Injecting Earthquakes into the Energy Debate

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ABSTRACT

Of all the new concerns to emerge in the wake of unconventional shale energy development, induced earthquakes are perhaps the most surprising. The frequency and occurrence of seismic activity in the central and eastern United States has increased dramatically since the shale boom began in 2009. This uptick in seismic events has led many to suspect that the connection between unconventional production and induced seismicity is far from coincidence. Plenty of myths and inaccurate reporting surround this issue, but the consensus from the scientific community is that the injection of wastewater fluids is the most likely culprit for the increasing rates of seismicity. This concern has prompted a varied response from concerned citizens, regulators, and the industry. This article discusses how the oil and gas industry induces earthquakes from wastewater disposal activities, outlines the existing regulatory framework by comparing the response of state officials in Oklahoma and Colorado, and offers several non-regulatory strategies that companies should implement to prevent these damaging earthquakes. This article concludes that the best approach to mitigate seismic risk requires both proactive state regulatory measures with voluntary efforts from the industry.

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I.
INTRODUCTION

Beneath the earth are natural forces with the potential to damage property resting above the surface. Throughout history, human progress has always been subservient to the physical laws of nature. But through technological improvement and innovation, mankind's ability to shape the world is increasingly blurring the lines between natural and anthropogenic (i.e., caused by humans) events.[1] The oil and gas industry's ability to

1. *See* Adam F. Scales, *Man, God and the Serbonian Bog: The Evolution of Accidental Death Insurance*, 86 IOWA L. REV. 173, 269–270 (2000) (explaining that accidents lie in the middle of a spectrum between human and natural events, and occur "when the gravitational pull of neither pole is strong enough to dominate.").

extract ancient deposits of energy is one of the greatest examples of this phenomenon, and through the advent of unconventional drilling techniques, "the orbit of humanity's reach has enlarged itself dramatically" in the past decade.[2]

Our ability to harness energy is what makes our modern society possible.[3] The development of unconventional sources of oil and gas using horizontal drilling and hydraulic fracturing offers a variety of benefits, including a more secure energy supply, improved geopolitical stability, and a boost to the industrial economy.[4] At the same time, unconventional production has become increasingly controversial as new environmental and social concerns emerge in the wake of shale development.[5] Induced earthquakes are perhaps the "most unexpected phenomenon" of America's energy boom.[6]

The frequency and occurrence of seismic activity in the central and eastern United States has increased dramatically since the boom took off around 2009.[7] This uptick in seismic events has led many to suspect that the connection between unconventional production and induced seismicity is far from coincidence. Plenty of myths and inaccurate reporting surround this supposed connection, but the consensus from the scientific community is that the injection of wastewater fluids is the most likely culprit for the increasing rates of seismicity.[8] While hydraulic fracturing

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2. *Id.*

3. *See* DANIEL YERGIN, THE QUEST 712 (2011) (explaining that "[t]he bounty can be measured in terms of virtually everything we do in the course of a day.").

4. *See* Monika Ehrman, *The Next Great Compromise: A Comprehensive Response to Opposition Against Shale Gas Development Using Hydraulic Fracturing in the United States*, 46 TEX. TECH L. REV. 423, 460 (2014).

5. Keith B. Hall, *Recent Developments in Hydraulic Fracturing Regulation and Litigation*, 29 J. LAND USE & ENVTL. L. 29, 30 (2013).

6. Ehrman, *supra* note 4, at 460.

7. *See* PETER FOLGER & MARY TIEMANN, CONG. RESEARCH SERV., R43836, HUMAN-INDUCED EARTHQUAKES FROM DEEP-WELL INJECTION: A BRIEF OVERVIEW 5 (2015), *available at* https://www.fas.org/sgp/crs/misc/R43836.pdf. Seismicity in parts of the central and eastern U.S. increased dramatically since 2009, from an average of approximately 29 per year (1970-2000) to over 100 per year (2010-2013). *Id.*

8. *See* Justin L. Rubinstein & Alireza B. Mahani, *Myths and Facts on Wastewater Injection, Hydraulic Fracturing, Enhanced Oil Recovery, and Induced Seismicity*, SEISMOLOGICAL RES. LETTERS, July-Aug. 2015, at 2-3.

itself is unlikely to result in any significant levels of seismicity felt at the surface, the rapid development of unconventional sources using this technique has increased the need for disposal capacity, sometimes in areas where disposal has not previously occurred.[9]

The "exponential growth patterns of seismicity" in some parts of the country have prompted a varied response from concerned citizens, regulators, and the industry.[10] This article analyzes how existing measures to regulate the oil and gas industry could be improved to provide greater protection against the risk of induced seismic activity. Section II discusses how the oil and gas industry induces earthquakes, primarily in the context of wastewater disposal from Class II injection wells. Sections III and IV outline the existing regulatory framework at the federal and state levels through a comparative survey of the response of state officials in Oklahoma and Colorado. Section V identifies several non-regulatory strategies that companies can employ to mitigate the incidence of damaging earthquakes. Section VI concludes by suggesting that the best approach to mitigate seismic risk involves proactive regulatory measures such as those adopted in states like Colorado, in conjunction with voluntary efforts from the industry itself.

II.
RECENT INCREASE AND INTEREST IN INDUCED SEISMICITY

A. *Basic Mechanics of Inducing Earthquakes*

Induced earthquakes occur when anthropogenic activity "causes a rate of energy release, or seismicity, which would be expected beyond the normal level of historical seismic activity."[11]

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9. Memorandum from Ronald Bergman, Acting Dir., Drinking Water Prot. Div. of the U.S. Envtl. Prot. Agency to the UIC Program Managers of EPA Regions I-X, at ES-1 (Feb. 6, 2015) (on file with the Envtl. Prot. Agency) [hereinafter Bergman Memorandum].

10. *See* MARK D. PETERSEN ET AL., U.S. GEOLOGICAL SURVEY, INCORPORATING SEISMICITY IN THE 2014 UNITED STATES NATIONAL SEISMIC HAZARD MODEL—RESULTS OF 2014 WORKSHOP AND SENSITIVITY STUDIES 5 (2015).

