have

349. *Edwards*, 24 S.W.2d at 620.

350. John G. Sprankling, *Owning the Center of the Earth*, 55 UCLA L. REV. 979, 989–91 (2008) (asserting that "[b]y the end of the nineteenth century, judges and scholars had repeated Blackstone's assertion so frequently that it was assumed to be a rule of American law" and that "[m]ost modern legal texts continue to endorse the center of the earth theory"); DALE A. WHITMAN, ANN M. BURKHART, R. WILSON FREYERMUTH & TROY A. RULE, THE LAW OF PROPERTY 329 (4th ed. 2019) (stating that "ownership is viewed as extending downward indefinitely," though recognizing that "the surface owner's rights in the superjacent air space are subject to a public easement for air travel"); *see also* W. Va. Dep't of Transp. v. Veach, 799 S.E.2d 78, 93 (2017) (quoting two West Virginia Supreme Court decisions from 1968 and 2013 to support the proposition that "[t]he starting point of all real estate law is that 'a parcel of land includes all interests and estates therein from the center of the earth to the heavens'").

351. Sato et al., *supra* note 342, at 310–16 (discussing the "relaxation" of the doctrine in American jurisprudence).

352. Hinman v. Pacific Air Transport, 84 F.2d 755, 757 (9th Cir. 1936), *cert. denied*, 300 U.S. 654 (1937).

353. United States v. Causby, 328 U.S. 256, 264 (1947). The Court further criticized the *ad coelum* doctrine's scope and stated that "doctrine has no place in the modern world," *Id.* at 261. *See* Hirokawa, *supra* note 245, at 10410 (discussing the *Causby* decision and removal of boundaries above and below the land surface in the context of geosystem services).

354. DEP'T OF COM. AERONAUTICS BRANCH, INFO. BULL. NO. 7, AIR COMMERCE REGULATIONS, CH. 7, § 74(G) (1928).

355. FAA Reauthorization Act of 2018, Pub. L. No. 115-254, 132 Stat. 3289. Interestingly, various states have imposed their own recreational drone height limitations on recreational drones. Nevada set the maximum flying height at 250 feet above the ground, while Tennessee set it at 500 feet. NEV. REV. STAT. ANN. § 493.109 (West 2015); TENN. CODE ANN. § 39-14-405 (West 2017).

never been successfully challenged in relation to the *ad coelum* doctrine,[356] they support the continuing diminution of property rights in overlying air space.

In the context of wind, there are no cases on record connecting land ownership, whether under the *ad coelum* doctrine or otherwise, to ownership of the wind located immediately above a particular tract of land.[357] Moreover, the few cases that have addressed so-called "wind rights" have viewed them as something less than full property rights.[358]

Moving in the other direction, below the surface, the scope of the doctrine also has been diminished.[359] In particular, application of the *ad coelum* doctrine to fugacious natural resources, such as water, oil, and gas, has been tempered by the recognition of competing principles that exclude certain subsurface resources

356. See Lora D. Lashbrook, *Ad Coelum Maxim as Applied to Aviation Law*, 21 NOTRE DAME L. REV. 143, 144 (1946) (noting that "[n]o court has ever said that ownership of the air extends upward to an indefinite distance, since such a question has never been presented to a court for decision").

357. *Cf.* Yael R. Lifshitz, *The Geometry of Property*, 71 U. TORONTO L.J. 480, 481 (2021).

358. In 2009 in *Romero v. Bernell*, where a landowner sought to severe a wind estate in a partition hearing, the U.S. District Court for the District of New Mexico concluded that, "[w]ind is never embedded in the real estate; rather, it is more like water or wild animals which traverse the surface and which do not belong to the fee owner until reduced to possession." 603 F. Supp. 2d 1333, 1335 (D.N.M. 2009). The court further asserted that "[t]he right to 'harvest' wind energy is, then, an inchoate interest in the land which does not become 'vested' until reduced to 'possession' by employing it for a useful purpose. Only after it is reduced to actual wind power can wind energy then be severed and/or quantified." *Id.* Similarly, in *Zimmerman v. Board of County Commissioners of Wabaunsee County*, a 2011 case involving a zoning ordinance prohibiting placement of commercial wind farms in the county, the Supreme Court of Kansas concluded that there was no violation of the Takings Clause because "interests such as developing, constructing, or operating [commercial wind energy conversion systems] were not vested rights." 293 Kan. 332, 349 (2011). Thus, these court decisions seem to indicate a preference for the rule of capture.

In contrast, although, not directly asserting a property right in wind, in 1997 in *Contra Costa Water District v. Vaquero Farms, Inc.*, the California Court of Appeals concluded that a "wind estate" could be severed from the fee estate in the context of an eminent domain proceedings. 68 Cal. Rptr. 2d 272, 277, 278 (Cal. Ct. App. 1997). That decision, however, was grounded primarily in the unique scope of California's eminent domain law, which permits authorized entities to acquire property for particular uses through eminent domain regardless of how limited or unusual the interest might be. *Id.* at 276.

More recently, in 2023, the 64th District Court in Hale County, Texas, concluded that under Texas state law, wind rights are a severable property interest that originates in the surface estate. Adolfo Pesquera, *$1.2M Win for San Antonio Law Firm: Santoyo Wehmeyer Secures Unique Verdict*, LAW.COM (May 16, 2023, 2:57 PM), https://www.law.com/texaslawyer/2023/05/16/1-2m-win-for-san-antonio-law-firm-santoyo-wehmeyer-secures-unique-verdict/?slreturn=20230616014139 [https://perma.cc/5MTX-Y8Q6]; Jeffrey A. Chester & Craig Duewall, *The Severability of Wind Rights from a Surface Estate*, XIII NAT'L L. REV. (July 11, 2023), https://www.natlawreview.com/article/severability-wind-rights-surface-estate [https://perma.cc/3JQW-8MPU]. In that case, the trial court also asserted that such rights can be subject to trespass claims and awarded trespass damages to the plaintiff, though it is unclear whether the severed wind rights relate only to the right to harvest the wind on a specific tract of land, or whether it extended ownership to the wind blowing over that property. If the former, the severed property interest might be better couched as an easement; if the latter, it would suggest application of the *ad ceolum* doctrine. *Id.* Hence, a number of state courts seem to suggest that some ownership rights can exist in a wind estate, though, it remains unclear whether that affords a right to access the wind from the particular property or something more.

359. For example, in *Boehringer v. Montalto*, the Supreme Court of New York in Westchester County ruled that a public sewer line 150 below the surface did not violate a deed covenant against encumbrances because:

> the old theory that the title of an owner of real property extends indefinitely upward and downward is no longer an accepted principle of law in its entirety. Title above the surface of the ground is now limited to the extent to which the owner of the soil may reasonably make use thereof. By analogy, the title of an owner of the soil will not be extended to a depth below ground beyond which the owner may not reasonably make use thereof.