11. Lawrence Berkeley Nat'l Lab., *What is Induced Seismicity?*, U.S. DEPT.

Over the decades, scientists have recognized an array of human activities known to cause earthquakes.[12] Induced seismicity has been observed in the oil and gas industry since at least the 1930s[13] and can be attributed to three types of large-scale fluid injection: wastewater disposal, hydraulic fracturing, and enhanced recovery.[14] While each process is capable of triggering seismicity,[15] the "vast majority" of the recent increase, "including the largest and most damaging quakes," has been attributed to wastewater disposal.[16] For this reason, the following analysis is primarily concerned with addressing seismicity from wastewater disposal.[17]

The basic process by which wastewater disposal causes earthquakes is relatively well understood.[18] Injecting fluids deep into a geologic fault can lubricate the formations and in rare cases may cause them to slip (i.e. suddenly release stored energy).[19] This release of energy is felt at the surface in the form of a vibration, or earthquake. Scientists at the United States Geological Survey (USGS) explain that most injection operations "do not appear to induce earthquakes," and when they do, the

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OF ENERGY EARTH SCI. DIV., http://esd1.lbl.gov/research/projects/induced_seismicity/primer.html#defined (last visited Apr. 7, 2016) [hereinafter Lawrence Lab, *Induced Seismicity*].

12. Human activities known to induce seismic events include: impoundment of reservoirs, mining, withdrawal of fluids such as oil and gas, and injection of fluids into subsurface formations. *See* FOLGER & TIEMANN, *supra* note 7, at 1.

13. Lawrence Berkeley Nat'l Lab., *Induced Seismicity-Oil & Gas*, U.S. DEPT. OF ENERGY EARTH SCI. DIV., http://esd1.lbl.gov/research/projects/induced_seismicity/oil&gas/ (last visited Apr. 7, 2016) [hereinafter Lawrence Lab, *Oil & Gas*].

14. *See* Rubinstein & Mahani, *supra* note 8, at 2.

15. Enhanced oil recovery involves production techniques (e.g. water flooding) that sweep more oil and gas toward wells than would come out on their own. *Id.* at 4.

16. *Id.* at 5.

17. The magnitude of potential harm is greatest with wastewater disposal wells because they can raise fluid pressures "more, over longer periods of time, and over larger areas, than either of the other injection methods." *Id.* at 6.

18. *See* FOLGER & TIENMANN, *supra* note 7, at 3 ("Earthquakes are induced when "human perturbation changes the amount of stress in [the] Earth's crust, and the forces that prevent faults from slipping become unequal.").

19. *See* Lawrence Lab, *Oil & Gas*, *supra* note 13.

damage is often minimal.[20] Most of the earthquakes have been aseismic, i.e. not causing any appreciable seismic activity for quakes that measure below a magnitude of three on the Richter scale.[21] However, induced seismicity associated with wastewater disposal "will become an increasingly important issue" as the United States continues to develop its domestic energy resources.[22]

B. *Hydraulic Fracturing ("Fracking") & Induced Seismicity*

Hydraulic fracturing, or "fracking," is the process of injecting a cocktail of mostly water, sand, and chemicals at high pressure into deep geologic strata to fracture hydrocarbon-bearing source rocks in order to provide permeable pathways to extract the oil and gas.[23]

However, the role that fracking plays in the increased rate of seismic activity has been misrepresented by the media and interest groups on both sides of the fracking debate.[24] Opponents sometimes assert that the fracking process itself is the cause of the recent trend in damaging earthquakes.[25] Industry loyalists counter by stating that fracking plays no role since the injections

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20. Rubinstein & Mahani, *supra* note 8, at 1. Damaging earthquakes are usually greater than magnitude 5. *See* Lawrence Lab, *Induced Seismicity*, *supra* note 11. *See also* FOLGER & TIEMANN, *supra* note 7, at 25 (explaining that "only a small fraction of the more than 30,000 U.S. wastewater disposal wells appears to be problematic for causing damaging earthquakes.").

21. FOLGER & TIEMANN, *supra* note 7, at 10.

22. Lawrence Berkeley Nat'l Lab., *About Induced Seismicity,* U.S. DEPT. OF ENERGY EARTH SCI. DIV., http://esd1.lbl.gov/research/projects/induced_seismicity/ (last visited Apr. 7, 2016) [hereinafter Lawrence Lab, *About Induced Seismicity*].

23. *See* RUSSELL GOLD, THE BOOM: HOW FRACKING IGNITED THE AMERICAN ENERGY REVOLUTION AND CHANGED THE WORLD 2 (2014).

24. Keith B. Hall, *Recent Developments in Hydraulic Fracturing Regulation and Litigation*, 29 J. Land Use & Envtl. L. 22 (2013). (explaining that "some media reports have inaccurately suggested that the injection disposal wells were wells in which hydraulic fracturing was being conducted, but those reports given an erroneous impression."). *See also* Rubinstein & Mahani, *supra* note 8, at 1 (noting that "there remains confusion in the popular press beyond this basic level of understanding" that oil and gas fluid injection contributes to seismic activity).

25. *See* Rubinstein & Mahani, *supra* note 8, at 2.

are of a short duration and use much lower volumes of water than other types of injection activities.[26] Yet both sides miss the point by focusing on the fracking process itself, rather than its contribution to the overall volume of wastewater requiring disposal. Although a few instances of fracking-related earthquakes have been observed,[27] the hydraulic fracturing process itself "does not typically induce felt earthquakes" and "does not play a key role" in the overall increase in seismicity.[28]

In other words, the process of injecting high pressure liquids during the fracking process does not, by itself, lead to the vast majority of observed seismic activity. Nevertheless, there is a connection: the exploitation of unconventional formations—made possible by fracking and other production techniques—"has contributed significantly to a growing volume of wastewater requiring disposal."[29] As a result of unconventional drilling, some of these disposal wells are also "located in geographic areas where disposal has not previously occurred."[30] Sometimes disposal wells are "bored into unmapped faults," and this practice has only become more widespread since the domestic energy boom.[31]

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26. *See id.* at 6 (explaining common misconceptions about fluid injection and earthquakes).