254 N.Y.S. 276, 278 (N.Y. Sup. Ct. 1931).

from its scope.[360] For example, in the considerable majority of U.S. states, groundwater is excluded from a landowner's bundle of sticks and effectively is unowned or vested in the state, either in quasi-ownership terms or held in trust on behalf of the citizenry.[361] Thus, these states only provide users with a usufructuary right[362] to the groundwater in the context of one of the recognized groundwater rights regimes: prior appropriation,[363] correlative rights,[364] reasonable use,[365] or rule of capture.[366] In only a small handful of states (*e.g.*, Arkansas, Louisiana, and Texas) is groundwater affirmatively "owned" by the overlying landowner *in situ*.[367]

360. David Pierce, *Employing a Reservoir Community Analysis to Define and Marshal Correlative Rights in the Oil and Gas Reservoir*, 76 LA. L. REV. 787, 791 (2016).

361. *See, e.g.*, Frazier v. Brown, 12 Ohio St. 294, 308 (1861).

362. A usufruct is "[a] right for a certain period to use and enjoy the fruits of another's property without damaging or diminishing it, but allowing for any natural deterioration in the property over time." *Usufruct*, BLACK'S LAW DICTIONARY (12th ed. 2024). In the context of water, a usufructuary right provides the rights holder with the right to use the water, but not to own it. Christine A. Klein, *Groundwater Exceptionalism: The Disconnect Between Law and Science*, 71 EMORY L.J. 487, 548–49 (2022).

363. The prior appropriation doctrine for groundwater is followed by Idaho, New Mexico, Oregon, and a host of other mostly western states. *See* ALEXANDER BENNET ET AL., GROUNDWATER LAWS AND REGULATIONS: A PRELIMINARY SURVEY OF THIRTEEN U.S. STATES, VOL. I 142 (Gabriel Eckstein & Amy Hardberger eds., 2020), https://scholarship.law.tamu.edu/cgi/viewcontent.cgi?article=1006&context=nrs-publications [https://perma.cc/E8HF-PR4A]; ABIGAIL ADKINS ET AL., GROUNDWATER LAWS AND REGULATIONS: SURVEY OF SIXTEEN U.S. STATES, VOL. II 89, 225 (Gabriel Eckstein & Amy Hardberger eds., 2022), https://scholarship.law.tamu.edu/cgi/viewcontent.cgi?article=1011&context=nrs-publications [https://perma.cc/B5N6-QKKG]. Under the prior appropriation doctrine, groundwater users are allotted a usufructuary right (right of use) to groundwater based on a first in time, first in right system. When supplies become limited, those with junior rights must forego their allocation until all those with more senior rights get their full allocation. Christine A. Klein, *Water Bankruptcy*, 97 MINN. L. REV. 560, 569–70 (2012).

364. The correlative rights system is applied in California, Nebraska, and a few other states. *See* BENNET ET AL., *supra* note 363, at 10; ADKINS ET AL., *supra* note 363, at 9. Under the correlative rights doctrine, users are allotted a usufructuary right (right of use), but the right to extract and use groundwater is prioritized for use on overlying land by overlying landowners. Typically, the amount of groundwater that can be extracted is apportioned in relation to the size of the property overlying the aquifer. Use on non-overlying land is secondary and subject to availability. *See* Hannes D. Zetzsche, *Severance: Ownership of Land and the Right to Withdraw Groundwater in Nebraska*, 23 U. DENV. WATER L. REV. 193, 214–17 (2020).

365. Under the reasonable use doctrine, also known as the "American rule," groundwater is owned by the state. In states that follow this approach, which includes Alabama, Illinois, Missouri, and at least a dozen other U.S. states, users are allotted a usufructuary right (right of use), and the right to extract and use groundwater is prioritized for use on overlying land by overlying landowners. *See* BENNET ET AL., *supra* note 363, at 18, 73, 120. The amount of groundwater that can be extracted is limited by a reasonableness standard, albeit use on non-overlying land is often regarded as de facto unreasonable. *Id.*

366. The rule of capture for groundwater is employed in Indiana, Massachusetts, Maine, and Texas. *See* BENNET ET AL., *supra* note 363, at 89, 182; ADKINS ET AL., *supra* note 363, at 180. While the doctrine is most closely associated with Texas where groundwater is owned directly by the landowner, in the other three rule of capture states, the groundwater is owned by the state on behalf of its residents. *See* BENNET ET AL., *supra* note 363, at 89, 182; ADKINS ET AL., *supra* note 363, at 180. Under the rule of capture, ownership in the groundwater occurs only once the resource was captured. *See* BENNET ET AL., *supra* note 363, at 89, 182; ADKINS ET AL., *supra* note 363, at 180. It is noteworthy that some of these states characterize their groundwater regime using the deceptively titled rule of "absolute ownership" or "absolute dominion." *See* BENNET ET AL., *supra* note 363, at 89, 182; ADKINS ET AL., *supra* note 363, at 180. According to the Restatement (Second) of Torts § 857, in its Introductory Note on the Nature of Ground Water and Theories Concerning, the Restatement provides that, "[a]though framed in property language, the rule [of absolute ownership] was in reality a rule of capture, for a landowner's pump could induce water under the land of his neighbor to flow to his well—water that was in theory the neighbor's property while it remained in place." RESTATEMENT (SECOND) OF TORTS § 857 (AM. L. INST. 1979).

367. ARK. CODE ANN. § 15-22-911(h) (West 2023); LA. CIV. CODE ANN. art. 490 (West 2022); TEX. WATER CODE § 36.002(a) (West 2015).

With regard to subsurface oil and gas reserves, all jurisdictions in the United States have similarly done away with the *ad coelum* doctrine.[368] In its stead, they first adopted the rule of capture, which historically recognized ownership in the resources only upon capture (discussed in more detail below).[369] Application of this rule resulted in a conclusion that there was no owner of subsurface fugacious minerals until they were actually captured.[370] Later, though, many states supplemented the rule of capture with the "absolute ownership" theory,[371] which resulted in an inherent conflict[372] that, some courts resolved in favor of the rule of capture and a so-called "no-ownership" theory,[373] while others sought a more nuanced approach in which landowners owned the hydrocarbons found beneath their land but only so long as they remained there.[374] Yet, in a further and final abandonment of the *ad coelum* doctrine, the majority of oil and gas producing states imposed conservation measures on the oil and gas industry designed to minimize waste by individual producers, optimize collective productivity, and protect the energy interests of the general public.[375]

Regardless, in both the groundwater and oil and gas contexts, the *ad coelum* doctrine was abandoned largely because of the impossibility of removing only those water, oil, or gas molecules that underly a particular tract of land, while excluding those found under a neighboring parcel.[376] It was also discarded because of the potential liabilities that overlying landowners would have to assume if they or their agent inadvertently and improperly extracted or interfered with the resource located below a neighboring tract.[377] Thus, the United States Supreme Court bluntly asserted in *United States v. Causby* that the *ad coelum* "doctrine has no place in the modern world."[378] As a result, scholars like John Sprankling have argued that, "Just as the *ad coelum* doctrine crumbled with the

368. *See* Joseph A. Schremmer, *Ad Coelum and the Design of Property Rights*, 9 TEX. A&M J. PROP. L. 707, 711 (2023).

369. *See generally infra* note 406 and accompanying text.

370. *See* Schremmer, *supra* note 368, at 717.

371. The absolute ownership rule effectively follows the *ad coelum* doctrine but recognizes that adjacent property owners have correlative rights to appropriate oil and gas underlying the other's tract through the rule of capture. Woodward, *supra* note 289, at 358.