27. Hall, *supra* note 24, at 23 n.169. There are several locations worldwide (Oklahoma, Ohio, England, and Canada) where there is "substantial suspicion that hydraulic fracturing itself, rather than the operation of an injection well, caused induced seismic activity." *Id. See also* FOLGER & TIEMANN, *supra* note 7, at 11-12 (noting that Ohio state officials said that the fracking process "may have produced tremors in Poland Township in March 2014."); Rubinstein & Mahani, *supra* note 8, at 4 (clarifying that "in these cases, total injected volumes (630,000) were remarkably high.").

28. Rubinstein & Mahani, *supra* note 8, at 6.

29. *See* FOLGER & TIEMANN, *supra* note 7, at 13. This is especially true in places like Colorado and Texas, where production yields large volumes of produced water that must be put back underground. *See id.* However, it should be noted that in Oklahoma, the location of the largest increase, "spent hydraulic fracturing liquid does not represent a large percentage of the fluids compromising disposed wastewater." Rubinstein & Mahani, *supra* note 8, at 6.

30. Bergman Memorandum, *supra* note 9, at ES-1.

31. Miguel Bustillo & Daniel Gilbert, *Energy's New Legal Threat: Earthquake Suits*, WALL ST. J. (Mar. 30, 2015, 1:22 PM), http://www.wsj.com/articles/frackings-new-legal-threat-earthquake-suits-1427736148.

Considering this incredible uptick in seismic activity, it seems clear that finding a solution to prevent, or at least mitigate, this phenomenon is of great importance to communities feeling the brunt of the impact. Efforts are needed to ensure that oil and gas wastewater injection operations do not pose an undue risk of creating damaging earthquakes. These operations are regulated to varying degrees at the federal, state, and local level.[32]

III.
FEDERAL REGULATORY FRAMEWORK AND RESPONSE

The primary federal legal authority to address induced seismicity comes from the Safe Drinking Water Act (SDWA), which directs the EPA to "publish proposed regulations for State underground injection control programs" in order to prevent any underground injections that endanger sources of drinking water.[33] Of the more than 800 billion gallons of fluid generated annually by the oil and gas industry, over one-third is injected into Class II disposal wells.[34] The SDWA authorizes the EPA to delegate primary enforcement authority, or what is often referred to as "primacy," over the UIC program to states if they meet certain requirements.[35] If a state chooses not to assume primacy, or its plan is not approved, the EPA is responsible for implementing the UIC program in that state.[36] Most oil and gas producing states, including Colorado and Oklahoma, have assumed primacy for Class II disposal wells.[37] For this reason, and because the SDWA was not designed to address seismicity, the federal government's ability to remedy induced earthquakes is relatively limited.

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32. *See* Darlene A. Cypser, Colorado Law and Induced Seismicity 36 (Jan. 1997) (unpublished manuscript), *available at* http://www.darlenecypser.com/induceq/CLISnotes.html.

33. 42 U.S.C. § 300h(a)(1) (2012).

34. FOLGER & TIEMANN, *supra* note 7, at 13. There are 6 classes of UIC wells. *Id.* at 14.

35. *See* 42 U.S.C. § 300h-1(b); FOLGER & TIEMANN, *supra* note 7, at 14.

36. *See* 42 U.S.C. § 300h-1(c).

37. *See* FOLGER & TIEMANN, *supra* note 7, at 14.

A. *Limited Federal Jurisdiction*

The Obama Administration, through the EPA, has mostly stayed out of the issue in terms of direct regulation or federal rulemaking.[38] This is primarily due to the fact that the EPA's jurisdiction to regulate induced earthquakes "remains unclear" and it lacks the authority to do so in places where the induced seismic activity is most prolific.[39] Instead, the EPA and other federal agencies have played more of an investigative role and encouraged states to adopt certain mitigation measures.

In states like Pennsylvania where the EPA implements the UIC program, the EPA evaluates seismicity risk factors through the permitting process authorized under § 300 of the SDWA.[40] In most states where increased seismicity has been observed, however, primacy was obtained under SDWA Section 1425, thereby reducing EPA supervision over the implementation of the UIC program.[41] This means the EPA regulations "provide limited avenues for deterring" the most damaging potential threats from induced earthquakes.[42]

B. *Limited Statutory Application*

The SDWA is hampered in its ability to address induced earthquakes for several reasons. First, the statute's UIC provisions do not mention seismicity for Class II wells.[43] Even

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38. *See* Matthew Philips, *Oklahoma Earthquakes Are a National Security Threat*, BLOOMBERG (Oct. 23, 2015), http://www.bloomberg.com/news/articles/2015-10-23/oklahoma-earthquakes-are-a-national-security-threat.

39. *See* Emery G. Richards, *Finding Fault: Induced Earthquake Liability and Regulation*, 40 COLUM. J. ENVTL. L. FIELD REP. 1, 5 (2015).

40. *See* FOLGER & TIEMANN, *supra* note 7, at 17 n.69. Federal implementation requires the EPA to adhere to the minimum requirements set forth for any state implementation plan. 42 U.S.C. § 300h-1(c). Those requirements include a permitting process for underground water injection whereby only applicants that prove the injection will not endanger drinking water supply are eligible to receive a permit. *Id.* § 300h(b)(1)(A)-(B).

41. *See* Richards, *supra* note 39, at 10 n.40; 42 U.S.C. § 300h-4.

42. Richards, *supra* note 39, at 9.

43. *See* FOLGER & TIEMANN, *supra* note 7, at 17 (citing EPA regulations that cover Class II wells).

though regulations covering two categories of wells[44] do require some level of seismic evaluation in terms of siting and testing, these regulations do not apply to Class II wells.[45] Additionally, the SDWA is not well-tailored to address induced seismicity because the statute's primary aim is the protection of drinking water.[46] The UIC provisions only authorize the EPA or state overseeing the program to regulate the underground injection of fluids in order to abate hazards to aquifers and other subterranean sources of drinking water.[47] Thus, while it is "conceivable" that an induced earthquake could threaten the structural integrity of infrastructure or geologic formations that provide the public with drinking water, using this hypothesis as a justification for federal oversight of induced seismicity under the SDWA is tenuous at best.[48] The regulations do give UIC directors considerable discretion in how to protect these underground sources of drinking water, but as previously mentioned, this discretion is primarily exercised at the state level.[49] Therefore, given the limited reach of the EPA's jurisdiction to regulate seismicity under the UIC framework, regulation of induced seismicity under the SDWA is restricted to state discretion.[50]

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44. EPA regulations for Class I (hazardous waste disposal), and Class VI (CO2 sequestration) wells "specifically address evaluation of seismicity risks with siting and testing requirements." *Id. See also* 40 C.F.R. § 146.62(b)(1) (2012); *id.* § 146.82(a)(3)(iii), (v).