372. *See, e.g.*, Pierce, *supra* note 360, at 791 (recognizing that "[t]he *ad coelum* doctrine and rule of capture create what appear to be absolute and therefore seemingly conflicting property rights").

373. Woodward, *supra* note 289, at 359 (discussing the "qualified ownership theory" as another name for the no-ownership theory); *see also* Bruce M. Kramer & Owen L. Anderson, *The Rule of Capture—An Oil and Gas Perspective*, 35 ENV'T L. 899, 903, 950 (2005).

374. *See, e.g.*, Westmoreland & Cambria Nat. Gas Co. v. DeWitt, 18 A. 724, 725 (Pa. 1889) (explaining that oil and gas deposits "belong to the owner of the land, and are a part of it, so long as they are on or in it, and are subject to his control; but when they escape, and go into other land, or come under another's control, the title of the former owner is gone . . . If an adjoining, or even a distant, owner, drills his own land, and taps your gas, so that it comes into his well and under his control, it is no longer yours, but his"); *see also* Kramer & Anderson, *supra* note 373, at 950–51.

375. Kramer & Anderson, *supra* note 373, at 901.

376. *See, e.g.*, Coastal Oil & Gas v. Garza, 268 S.W.3d 1, 15 (Tex. 2008).

377. *See* James W. Coleman, *The Third Age of Oil and Gas Law*, 95 IND. L.J. 389, 394–95 (2020); Gabriela Engler Pinto, *Upstream Oil and Gas Legal Frameworks: Brazil and the United States Compared*, 115 W. VA. L. REV. 975, 995 (2013); Daintith, *supra* note 341, at 46.

378. 328 U.S. 256, 261 (1946). In reiterating the *Causby* conclusion, the Texas Supreme Court in *Coastal Oil v. Garza Energy Trust* asserted that "The law of trespass need no more be the same two miles below the surface than two miles above." 268 S.W.3d. at 11.

invention of the airplane, the center of the earth theory is destined to collapse with the advent of new subsurface technology."[379]

b. The *Ad Coelum* Doctrine and Geothermal Energy Resources

In the case of geothermal energy, application of the *ad coelum* doctrine is likely as, or even more challenging than it is for wind, water, oil or gas. As discussed above, geothermal energy manifests as heat in the subsurface.[380] While it is not fluidic or gaseous in nature, it is fugacious and moves through the Earth through conductive and convective processes.[381] As such, it cannot be contained or corralled within artificial property boundaries and, thus, cannot be relegated to a restrictive ownership regime while it is in the ground.[382] Even if a landowner enjoys the right to extract all nature of resources below their feet, that in no way means that they can prevent any of their neighbors from enjoying the same rights.[383] Moreover, even if the *ad coelum* doctrine was applied, because heat is nearly ubiquitous at depth in the subsurface, efficient exploitation would require cooperation among hundreds or even thousands of land owners. While conceptually not impossible, coordinating so many landowners could be a significant obstacle to large scale development of geothermal resources.[384]

In addition, as Ostrom and Hess suggest, there are significant and often unexpected costs associated with efforts to implement an effective and efficient ownership rights system for mobile resources:[385]

> Implementing operational and efficient individual withdrawal rights to mobile resources is far more difficult in practice than demonstrating the economic efficiency of hypothetical systems. Simply gaining valid and accurate measurements of 'sustainable yield' is a scientifically difficult task . . . . [Moreover, m]any mobile resource systems do not have natural or constructed storage facilities, and gaining accurate information about the stock and reproduction rates is very costly and involves considerable uncertainty . . . . [In addition] . . . appropriators from such resources can engage in a wide diversity of evasive strategies that can destabilize the efforts of government agencies trying to manage these systems. Further, once such systems have allocated individual withdrawal rights, efforts to further

379. Sprankling, *supra* note 350, at 981.

380. *See supra* Section II.B.

381. Conduction refers to the direct transfer of heat through physical contact between particles in a solid. Convection refers to heat transfer that results from the movement of fluids caused by density differences within the fluid. *See supra* notes 47–48 and accompanying text.

382. McClean & Pedersen, *supra* note 21, at 349.

383. *See id*. (asserting that "the mobility of the heat in the subsurface and the fact that reserves will frequently cross property boundaries mean that it might be impractical to exclude other users and difficult to establish the extent of each owner's rights").

384. Sprankling, *supra* note 350, at 1031. Yael Lifshitz describes this dilemma in the context of a spatial mismatch or misalignment between the application of vertically oriented legal regimes, like the *ad coelum* doctrine and the rule of capture, to natural resources with a horizontal nature, like groundwater, oil and gas, and geothermal energy. *See* Lifshitz, *supra* note 357, at 496–97.

385. Ostrom & Hess, *supra* note 242, at 70–71.

> regulate patterns of withdrawal may be very difficult and involve expensive buy-back schemes.[386]

Finally, the unique characteristics of geothermal energy also make application of the *ad coelum* doctrine questionable. Given its non-tangible and non-corporeal existence, geothermal energy cannot be extracted or used directly.[387] Rather, its capture requires either a physical medium to contain and convey the energy, or technology to convert the heat energy into electricity or other readily usable energy form.[388] As a result, the direct application of the *ad coelum* doctrine to geothermal energy would seem irrelevant since the resource would be worthless until after it was converted into a form that could be captured or utilized.[389]

3. The Rule of Capture

a. Overview of the Rule of Capture

The rule of capture is a common law-based legal theory applied most often to the ownership and control of natural resources, including those that are fluidic or fugacious and found in the subsurface.[390] Under the rule, ownership of an unowned thing is awarded to the person who first reduces it to possession.[391] In the context of natural resources, a landowner who can capture an unowned resource beneath, on, or above their property has the exclusive right to own that resource.[392] Capture is defined in relation to confinement and dominion, and the origin of the resource is irrelevant.[393] Thus, the rule of capture is applicable even to resources that migrate from across a neighboring property.[394] Logically, this also means that the surface owner holds no right in subsurface (or overlying) resources until and unless they have made some effort to extract the resources for economically viable use and convert this resource into possession.[395] Following this analysis, in a dispute over the right to drill for oil, the Texas Supreme Court explained in 1935 in *Brown v. Humble Oil Co.* that:

> [The law of capture] gives the right to produce all of the oil and gas that will flow out of the well on one's land; and this is a property right. And it

386. *Id.*

387. *See supra* notes 272–73 and accompanying text.

388. *Id.*

389. This is very different from other subsurface natural resources, such as oil and gas, which can be used directly as an energy source in their raw form. In contrast, the energy contained in geothermal resources must be transferred to water, air, or other medium, or converted into electricity, before it can actually be used. *See id.*

390. The rule of capture has also been applied to other unowned and mobile items, including wild animals and baseballs hit out of Major League Baseball stadiums. *See* Pierson v. Post, 1805 WL 781 (N.Y. Sup. Ct. 1805); Popov v. Hayashi, No. 400545, 2002 WL 31833731, at *8 (Cal. Super. Ct. Dec. 18, 2002). To some extent, the doctrine also appears to be emerging in the context of wind energy. *See supra* note 358 and accompanying text.

391. *See Pierson*, 1805 WL at 781.

392. *See* Coleman, *supra* note 377, at 394–95.