45. *See* FOLGER & TIEMANN, *supra* note 7, at 17.

46. Richards, *supra* note 39, at 10 n.40.

47. *See* 42 U.S.C. § 42 U.S.C. § 300h(b)(1) (2012) (requiring minimum regulations intended "to prevent underground injection which endangers drinking water sources.").

48. Richards, *supra* note 39, at 10 n.40.

49. FOLGER & TIEMANN, *supra* note 7, at 17.

50. *See* Barclay R. Nicholson, *Induced Seismicity Legal Issues Break New Ground*, LAW360 (May 15, 2015, 10:31 AM), http://www.law360.com/articles/654837/induced-seismicity-legal-issues-break-new-ground.

IV.
STATE REGULATORY RESPONSE

Unlike the federal framework, addressing induced seismicity at the state level "rests on a strong legal foundation" because regulations are passed under state enabling statutes that are designed to give state agencies broad authority to regulate sources of induced seismicity.[51] State-level regulation also has the ability to account for various factors unique to the individual state, such as "local geology, environmental concerns, and economic priorities."[52] Accordingly, it should come as no surprise that the states have been relatively more successful in regulating seismicity and wastewater disposal operations than the federal government. In their attempts to address the risks associated with increased seismicity, states have responded in a variety of ways, such as requiring seismic analysis through the well permitting process, imposing moratoriums or issuing orders to scale back on wastewater injection (and hydraulic fracturing), even enacting legislation concerning wastewater disposal.[53]

In states that administer the UIC program under Section 1425, such as Colorado and Oklahoma, the scope of authority to regulate induced earthquakes depends on the legislative delegation of power to the state entity charged with administering Class II wells in that state.[54] Since these regulatory bodies are generally provided with a "broad mandate to protect public safety and regulate oil and gas production activities," it is likely that state officials have adequate authority to address the risks of induced seismicity.[55] This broad mandate

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51. Richards, *supra* note 39, at 11.

52. *Id.*

53. *Id.* at 11 n.41. Colorado, Oklahoma, Texas, California, Ohio, Pennsylvania, South Dakota, New York, New Mexico, Louisiana, Mississippi, and West Virginia are among the states that have made changes to their Class II well requirements. *Id.* Arkansas and Ohio have imposed moratoria on wastewater injection in areas where earthquakes have occurred. *Id.* at 6.

54. *Id.* at 10 n.40, 11.

55. *Id.* at 10 n.40. States that administer the UIC program under Section 1422 also probably have authority to address seismicity since the SDWA allows these states to implement requirements more stringent than the minimum standards set by the EPA. *See* FOLGER & TIEMANN, *supra* note 7, at 18.

to protect health and safety, combined with the discretionary authority under the UIC program, allows states to add conditions to the permit process on a case-by-case basis, in addition to imposing "requirements for construction, corrective action, operation, monitoring, or reporting" as necessary to protect sources of drinking water.[56] The next section will discuss how two states, Colorado and Oklahoma, have approached this broad mandate of power and will survey the different regulatory responses from two states with the potential for induced seismicity.

A. *Colorado's Regulatory Response*

There are currently around 885 active class II wells in Colorado, and none of these injection wells have been implicated in the recent spate of earthquakes being observed east of the Rockies.[57] Nonetheless, the state has a long and familiar history with induced seismicity.

1. Rocky Mountain Arsenal

One of America's most infamous cases of injection-induced seismicity involved a series of quakes that struck near Denver in the 1960 and 1970s.[58] The most damaging earthquake weighed in at M5.3 and was considered to be the largest recorded induced earthquake in history until the M5.7 tremor that rocked Oklahoma in 2011.[59] The seismic events were eventually linked to disposal well injections of hazardous chemical wastes at the Rocky Mountain Arsenal defense plant.[60] There are similarities between the Rocky Mountain Arsenal earthquakes and recent

56. Bergman Memorandum, *supra* note 9, at ES-2. This includes the power to close an injection well. *Id.*

57. Richards, *supra* note 39, at 20.

58. *Id.*

59. *Colorado Earthquake History*, U.S. GEOLOGICAL SURVEY, http://earthquake.usgs.gov/earthquakes/states/colorado/history.php (last updated Apr. 6, 2016); Susan Garcia, *2011 Oklahoma Induced Earthquake May Have Triggered Larger Quake,* USGS NEWSROOM (Mar. 6, 2014), http://www.usgs.gov/newsroom/article.asp?ID=3819&from=rss#.VxUIu3BkBKo.

60. U.S. GEOLOGICAL SURVEY, *supra* note 59.

instances of induced seismicity occurring in the central U.S.[61] Colorado's proactive approach to managing induced seismicity is likely a reaction to the Rocky Mountain Arsenal earthquakes.

2. Rangeley Experiments

In response to the Rocky Mountain Arsenal events, USGS scientists conducted a field experiment at the Rangeley oil field in Colorado to test their suspicions regarding earthquakes and the manipulation of underground fluid pressures.[62] The scientists pumped water into a well and monitored seismic activity as they varied the amount of fluid and injection pressure.[63] The studies revealed that humans could induce earthquakes "by varying fluid pressure in a seismically active zone."[64]

3. COGCC Authority to Address Induced Seismicity

The Colorado Oil & Gas Conservation Commission (COGCC) regulates all aspects of oil and gas production within the state, including the disposal of production and exploration wastes.[65] Since it was granted primacy from EPA in 1984, the COGCC has enforced the provisions of the UIC program for Class II injection wells.[66] This broad authority includes the power to set maximum injection pressures and condition permits on certain monitoring and siting requirements that can be used to mitigate seismic

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61. *See* FOLGER & TIEMANN, *supra* note 7, at 5 (explaining that both events were induced by injecting large volumes of liquid waste under high-pressure).

62. Darlene A. Cypser & Scott D. Davis, *Liability for Induced Earthquakes*, 9 J. ENVTL. L. & LITIG. 551, 555-56 (1994). *See also* C.B. Raleigh et al., *An Experiment in Earthquake Control at Rangely, Colorado*, 191 SCI. 1230 *passim* (1976).

63. Alexandra Witze, *Artificial Quakes Shake Oklahoma*, 520 NATURE 418, 418 (2015).

64. J. Thomas Lane et al., *Carbon Sequestration: Critical Property Rights and Legal Liabilities—Real Impediments or Red Herrings?*, 32 ENERGY & MIN. L. FOUND. §23.05, §23.05(1)(b) (2011).

65. COLO. OIL & GAS CONSERVATION COMM'N, COGCC UNDERGROUND INJECTION CONTROL AND SEISMICITY IN COLORADO (Jan. 19, 2011), *available at* http://www.oilandgasbmps.org/docs/cogcc_seismicity_co.pdf.

66. *Id.*

risk.[67] Historically, the COGCC has regulated seismicity indirectly through its regulations on maximum injection pressures even though there has been relatively little incidence of induced earthquakes since Rocky Mountain Arsenal. Its regulations have also evolved in response to the increased concern related to oil and gas wastewater disposal.[68]

In 2011, the injection of produced wastewater from a coal bed methane field in the Raton Basin very likely triggered a large earthquake (M5.3) near Trinidad, Colorado.[69] The COGCC responded a month later by expanding the UIC permit review process to specifically include a seismicity review for Class II oil and gas wastewater disposal.[70] The COGCC now works in conjunction with the Colorado Geological Service (CGS) and USGS to conduct an initial report analyzing the potential of inducing seismicity.[71] If historic seismicity or certain preexisting conditions are identified near a proposed disposal site, the agency requires the well operator "to define the seismicity potential and the proximity to faults through geologic and geophysical data prior to any permit approval."[72]

Outside the permit review process, COGCC utilizes a "stoplight system"[73] to shut down injection wells if certain levels

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67. Darlene A. Cypser, Colorado Law and Induced Seismicity, at 37 (Dec. 1996) (unpublished manuscript), *available at* http://www.researchgate.net/publication/273789334_Colorado_Law_and_Induced_Seismicity.

68. Richards, *supra* note 39, at 21-22.

69. *Id.* at 21; *see also* W. D. Barnhart et al., *Seismological and Geodetic Constraints on the 2011 M_w5.3 Trinidad, Colorado Earthquake and Induced Deformation in the Raton Basin*, 119 J. GEOPHYSICAL RES., 7923 *passim* (2014).

70. Richards, *supra* note 39, at 21-22; FOLGER & TIEMANN, *supra* note 7, at 20-22.

71. COLO. OIL & GAS CONSERVATION COMM'N, CLASS II UNDERGROUND INJECTION CONTROL WELLS 1-2 (2015), *available at* http://cogcc.state.co.us/documents/about/TF_Summaries/GovTaskForceSummary_Engineering%20UIC%20Wells.pdf. The permit process also involves review and approval of well construction, isolation of ground water aquifers, maximum injection pressure, maximum injection volume, and injection zone water quality. *Id.*

72. *Id.* at 2.

73. Nicholson, *supra* note 50. Like a traffic light, the regulations authorize injection disposal activities "when observed seismicity levels are low, slow operations when seismicity reaches a certain threshold, and cut operations off entirely above a point." *Id.*

of seismicity are observed.[74] Further, the agency partnered with the CGS, USGS, and state universities to establish an "induced seismicity advisory group" in order to foster a more comprehensive monitoring and guidance network.[75] Colorado's proactive measures also include financial assurance requirements imposed on well operators to compensate persons or property injured by earthquakes.[76] These requirements are "likely insufficient to fully compensate" the damage, however, since they were originally designed to protect against "more garden-variety forms of environmental damage" like water contamination.[77] Nonetheless, since the COGCC implemented these requirements, the state has not experienced significant seismicity connected to anthropogenic activity.[78]

B. *Oklahoma's Response to Induced Earthquakes*

Nowhere has the recent uptick in seismic activity been more evident than in Oklahoma.[79] In 2014, Oklahoma was the most seismically active state in the continental U.S., enduring more earthquakes than it experienced in the previous thirty years combined.[80] The Sooner State is on pace to double that amount in 2015,[81] as "the frequency and severity of these earthquakes are both on the rise."[82] The explanation for these events appears

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74. Trent Jacobs, *Searching for Solutions to Induced Seismicity*, J. PETROLEUM TECH. (Sept. 1, 2014), http://www.spe.org/jpt/article/7139-searching-for-solutions-to-induced-seismicity/; Bridgett Weaver, *COGCC Has a Plan for Future Earthquakes*, GREELEY TRIB. (Jan. 29, 2015), http://www.greeleytribune.com/news/14763491-113/cogcc-has-a-plan-for-future-earthquakes.

75. FOLGER & TIEMANN, *supra* note 7, at 22.

76. COLO. CODE REGS. § 404-1:706-07, 712 (2015).

77. Richards, *supra* note 39, at 22.

78. *Id.*

79. *Id.* at 3. Arkansas, Texas, and Ohio have also experienced damaging quakes with suspected links to wastewater from oil and gas operations. *Id.*

80. Bustillo & Gilbert, *supra* note 31.

81. Philips, *supra* note 38.

82. Blake Watson & Catrina Rorke, *Should Oil Firms Be Held Liable in Earthquake Lawsuits?*, WALL St. J. (Nov. 15, 2015, 10:11 PM), http://www.wsj.com/articles/should-oil-firms-be-held-liable-in-earthquake-lawsuits-1447643517.

to be induced seismicity.[83]

In 2011, a M5.6 earthquake struck near the town of Prague, damaging roads and destroying at least fourteen homes.[84] The seismic event was the largest recorded earthquake in Oklahoma history and one of many unprecedented tremors that have hit the region in recent years.[85] Scientists concluded that the massive tremor was facilitated by the operations of nearby oil and gas wastewater disposal wells.[86]

1. Denial and Delayed Response from State Officials

Oklahoma regulators have been slow to address their problems of induced seismicity, but in the face of increasing outside pressure and studies warning of the risk, state officials have started to implement mechanisms similar to those employed in Colorado.