393. *Cf.* Brown v. Spilman, 155 U.S. 665, 670 (1895) (asserting that oil and gas deposits "belong to the owner of the land, and are part of it, so long as they are on it or in it or subject to his control; but when they escape and go into other land, or come under another's control, the title of the former owner is gone"); Kramer & Anderson, *supra* note 373, 906–08 (discussing the "pure" form of the rule of capture).

394. *See Spilman*, 155 U.S. at 670.

395. Sprankling, *supra* note 350, at 1003–04.

> is limited only by the physical possibility of the adjoining landowner diminishing the oil and gas under one's land by the exercise of the same right of capture.[396]

The rule of capture generally can be traced back to the treatment of groundwater under English common law, though some claim its roots can be found much earlier in European history.[397] The case most often referenced as the origin of the modern version of the rule is the 1843 English case of *Acton v. Blundell*.[398] In that case, the Court of Exchequer, an appellate court, asserted that the case fell

> within that principle, which gives to the owner of the soil all that lies beneath his surface, but then concluded that if, in the exercise of such right, he intercepts or drains off the water collected from underground springs in his neighbour's well, this inconvenience to his neighbour falls within the description of *damnum absque injuria*, which cannot become the ground of an action.[399]

Thus, while in the first instance, the *Acton* court suggested something akin to the *ad coelum* doctrine, it then backtracked by asserting that the groundwater below one's property could lawfully be taken or captured by a neighboring landowner.[400] In so doing, it interpreted the rule of capture as a right that confers ownership in the resource only after it is reduced to possession.[401]

Of course, under the rule of capture, the right to pursue groundwater beneath a landowner's property has always been exclusive to the landowner and part of the fee ownership.[402] Yet, that exclusive right is a separate and independent corporeal right, while the rule of capture is something less than corporeal. The rule of capture establishes a right of the landowner to capture and take possession of subsurface natural resources that are not yet possessory or under anyone's control.[403] Thus, to the extent that it is a legally recognized entitlement that exists independently of physical possession and control, it resembles an incorporeal, intangible right, such as those found in intellectual property and contracts law.[404]

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396. Brown v. Humble Oil Co., 83 S.W.2d 935, 940 (Tex. 1935).

397. *See, e.g.*, Dylan O. Drummond, Lynn Ray Sherman & Edmond R. McCarthy Jr., *The Rule of Capture—Still So Misunderstood After All These Years*, 37 TEX. TECH L. REV. 1, 16 (2004).

398. 152 Eng. Rep. 1223, 1235 (1843).

399. *Id.*

400. *Id.* The rule of capture is not entirely absolute. In most jurisdictions that follow the rule, liability can be imposed on a landowner if they extract the fugacious resource from underneath a neighboring parcel with malice or the intent to harm that adjacent landowner. Evidence of intent, however, must be manifest as would be in situations of intentionally slant drilling. *See, e.g.*, Hastings Oil Co. v. Tex. Co., 234 S.W.2d 389, 397 (Tex. 1950) (discussing the rule of capture in the context of oil and gas resources). In other words, if a landowner deliberately drilled a well at an angle toward a neighboring parcel of land in order to draw off the resource from beneath that adjacent tract, and especially if the well bottomed out across the boundary line, that could suffice to establish the requisite intent for liability.

401. *Acton*, 152 Eng. Rep. at 1235.

402. *See, e.g.*, Chatfield v. Wilson, 28 Vt. 49, 54 (1855).

403. *See, e.g.*, *Acton*, 152 Eng. Rep. at 1235.

404. *See* TERENCE DAINTITH, FINDERS KEEPERS? HOW THE LAW OF CAPTURE SHAPED THE WORLD OIL INDUSTRY 414 (2010).

The peculiarity of incorporeality was particularly vexing for cases addressing ownership of oil and gas resources in the ground.[405] Initially, these hydrocarbons were subjected to the pure form of the rule of capture, meaning that ownership could only be established with actual possession and control, and that while the fugacious hydrocarbons remained in the subsurface, no one owned them.[406] The rule was adopted, in part, because of a lack of understanding of the origin and movement of oil and gas resources,[407] though possibly more so because of a desire to encourage the expansion of the budding energy sector and, thereby, economic development and growth.[408] By eliminating most liability associated with extracting these resources, it was believed that companies would be incentivized to optimize their extractive operations, which would thereby spur the economy.[409] This was also the perspective taken by some states in administering their groundwater resources, including Ohio and Texas.[410] Later, in the late 1800s and early 1900s, in order to further facilitate development and create a more attractive investment model for oil and gas exploration and production companies, many states adopted the "absolute ownership" theory on top of the rule of capture.[411] Under the basic rule of capture, a leased right to access the underlying minerals was akin to an easement and, thus, could only be deemed an incorporeal hereditament.[412] The absolute ownership approach, also known as

405. Kramer & Anderson, *supra* note 373, at 903.

406. *See, e.g.*, Dark v. Johnston, 55 Pa. 164, 168 (1867) (stating that "[o]il is a fluid, like water, it is not the subject of property except while in actual occupancy"); Westmoreland & Cambria Nat. Gas. Co. v. de Witt, 18 A. 724, 725 (1889) (explaining that "[p]ossession of the land, therefore, is not necessarily possession of the gas. If an adjoining, or even a distant, owner, drills his own land, and taps your gas, so that it comes into his well and under his control, it is no longer yours, but his"); Coleman, *supra* note 377, at 394–95 (2020) (asserting that under the basic rule of capture, "a landowner owns [only] the oil and gas that can be extracted from his or her land"); *see also* Daintith, *supra* note 341, at 38, 46.

407. *See* DAINTITH, *supra* note 404, at 13–15 (discussing criticism of the judicial application rule of capture on grounds of "scientific ignorance").

408. *See* PAUL H. FRANKEL, ESSENTIALS OF PETROLEUM: A KEY TO OIL ECONOMICS 19 (1969) (asserting that the rule of capture was "exactly what was required to make the young industry, in the first instance, aggressive and, in due course, great"); Pogue, *supra* note 267, at 165 (stating that the rule of capture "gave speed to the enterprise, supporting and sustaining the rate of expansion that the requirements of consumers demanded").

409. *Cf.* HOLLY WISE & SOKOL SHTYLLA, HARV. UNIV. KENNEDY SCH. OF GOV'T, THE ROLE OF THE EXTRACTIVE SECTOR IN EXPANDING ECONOMIC OPPORTUNITY 6 (2007), https://www.hks.harvard.edu/sites/default/files/centers/mrcbg/programs/cri/files/report_18_EO%2BExtractives%2BFinal.pdf [https://perma.cc/CY5V-UGW7].

410. In *Frazier v. Brown*, for example, the Ohio Supreme Court concluded that:

> Because the existence, origin, movement and course of such waters, and the causes which govern and direct their movements, are so secret, occult and concealed, that an attempt to administer any set of legal rules in respect to them would be involved in hopeless uncertainty, and would be therefore, practically impossible.

12 Ohio St. 294, 311 (1861). Moreover, it asserted that application of any doctrine other than rule of capture "would interfere, to the material detriment of the common wealth [*sic*], with drainage and agriculture, mining, the construction of highways and railroads, with sanitary regulations, building and the general progress of improvement in works of embellishment and utility." *Id.* That decision and specific language was later borrowed by the Texas Supreme Court in *Houston Texas Central Railway Co. v. East*, 81 S.W. 279, 280–81 (1904).