Like the COGCC, the Oklahoma Corporation Commission ("OCC") is vested with exclusive jurisdiction over oil and gas Class II UIC disposal wells.[87] Given the state's historically low incidence of earthquakes, the OCC traditionally did very little to address potential risks from induced seismicity. Yet despite being the focus of the current upswing in earthquake activity, Oklahoma did not enact permit requirements or other regulations until very recently.[88] The delayed response may have

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83. The U.S. Geological Survey began warning in 2012 that a "remarkable" surge in earthquakes in Oklahoma was likely linked to disposal operations (or paying attention since). *See* Mike Soraghan, *Earthquakes: Sierra Club Threatens to Sue Drillers to Stop Okla. Shaking*, E&E NEWS (Nov. 3, 2015), http://www.eenews.net/stories/1060027316.

84. Bustillo & Gilbert, *supra* note 31.

85. *Id.*

86. *Id.* Several lawsuits have been filed against the companies seeking damages under common law tort theories. *See, e.g.*, Ladra v. New Dominion, LLC, 353 P.3d 529 (Okla. 2015) (seeking damages for personal injury stemming from the 2011 earthquake); Cooper v. New Dominion, LLC, No. CJ-2015-0024 (Lincoln Cnty. Dist. Ct. Okla. Feb. 10, 2015) (seeking class-action status for people whose property was damaged by the 2011 earthquake).

87. OKLA. STAT. tit. 52, §139(D) (2006). The OCC is an independent agency with three elected commissioners. *See* Craig D. Sundstrom, *Oklahoma Regulators Implement Evolving Regulatory Directives in Response to Earthquakes*, 46 NO. 6 ABA TRENDS 4 (2015).

88. Richards, *supra* note 39, at 11.

something to do with petroleum politics.[89]

It is important to remember that "[o]il is the Oklahoma business"[90] and the state's largest employer. Interfering with the industry is highly unpopular.[91] Oil and gas officials have been slow to acknowledge the link connecting seismicity to injection wells, and they successfully lobbied the state legislature to pass laws limiting the ability of municipalities to regulate wells within their communities.[92] OCC officials explain that they are "struggling to devise a plan that would curb earthquakes without hamstringing" the oil and gas industry.[93]

Scientists at the Oklahoma Geological Survey (OGS) have also been pressured to deemphasize the evidence linking wastewater disposal to induced seismicity.[94] The OGS's chief seismologist stepped down in the fall of 2015 after relentless pressure from the industry to minimize the impact of injection wells on earthquakes in the area.[95] OCC officials had been "waffling" about the science for years until April 2015, finally succumbing to mounting evidence showing a link between the earthquakes

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89. *Id.* at 30-31. *See generally* Witze, *supra* note 63, at 419 (emphasizing that oil and gas companies wield great power in Oklahoma).

90. GOLD, *supra* note 23, at 170 (explaining that it is a "point of pride for many Oklahomans to be invested in a well or two").

91. *See* Mike Soraghan, *Earthquakes: Okla. Officials May Lack Authority on Seismicity Issues*, E&E NEWS (Oct. 9, 2015), http://www.eenews.net/stories/1060026113 (noting that "as many as one in five jobs are tied to the industry, and most politicians rely on industry executives for campaign contributions.").

92. Richard A. Oppel, Jr., *Oklahoma Court Rules Homeowners Can Sue Oil Companies Over Quakes*, N.Y. TIMES (June 30, 2015), http://www.nytimes.com/2015/07/01/us/oklahoma-court-rules-homeowners-can-sue-oil-companies-over-quakes.html.

93. Maria Gallucci, *Oklahoma Earthquake Swarm: Groups Start Legal Process To Sue Oil Companies Over Wastewater Injections*, INT'L BUS. TIMES (NOV. 2, 2015, 6:16 PM), http://www.ibtimes.com/237klahoma-earthquake-swarm-groups-start-legal-process-sue-oil-companies-over-2165858 (emphasizing that the industry is a major driver of state revenues).

94. Michael Wines, *New Concern Over Quakes in Oklahoma Near a Hub of U.S. Oil*, N.Y. TIMES (Oct. 14, 2015), http://www.nytimes.com/2015/10/15/us/new-concern-over-quakes-in-oklahoma-near-a-hub-of-us-oil.html.

95. *Id.* The OCC's enforcement budget was also cut by about 45% in July 2015. *Id.*

and injection well disposal.[96] The OCC's shift in stance was unexpected, and state leaders released a statement citing a determination by the OGS that "the majority of recent earthquakes in central and north-central Oklahoma are very likely triggered" by wastewater disposal wells.[97] Since then, the OCC has developed a slowly evolving regulatory response.[98]

2. Recent OCC Efforts & Challenged Authority

The OCC has used authority to "persuade" companies in seismically sensitive areas to limit the amount of wastewater they inject.[99] For example, after a series of quakes hit near the Cushing Oil Hub complex[100] – one of the largest crude storage hubs in the world and critical to America's energy security in terms of supply – the OCC "ordered wells within three miles to shut down entirely" and ordered some more remote wells to reduce their volume by twenty-five percent.[101] The OCC has also instituted a stoplight system for UIC well permitting similar to the framework adopted by Colorado.[102] Entities subject to the

96. *See* Soraghan, *supra* note 91.

97. *See* Oppel, *supra* note 92.

98. Okla. Office of the Sec'y of Energy & Env't, *Oklahoma Corporation Commission*, EARTHQUAKES IN OKLA., http://earthquakes.ok.gov/what-we-are-doing/oklahoma-corporation-commission/ (last visited Apr. 7, 2016).

99. *See* Wines, *supra* note 94. For example, in August 2015 the OCC ordered a 38% cut in the amount of wastewater injected underground by operators of 23 injection wells located within a 40-mile stretch northeast of Oklahoma City. *See* Media Advisory, Okla. Corporation Comm'n, Oil and Gas Disposal Well Volume Reduction Plan (Aug. 3, 2015), *available at* https://www.occeweb.com/News/08-03-15VOLUME%20ADVISORY%20RELEASE.pdf.

100. YERGIN, *supra* note 3, at 159. The Cushing Hub is often considered "ground zero" for the world price since is serves as the "gathering point for light, sweet crude known as West Texas Intermediate (WTI)" that provides a reference point for futures traded on the New York Mercantile Exchange. *Id.* After 9/11, U.S. government officials highlighted Cushing as a potential terrorist target, labeling the hub as "critical national infrastructure." *See also* Philips, *supra* note 38 (arguing that "[I]f even a couple of Cushing's tanks had to shut down, or a pipeline were damaged, the impact could ripple through the market.").

101. Philips, *supra* note 38. The largest quake (M4.5) hit within a few miles of town and rattled the complex's massive tanks. *Id.*

102. KYLE E. MURRAY, OKLA. GEOLOGICAL SURVEY, CLASS II UNDERGROUND INJECTION CONTROL WELL DATA FOR 2010–2013 BY GEOLOGIC ZONES OF

new regulations can appeal the OCC's actions and request a hearing before an administrative law judge.[103]

However, the success of these regulatory efforts hinges on voluntary compliance from the industry, given that existing permits issued before the stoplight system entered into force do not need to be renewed under this new regulatory scheme.[104] Further, concerns are mounting as to whether the OCC has the legal authority to limit the shaking at all.[105] In October 2015 a Tulsa-based energy company filed the first challenge to the OCC's efforts to rein in seismic inducing operations, particularly the agency's controversial volume restrictions adopted in August.[106] The company argues that the rules enacted under the UIC program are supposed to be focused on "cleaning up pollution, not preventing earthquakes," and more companies might join the effort to rein in the OCC's efforts.[107] In a recent review of Oklahoma's UIC program, the EPA urged the OCC to "implement additional regulatory actions."[108] However, even with the OCC stepping up its enforcement efforts, the agency might not have the power to "seriously curb waste disposal, and politicians in a state dominated by the energy industry have made no move to give it to them."[109] Accordingly, the best solution for mitigating seismicity might instead lie with voluntary efforts from the industry itself.

COMPLETION, OKLAHOMA 32 (2014), *available at* http://www.ogs.ou.edu/pubsscanned/openfile/OF1_2014_Murray.pdf. The traffic light regulations apply to both new and existing wells in seismically active areas. An important component is OCC's "delineation of areas of interest, which are determined by proximity to recent seismic swarms or groups of seismic events." *Id.*

103. Sundstrom, *supra* note 87.

104. *See id.*

105. *See id.*; Soraghan, *supra* note 91.

106. *See* Wines, *supra* note 94 (arguing that its wells are not contributing to the problem). However, OCC might "prevail under its public safety backstop authority," though this argument has not yet been tested with regards to seismicity concerns. Sundstrom, *supra* note 87.

107. Soraghan, *supra* note 91. *See also* Murray, *supra* note 102 (explaining that the current regulatory controls "were designed to protect potable-water resources from contamination.").

108. Philips, *supra* note 38.

109. Wines, *supra* note 94.

V.

VOLUNTARY INDUSTRY EFFORTS IN RESPONSE TO INDUCED SEISMICITY: CORPORATE SOCIAL RESPONSIBILITY & SOCIAL LICENSE TO OPERATE

Mitigating the most damaging effects from induced seismicity will require "detailed seismic monitoring, careful selection of injection locations, variation of injection rates and pressures in response to ongoing seismicity, and a clear management plan."[110] But unfortunately, regulators have limited resources and information to address seismicity.[111] Due to the private sector's superior geophysical knowledge and capacity to address seismic issues as they unfold, voluntary mitigation efforts from industry participants will likely have the greatest impact.[112]

Addressing seismicity head-on is important to mitigating the effects of potentially damaging earthquakes, but is also important for gaining public acceptance and alleviating conflicts with the surrounding community.[113] Indeed, the mere presence of a potential seismic hazard "creates a stigma of harm," regardless of the fact that the threat of induced earthquakes is relatively low.[114] Rather than responding "only after the risk manifests into a full-blown crisis," companies should engage in more proactive measures to address induced seismicity.[115]

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110. Rubinstein, *supra* note 8, at 6.

111. *See* Murray, *supra* note 102 (explaining that "there is an urgent need to quantify volumes and pressures" and obtain additional data "to develop best management practices" for wastewater disposal).

112. Nicholson, *supra* note 50. It should be noted that well disposal operations are conducted by both "entities that charge hydraulic fracturing operators a fee for disposing of their wastewater" (i.e. commercial injection); in addition to oil and gas E&P companies that dispose of their own wastewater (i.e. non-commercial injection). While important for liability purposes, this distinction is beyond the scope of this article. For a more in-depth discussion of how this distinction plays into earthquake liability, see Richards, *supra* note 39, at 4, 31.

113. *See* Lawrence Lab, *About Induced Seismicity*, *supra* note 22 (providing "access to high quality, state of the art seismic information will be important for both public acceptance and industry response.").

114. Don C. Smith & Jessica M. Richards, *Social License to Operate: Hydraulic Fracturing-Related Challenges Facing the Oil & Gas Industry*, 1 OIL & GAS, NAT. RESOURCES, & ENERGY J. 81, 83 (2015).

115. Reilly Goodwin, Risk Mitigation Through CSR and Sustainability 4 (2015) (unpublished manuscript) (on file with author).

The oil and gas industry is "being scrutinized more than ever,"[116] and technology has enabled citizens to demand greater accountability from operators than in the past.[117] This is especially true in places like Colorado where population growth and urban sprawl collides with unconventional shale development.[118] Modern societies expect oil and gas companies to self-regulate, taking efforts beyond merely complying with the law.[119] Sometimes expressed as an "ongoing social contract with society" or a "social license to operate," companies should manage the risks of induced seismicity in terms of social political risk, not just in terms of actual physical damage resulting from the quakes.[120] This process involves engaging in early and "ongoing communication at the community level, transparency, and engagement in decision making, and the establishment of effective conflict resolution mechanisms."[121] But besides addressing local community issues and earning trust prior to the occurrence of a seismic event, what other strategies can companies deploy to mitigate the impact?[122]

These additional efforts might involve taking the operation management steps quoted at the beginning of this section.[123] In the absence of an insurance market, and in addition to financial assurance requirements like those imposed by the COGCC, the industry can create its own compensation pool to reimburse those injured by induced earthquakes.[124] Disposal wells could be

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116. GOLD, *supra* note 23, at 26.