411. *See also* Daintith, *supra* note 341, at 38, 46.

412. *Incorporeal Hereditaments*, BLACK'S LAW DICTIONARY (12th ed. 2024) (defining incorporeal hereditament as "an intangible right in land, such as an easement"). An incorporeal hereditament is an intangible right that is attached to property, but not the property thing itself. For example, an easement is a right of access across a tract of land, but not a right to the land itself. Cynthia J. Norland, *Dormant Mineral Statutes and Abandoned Severed Mineral Interests*, 58 N.D. L. REV. 611, 616–17 (1982) (discussing the differences between corporeal and incorporeal hereditaments). Under common law, interference with an incorporeal hereditament could be

the "ownership-in-place" theory, however, regards oil and gas resources as a corporeal hereditament owned by the surface estate as part and parcel of the land itself.[413] Thus, recognition of the absolute ownership of the subsurface minerals in place would convert a lease into a true property right.[414]

While the absolute ownership approach was attractive to a majority of the states, especially those where hydrocarbon resources were being developed, its adoption conflicted with the underlying rule of capture. By asserting that oil and gas resources belong to the landowner and are part of the land, and in the same breath declaring that this was only true so long as those minerals remain within the landowner's boundaries, the contradiction displaced any notion of true ownership with one of mere possession.[415] Some jurisdictions resolved the conundrum by recognizing the impossibility of owning a fugacious resource before it was converted into full possession.[416] Effectively, for them, ownership of a fugacious substance in place was simply a legal fiction since any adjacent landowner could legally secure ownership of the resource by pumping and capturing it.[417] Other courts, however, sought a more nuanced or flexible approach to the conflict between the two doctrines by concluding that landowners did actually "own" the oil and gas found beneath their land, but as a "defeasible" estate, meaning only insofar as it remained within the boundaries of their tract.[418] If the oil or gas migrated to a neighboring tract, either through natural or artificial forces, the owner was deemed to have lost title and any negative impact was regarded as *damnum absque injuria*, or loss without injury.[419]

protected only under a suit for equity, while one based on ownership could be subject to an action for ejectment. Daintith, *supra* note 341, at 47.

413. *Ownership-in-Place Theory*, BLACK'S LAW DICTIONARY (12th ed. 2024) (defining the ownership-in-place theory as "[a] characterization of oil-and-gas rights used in a majority of jurisdictions, holding that the owner has the right to present possession of the oil and gas in place as well as the right to use the land surface to search, develop, and produce from the property, but that the interest in the minerals terminates if the oil and gas flows out from under the owner's land"); *see also* Appeal of Stoughton, 88 Pa. 198, 201 (1878) (asserting that "[o]il, however, is a mineral, and being a mineral is part of the realty . . . . In this it is like coal or any other natural product which *in situ* forms part of the land . . . whenever conveyance is made of it, whether that conveyance be called a lease or deed, it is, in effect, the grant of part of the corpus of the estate and not of a mere incorporeal right"); Norland, *supra* note 412, at 616–17.

414. *See* Daintith, *supra* note 341, at 47.

415. DAINTITH, *supra* note 404, at 31.

416. *Id.*

417. *Id*. Sprankling asserts that "this supposed ownership is purely rhetorical, because the oil and gas underlying the land of any surface owner may be freely captured by others, just as in nonownership jurisdictions . . . Thus, 'ownership in place' is not ownership at all." Sprankling, *supra* note 350, at 1009–10; *see also* State v. Ohio Oil Co., 49 N.E. 809, 812 (1898) (arguing that "[t]o say that the title to natural gas vests in the owner of the land in or under which it exists to-day, and that to-morrow, having passed into or under the land of an adjoining owner, it thereby becomes his property, is no less absurd, and contrary to all the analogies of the law, than to say that . . . fish, in their passage up or down a stream of water, become the property of each successive owner over whose land the stream passes").

418. Tex. Co. v. Daugherty, 176 S.W. 717, 720 (1915) (asserting that if the subsurface resources "have not departed and are beneath [the land], they are there as a part of the realty; and their conveyance while in place, if the instrument be given any effect, is consequently the conveyance of an interest in the realty"); *see also* DAINTITH, *supra* note 404, at 32 (explaining that "the circle was squared by calling the oil and gas property right a 'defeasible' ownership, meaning that you had all the rights of an absolute owner to the oil and gas that was under your land—until it no longer was").

419. Woodward, *supra* note 289, at 354.

b. The Rule of Capture and Geothermal Energy Resources

At least in its pure form, the rule of capture may be appealing for regulating geothermal energy resources. Heat energy, even more so than oil, gas or water, is fugacious and moves through the Earth with virtually no impediment.[420] Any effort to impose ownership rights based on artificial property lines, such as through an absolute ownership or *ad coelum* approach, would be an exercise in futility. At the very least, such an effort would be highly difficult to monitor and incredibly expensive to protect. In addition, while heat energy is the resource, it is not usable directly and must either be transferred into a physical medium that can contain the heat or be converted into another, more readily useable energy form, like electrical energy.[421] In contrast, applying a rule that awards ownership only upon capture might make more sense as it might facilitate and encourage exploration and exploitation based on the promise of a reward if enough of the resource is captured and converted into possession. Moreover, it would simplify claims for liability since any causes of action would be limited to few scenarios, such as intentional harm.

On the other hand, applying a pure, unfettered rule of capture to geothermal energy would open up the possibility of a tragedy of the commons. As occurred in the early years of the oil and gas boom, the unfettered depletion of these resources spurred by efforts to reduce the hydrocarbons to possession, resulted in many deposits becoming economically or physically unrecoverable and caused significant environmental damage.[422] A similar outcome undoubtedly will ensue for geothermal energy if the rule of capture is applied without restraint or regulation.

C. Non-Private Property Rights in Geothermal Energy

As suggested above, not all natural resources are subject or can be subjected to ownership.[423] Ownership principles like *ad coelum* and the rule of capture typically rely on the corporeality, capturability, or excludability of the resource.[424] Yet, some resources defy these qualities to the extent that they resist all efforts to own them in their natural state. Among others, these distinct natural phenomena include air, wind, solar energy, fish stocks, migratory birds, and the atmosphere.[425] The following Section explores a number of non-ownership scenarios for natural resources.

420. *See* Bradbrook & Rønne, *supra* note 6, at 313.

421. *See supra* note 273 and accompanying text.

422. *See* Tara K. Righetti, *The Incidental Environmental Agency*, 2020 UTAH L. REV. 685, 692–93 (2020) (discussing the environmental impact of the early oil extraction industry and asserting that "application of the rule of capture to early [oil] production led to ruination"); Howard R. Williams, *Conservation of Oil and Gas*, 65 HARV. L. REV. 1155, 1159 (1952) (describing the early years of the oil industry as characterized by "profligate drilling and tremendous physical waste of oil").

423. *See supra* Section IV.B.

424. *See supra* Subsection IV.B.2.

425. *See supra* note 264 and accompanying text.

1. Common Pool and Open Access Natural Resource

Both common pool and open access refers to resources that are widely accessible. Common pool resources typically are resources collectively accessible to or claimed by a community or group of individuals, whereas open access resources are effectively unowned and accessible by any member of society.[426] A chief difference between the two is the degree of excludability—the extent to which others can be prevented from accessing or using the resource. In the case of a common pool resource, the size or characteristics of the resource typically makes it challenging, albeit not impossible, to exclude others from enjoying its benefits.[427] In contrast, the nature of an open access resource often makes it impossible to contain or corral, or to prevent the broader public from enjoying its benefits.[428] This is one of the chief reasons why private ownership in such resources is resisted. This is also why open access resources, for the most part, are unregulated.

A second critical characteristic of common pool and open access resources is rivalrousness. A resource is rivalrous if the amount or volume of that resource is finite and that users must compete for each unit.[429] In other words, when one user utilizes or consumes a unit of the resource, it diminishes the amount available for others.[430] While both common pool and open access resources can be rivalrous, most such resources are not finite. Examples of common pool natural resources include certain forests, grazing lands, fisheries, and lakes, while open access resources include solar energy, oceans, and the atmosphere.[431]

Because common pool and open access resources are, to varying degrees, non-excludable and rivalrous, they are susceptible to the so-called tragedy of the commons.[432] The tragedy occurs where a resource is overused or depleted because of an absence of individual ownership or property rights or inadequate management or regulation of the resource.[433] Under such conditions, individuals are incentivized to exploit the resource as much as possible for their own benefit.[434]

The tragedy of the commons, however, is not inevitable. Rather, various management strategies can be implemented to minimize overuse and depletion, such as establishing common rules, regulations, and institutions to administer access to, usage, and conservation of the resource.[435] Among others, these can

426. *See* Ostrom & Hess, *supra* note 242, at 56–57 (discussing the confusion between common pool and open access resources).

427. Brett M. Frischmann, Alain Marciano & Giovanni Battista Ramello, *Retrospectives: Tragedy of the Commons After 50 Years*, 33 J. ECON. PERSP. 211, 221 (2019).

428. *Id.* (discussing the difference between common pool and open access resources). In comparison, access to private goods can be restricted through property rights, fences, locks, and other mechanisms.

429. *See id.* at 214.

430. *Id.* at 214.

431. Garrett Hardin, *The Tragedy of the Commons*, 162 SCI. 1243, 1245 (1968).

432. *Id.* at 1244.

433. *See* Frischmann et al., *supra* note 427, at 212–15 (discussing Garrett Hardin's analysis of the tragedy of the commons); *see generally* Hardin, *supra* note 431.

434. Hardin, *supra* note 431, at 1244.

435. Frischmann et al., *supra* note 427, at 216.

include permit and licensing regimes, quotas, protected areas, user associations and community-based management schemes, monitoring and reporting systems, enforcement mechanisms, various incentives to encourage sustainable use, educational programs, and more.[436] Nevertheless, while such regimes can prevent an environmental tragedy, they are not always suited to maximizing efficient and economical exploitation of natural resources.

Geothermal resources can certainly possess the characteristics of either a common pool or open access natural resource.[437] Such resources certainly are non-excludable as, in their natural form, they cannot be corralled or easily controlled.[438] Anyone who drills into the Earth's surface can tap into the heat if they have the appropriate technology.[439] While access to land areas containing specific geothermal sites can be restricted by the landowners (whether private or governmental actors),[440] it would be considerably difficult to restrict overall access to the energy resource itself.

Yet, geothermal energy is not entirely rivalrous. While the recharge rate of geothermal energy varies by location throughout the world, in many cases, multiple users can extract the resource indefinitely without depleting it.[441] Nevertheless, unlike sunlight and solar energy, the recharge rate of geothermal energy does have a limit.[442] Thus, in some geothermal reservoirs, extraction can exceed replenishment, impacting the energy remaining in the reservoir and reducing its availability for other users.[443] In these scenarios, geothermal energy can be deemed rivalrous.

The possibility of overexploiting geothermal energy, however, is far from a uniform phenomenon across geothermal energy sites, and in most cases is unlikely to be permanent. Even where the replenishment rate of a specific geothermal energy extraction site is exceeded, because of the continuous release of heat from both residual origins and the decay of radioactive isotopes, following a recovery period, the reservoir is likely to recover to its former potential.[444] Thus, absent some major global catastrophe, geothermal energy resources are unlikely

436. *Id.*

437. McClean & Pedersen, *supra* note 21, at 349.

438. *Id.* (asserting that "the mobility of the heat in the subsurface and the fact that reserves will frequently cross property boundaries mean that it might be impractical to exclude other users and difficult to establish the extent of each owner's rights").

439. *See id.* at 345.

440. MARSHALL J. REED & R. GORDON BLOOMQUIST, NATIONAL GEOTHERMAL POLICY AND REGULATION IN THE UNITED STATES 629, 630 (World Geothermal Congress, 1995), https://www.geothermal-energy.org/pdf/IGAstandard/WGC/1995/1-reed.pdf [https://perma.cc/K4BS-XVRQ].

441. *See, e.g.*, *supra* notes 7 and 156–57 and accompanying text (discussing renewability of geothermal energy, and providing examples of sustainable geothermal energy generation operations at Matsukawa, Japan, and Reykjavík, Iceland).

442. *See* VALGARDUR STEFANSSON, THE RENEWABILITY OF GEOTHERMAL ENERGY 883, 885 (World Geothermal Congress 2000), https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2000/R0776.PDF [https://perma.cc/UP4Y-Q8TQ].

443. *See, e.g.*, *supra* notes 150–55 and accompanying text (discussing depletion of The Geysers geothermal field in California and the Wairakei-Tauhara geothermal system in New Zealand).

444. *See, e.g.*, *supra* notes 153–55 and accompanying text (discussing the Wairakei-Tauhara geothermal system in New Zealand, which is expected to regain its depleted energy reservoir following a recovery period estimated at 300 years).

to fall victim to a permanent tragedy of the commons scenario. As a result, the extent to which geothermal energy behaves like a common pool or open access resource depends on various factors, such as the geology at the specific geothermal location, the number of users extracting from the site and the rate of extraction, the technology used to mine the resource, and any management strategies implemented to support the sustainable exploitation of the resource.

2. *Public Ownership of Natural Resources*

In the United States, various natural resources are owned by the government, either at the local, state, or federal level, on behalf of the public.[445] While the use and exploitation of these resources may be, at least theoretically, more efficient under private ownership, they are titled in the sovereign because of their unique and significant value to society.[446] These resources—whether they be life sustaining water, historically significant lands, or distinct ecosystems—are safeguarded under public authority in order to secure their protection, responsible use, and exploitation.[447] They are also entrusted to the government to ensure that their benefits and value are not monopolized by the few, but rather made accessible to the public at large.[448] Moreover, in some cases, natural resources may be placed under government oversight because of their strategic importance for economic or national security reasons, or because of high start-up costs that cannot be borne by private capital markets.[449]

A government may develop or designate certain land resources as publicly owned spaces in order to preserve their distinct ecological, recreational, cultural, or educational values.[450] Examples may include certain park lands, wildlife refuges, and archeological sites.[451] These lands' distinct values are typically reflected in unique or fragile habitats and ecosystems, the abundance or rarity of particular species, places of cultural or historical significance, or distinct environmental features that should be protected and studied.[452] In placing them under public custody, governments take steps to prioritize their conservation, secure them from harmful exploitation, and enable managed access by the broader public.[453]

445. For example, "states have primary authority and natural resource ownership in the three-mile area extending outward from their coasts," while [t]he federal government owns oil, gas, and minerals located in the submerged lands on the Outer Continental Shelf." *How Revenue Works: Ownership*, OFF. OF NAT. RESOURCES REVENUE, https://revenuedata.doi.gov/how-revenue-works/ownership/ (last visited Mar. 5, 2025) [https://perma.cc/7WYE-UHCZ]; *see also supra* notes 168–76 and accompanying text (discussing ownership of geothermal energy resources on federal lands).

446. *See supra* notes 265–69 and accompanying text.

447. *See, e.g.*, Aoife Brophy Haney & Michael G. Pollitt, *New Models of Public Ownership in Energy*, 27 INT'L R. APPL. ECON. 174, 178 (2013); *see also* Bradbrook & Rønne, *supra* note 6, at 312.

448. *See* Haney & Pollitt, *supra* note 447, at 177–78.

449. *See generally id.* at 177–79 (discussing various reasons for why natural resources may be placed under public ownership emphasizing investment costs, societal concerns and priorities, and risks).

450. *See, e.g.*, 54 U.S.C. § 100101(a).

451. *See id.*

452. *See id.*

453. *See generally* Giorgio Resta, *Systems of Public Ownership*, *in* COMPARATIVE PROPERTY LAW: A RESEARCH HANDBOOK 216, 222–24 (Michele Graziadei & Lionel Smith, eds., 2017) (surveying the literature

Similarly, governments may also assume supervision over certain natural resources to facilitate sustainable management and exploitation.[454] This is based on the belief that public agencies will be better stewards of these resources for present and future generations.[455] Moreover, the agencies are regarded as more likely than the private sector to ensure that decisions about their management and utilization are made in the public interest, with consideration for environmental, social, and economic factors, and with transparency and accountability.[456] Thus, certain grazing lands, tracts containing hydrocarbons and other minerals, marine resources, and certain wildlife and endangered species, are often placed under state or federal control for the collective benefit of the citizenry.[457]

Governmental ownership of natural resources occurs most obviously for resources located on public lands. Thus, for example, timber and hydrocarbons on federal lands are owned by the federal government and subject to various controls and regulations to ensure public access, societally acceptable exploitation, and equitable distribution of the benefits.[458] Likewise, geothermal resources found on federal lands are owned by the federal government and managed under the Geothermal Steam Act of 1970, which provides permitting requirements and procedures for anyone wishing to exploit the resource and imposes royalties payable to the government.[459]

Although more common on public lands, government ownership of natural resources can also occur on private lands. All states, for example, consider their surface waters, and in most states, their groundwater resources, state owned regardless that the waters flow across, through, or below privately owned lands.[460] While the states typically assign usufructuary rights through a permitting process, which allows users some rights to benefit from the use and exploitation of the resource, title to the water is maintained by the sovereign, most often in a custodial capacity on behalf of the citizenry.[461] This is done to ensure the public broader access to water and minimize monopolization of a resource that is

justifying public ownership over certain resources on economic, institutional, and distributive justice grounds, and critiquing some of the arguments underlying those justifications).

454. *See, e.g.*, D. Michael Harvey, *Federal-State Relationships in Federal Land and Resource Management*, 54 DENV. L.J. 585, 588 (1977).

455. *See* Resta, *supra* note 453 at 222–23.

456. *See generally* Klass, *supra* note 256.

457. *How Revenue Works: Ownership*, *supra* note 445.

458. *See id.* (stating that "[t]here are 57 million acres of land in the U.S. where the federal government owns oil, gas, coal, and other minerals below the surface"); Harvey, *supra* note 454, at 588 (asserting that the Federal Government owns, on behalf of its citizenry, "sixty percent of the crude oil and natural gas, fifty percent of the coal, eighty percent of the oil shale, fifty percent of the recoverable geothermal energy, and fifty percent of the uranium" found in the United States).

459. *See supra* notes 173–82 and accompanying text.

460. REED BENSON, BURKE GRIGGS & A. DAN TARLOCK, WATER RESOURCE MANAGEMENT: A CASEBOOK IN LAW AND PUBLIC POLICY 24 (8th ed. 2021) (noting that in the U.S., "[a] water right holder does not own the corpus of water as a landowner owns the soil. The holder has only the right to use the water"); *see also supra* notes 360–67 and accompanying text (discussing groundwater ownership in the United States).

461. *See* Reed D. Benson, *Public on Paper: The Failure of Law to Protect Public Water Uses in the Western United States*, 1 INT'L J. RURAL L. & POL'Y 1, 6 (2011) (discussing the public nature of water ownership in western U.S. states); Joseph Regalia, *Why Mississippi's Plea to the Supreme Court That It "Owns" Its Water and That Tennessee Is "Stealing" It Is Just Wrong*, 2019 U. CHI. L. REV. ONLINE 1, 2 (2019) (describing water resources as "*res communes*; a unique public resource managed by states as trustees, not property owners").

indispensable for life, as well as for nearly every aspect of agricultural production, manufacturing, and energy development.[462] The array of federal laws—such as National Environmental Policy Act,[463] Clean Water Act,[464] Clean Air Act,[465] Coastal Zone Management Act,[466] Comprehensive Environmental Response, Compensation, and Liability Act,[467] Resource Conservation and Recovery Act,[468] Migratory Bird Act,[469] and Endangered Species Act[470]—as well as their state counterparts, all evidence the extent to which American society has determined that some resources are too important for private control and dominion.

In a similar approach, many U.S. states have adopted the Public Trust Doctrine for various natural resources, even when they are found within the bounds of private property.[471] The basic premise underlying the doctrine is that "some things are considered too important to society to be owned by one person."[472] Rather, they must be protected to ensure the interests of present and future generations in those resources. In other words, the state, acting as trustee on behalf of its population, must "look forward to the future and take actions in the present that will first, maintain and, second, enhance the trust property for the benefit of future generations."[473]

Rooted in Justinian Code dating back to 530 AD, the Public Trust Doctrine originally applied to air, water, the seas, and coastal shores.[474] Over time and through jurisprudential development, it expanded in the United States to encompass commerce, fishing, navigation, recreation, and tidal lands.[475] In some

462. *See* Regalia, *supra* note 461, at 1–2.
463. 42 U.S.C. §§ 4321–70.
464. 33 U.S.C. §§ 1251–1387.
465. 42 U.S.C. §§ 7401–7671.
466. 16 U.S.C. §§ 1451–64.
467. 42 U.S.C. §§ 9601–75.
468. 42 U.S.C. §§ 6901–92.
469. 16 U.S.C. §§ 701–18.
470. 16 U.S.C. §§ 1531–44.
471. *Cf.* Klass, *supra* note 256, at 1025.
472. Gregg L. Spyridon & Sam A. LeBlanc, III, *The Overriding Public Interest in Privately Owned Natural Resources: Fashioning a Cause of Action*, 6 TUL. ENV'T L.J. 287, 291 (1993); *see also* Klass, *supra* note 256, at 1023 (asserting that "there are some resources . . . that are forever to be held in trust for present and future generations"). In the seminal public trust case, *Illinois Central Railroad v. Illinois*, the U.S. Supreme Court concluded that the character of land subject to the trust "was different in character from that which the State holds in other lands intended for sale [to private parties]." 146 U.S. 387, 452 (1892).
473. Klass, *supra* note 256, at 1029.
474. Erin Ryan, *The Public Trust Doctrine, Property, and Society*, *in* THE ROUTLEDGE HANDBOOK OF PROPERTY, LAW, AND SOCIETY 240–41 (Nicole Graham, Margaret Davies & Lee Godden eds., 2022). The original (translated) quote by Justinian asserts:

> [T]he following things are by natural law common to all—the air, running water, the sea, and consequently the sea-shore. No one therefore is forbidden access to the sea-shore, provided he abstains from injury to houses, monuments, and buildings generally; for these are not, like the sea itself, subject to the law of nations.

THE INSTITUTES OF JUSTINIAN 35, (J. B. Moyle trans., Oxford 5th ed. 1913).
475. *See, e.g.*, Ill. Cent. R.R. v. Illinois, 146 U.S. at 452 (extending the doctrine "for the people of the State that they may enjoy the navigation of the waters, carry on commerce over them, and have liberty of fishing therein freed from the obstruction or interference of private parties"); Phillips Petroleum Co. v. Mississippi, 484 U.S. 469, 484–85 (1988) (extending the doctrine to all nonnavigational waters affected or influenced by the ebb and flow of tides).

jurisdictions, the Public Trust Doctrine has been extended to the environment, wildlife and its habitats, beach access, aesthetics, and other resources.[476] In addition, the Public Trust Doctrine has evolved "from an affirmation of sovereign authority over trust resources to a recognition of sovereign responsibility to protect them for present and future generations."[477]

With regard to geothermal energy resources, public ownership on both public and private lands may be justified, for example, by the ongoing climate crisis and the immediate need to find alternatives to fossil fuels.[478] Similarly, it could be rationalized as a resource critical to the survival interests of all humankind and, thus, worthy of perpetual governmental custodianship. In addition, governmental ownership or oversight responsibility could be maintained on economic grounds, namely economies of scale, the goal of preventing monopolies and maintaining competition, and minimization of externalities.[479] Alternatively, it might be defended on the argument that geothermal resources are strategic resources essential to national security or the economy.[480]

As a practical matter, the inherent qualities of geothermal energy also may support public ownership of this resource. As noted above, geothermal energy is ubiquitous throughout the country.[481] It emanates below and across the property lines of both public and private lands, and at depths that span a few yards to many miles below the surface.[482] Moreover, it cannot be contained by property lines on a map, yet its extraction can have effects on subsurface temperature beyond the extraction well and even across property boundaries.[483] Thus, in order to minimize disputes between neighbors, safeguard the sustainable development of the resource, and ensure that exploitation is conducted for the benefit of the citizenry, it could be argued that a governmental or public ownership regime may be better suited than a private ownership system for geothermal energy resources.

476. *See* Nat'l Audubon Soc'y v. Super. Ct. (*Mono Lake*), 658 P.2d 709, 719 (Cal. 1983) (extending the doctrine in California to recreational and ecological values); *In re* Water Use Permit Applications (*Waiahole Ditch*), 9 P.3d 409, 445 (Haw. 2000) (extending the doctrine in Hawaii to all water resources, not only navigable waterways); *see also* Klass, *supra* note 256, at 1028–31.

The expansion of the public trust to other natural resources, especially newly recognized resources, has not been entirely smooth and unchallenged. *See, e.g.*, Huffman, *supra* note 255, at 338–39 (arguing that expanding the Public Trust to other natural resources would undermine other important public values); Caroline Cress, *It's Time to Let Go: Why the Atmospheric Trust Won't Help the World Breathe Easier*, 92 N.C. L. REV. 236, 240–41 (2013) (highlighting various concerns and weaknesses for a Public Trust approach to climate change); George P. Smith, II & Michael W. Sweeney, *The Public Trust Doctrine and Natural Law Emanations Within a Penumbra*, 33 B.C. ENV'T AFFAIRS L. REV. 307, 309 (2006) (arguing that expansion of the doctrine would improperly interfere with private property rights).

477. Ryan, *supra* note 474, at 250.

478. *See* IPCC, 2023, *supra* note 1, at 104 (discussing the critical need for "[r]apid and deep reductions in GHG emissions" and "major energy system transitions" that include alternatives to fossil fuels).

479. Sho Sato, Thomas D. Crocker & L.J.P. Muffler, *Property Rights to Geothermal Resources—Part II*, 6 ECOLOGY L.Q. 481, 498–501 (1977).

480. For example, lithium, which is a relatively rare element used in rechargeable batteries and which is often found in geothermal brines brought up in open loop geothermal energy projects that use native water, "has been identified as a material essential to the economic or national security of the United States." *Lithium*, OFF. OF ENERGY EFFICIENCY & RENEWABLE ENERGY, U.S. DEP'T OF ENERGY, https://www.energy.gov/eere/geothermal/lithium (last visited Mar. 5, 2025) [https://perma.cc/3JAM-28HC].

481. *See supra* notes 114–15 and 75 and accompanying text.

482. *See supra* notes 114–15 and 130 and accompanying text.

483. *See supra* notes 291–94 and accompanying text.

Notwithstanding these arguments, and with the exception of public lands, geothermal energy resources have not garnered the necessary societal attention to indicate that public ownership or custodianship is likely in the near future. This lack of attention, however, is, in part, a function of the lack of public understanding and appreciation of geothermal energy and its potential.[484] Whether the government decides more fervently to pursue this energy opportunity itself or incentivizes the private sector to take on this role remains to be seen. In either case, clarifying ownership rights in geothermal energy resources would be a critical foundational step.

V. CONCLUSION

While geothermal energy holds tremendous promise for providing a nearly limitless source of power and heating, as well as decarbonizing the economy, its potential is stymied by a lack of clear property rights related to its development and ownership. The modern market-based economic model thrives when participants in the market have well-defined property and ownership rules that clarify opportunities for returns on investment. This is true for privately owned resources like oil, underlying private property, publicly owned resources, including government-owned forests, and unowned resources, such as fish stock. The key feature is clear and consistent ownership rules that investors can incorporate into their calculus.

Having such clearly defined and consistent rules could have profound implications for nearly every aspect of geothermal energy development, including the exploration, harvesting, conversion, and transfer of this promising, clean, renewable energy resource. Absent such clarity, neither the private sector nor government will have an incentive to undertake the risks associated with investing in expensive operations.

Accordingly, lawmakers at both the federal and state levels should explore establishing a property regime for geothermal energy resources under the umbrella of two chief priorities: incentivizing society, and especially the private sector, to invest in the geothermal energy sector; and ensuring that geothermal energy development is managed sustainably. In addition, they should strive to make the new regime consistent not only within states, but across the nation. What approach they might consider, and which one may be best suited to achieve these objectives, will be the subject of a follow-up article to this one.

484. *See supra* note 18 and accompanying text.