117. *See* Goodwin, *supra* note 115, at 4 (explaining that "[t]he collision of globalization, the internet, social media, and a growing consciousness of human impacts on the natural environment is empowering stakeholders and creating greater expectations of accountability and transparency from the world's corporate citizens.").

118. Smith, *supra* note 114, at 82.

119. *See* David B. Spence, *Corporate Social Responsibility in the Oil and Gas Industry: The Importance of Reputational Risk*, 86 CHI.-KENT. L. REV. 59, 60 (2010) (arguing that citizens demand CSR from oil and gas companies, "[p]erhaps more so than in any other industry.").

120. *See* Smith, *supra* note 114, at 89.

121. *Id.* at 84.

122. *See id.* at 138.

123. *See* Rubinstein & Mahani, *supra* note 8, at 6.

124. Watson & Rorke, *supra* note 82.

placed further apart or located in areas that are less populated.[125] Industry might also develop more creative ways of handling and disposing of oil and gas wastewater.

Currently, injection of wastewater deep underground is considered to be the "environmentally preferred option" for disposing of wastewater produced by, or associated with, oil and gas production.[126] One alternative disposal method would be to stop injecting wastewater into the traditional geologic formations that have resulted in seismic activity, and instead send the contaminated water back into the formation from which it was extracted.[127] Another option would be to reuse some of the wastewater to create new fracking fluids or to re-fracture the production wells. Water is the "hydraulic heart"[128] of the fracking process, and recycling the wastewater has the potential to cut down on the load of underground disposal wells while conserving precious water resources at the same time.[129] However, this relatively new practice may not be the most cost-effective option for oil and gas producers.[130]

Wastewater recycling and other alternative disposal methods entail significant transportation costs, in addition to treating the water and removing hazardous pollutants.[131] To reduce their injection volumes, companies have to either limit extraction operations or pay to ship waste further away for disposal.[132] This might be particularly burdensome for smaller companies already struggling to survive since the dramatic drop in oil prices of in 2014.[133] Since prices fell, the new mantra among shale producers

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125. Chris Faulkner, *Fracking-Related Quakes May Keep Courts Busy*, 32 WESTLAW J. TOXIC TORTS 11, at *4 (2014).

126. FOLGER & TIEMANN, *supra* note 7, at 13.

127. F. Rall Walsh III & Mark Zoback, *Oklahoma's Recent Earthquakes and Saltwater Disposal*, SCI. ADVANCES, June 18, 2015, at 8, *available at* http://advances.sciencemag.org/content/advances/1/5/e1500195.full.pdf.

128. GOLD, *supra* note 23, at 51. Almost all of the water that makes up the "gelatinous glop" used to frack wells is snowmelt from the Rocky Mountains that flows into the Missouri River and into giant reservoirs. *Id.*

129. *See* Faulkner, *supra* note, 125 at 3.

130. *See id.*

131. *See id.*

132. Soraghan, *supra* note 91.

133. The energy boom ended abruptly in mid-2014 when the price of oil in

is "thrift," and capacity has been cut across the industry – particularly in projects with high production costs.[134] Nevertheless, experience shows that mitigating the risk of seismicity can be handled in a cost-effective manner.[135]

Moreover, engaging in robust corporate social responsibility not only mitigates seismic risk, but it can also improve the competitive value of individual producers.[136] If producers remain passive, unmitigated seismic risk can create social risks with the potential to undermine industry finances.[137] Many oil and gas companies have reached this conclusion and recognize that it is in their financial interest to pay "greater attention to the needs and wants of external stakeholders."[138] Many industry participants are developing a set of best practices for mitigating seismic risk, and several leading companies now have seismic mitigation policies.[139] If more companies embrace this strategy, there will be less need for reactionary command-and-control regulation.

America dropped from $100 to $43. *See Fractured Finances*, ECONOMIST (July 4, 2015), http://www.economist.com/news/business/21656671-americas-shale-energy-industry-has-future-many-shale-firms-do-not-fractured-finances [hereinafter *Fractured Finances*].

134. *See id. See also*, *There Will Be Blood*, ECONOMIST (July 4, 2015), http://www.economist.com/news/leaders/21656707-ingenuity-americas-shale-industry-admirable-state-its-finances-awful-there-will (elaborating that "gone are the days when roughnecks were fed lobster in luxury camps and Texan towns were circled by Learjets.").

135. *See Fractured Finances*, *supra* note 133 (emphasizing the shale industry's "entrepreneurial spirit and its skill in both geological and financial engineering.").

136. *See* Goodwin, *supra* note 115, at 6; Spence, *supra note* 119, at 84.

137. *See* Daniel M. Franks et al., *Conflict Translates Environmental and Social Risk Into Business Costs*, 111 PROC. NAT'L ACAD. SCI. 7576, 7576 (2014) (explaining that social conflict is a "further means through which environmental and social risks are translated into business costs and decision making.").

138. Spence, *supra* note 119, at 84.

139. *See* Richards, *supra* note 39, at 5. ExxonMobil has established a protocol and other companies are beginning to follow suit. *Id.*; *see also* Nicholson, *supra* note 50 (noting that some companies voluntarily utilize stop light protocols in their injection operations).

VI.
CONCLUSION

State regulation of induced seismicity can have a strong deterrent effect, but if regulators are slow to address induced seismicity in a meaningful way, some operators may ignore the risk.[140] Given its extensive history with induced earthquakes and its preventative approach to mitigate potential threats, Colorado has developed a strong regulatory framework.[141] Its earthquakes ceased after proactive measures were imposed.[142] By contrast, in Oklahoma, where the oil and gas industry makes up a large portion of the economy and has substantial influence over the state's politics, "inertia against regulation" is particularly high.[143] The OCC's regulatory response was merely reactive, delayed, and the state continues to experience rising levels of induced seismicity.[144] The Colorado approach demonstrates that establishing an affirmative scientific link is not a prerequisite for taking early action to address the potential of induced seismicity.[145]

In the wake of America's energy boom, addressing induced seismicity can be difficult.[146] Whether you are an industry lobbyist or an ardent "fracktivist," solving the problems associated with seismicity requires constructive dialogue and compromise.[147] Finding the right balance requires continued development of hydrocarbon resources, but also judicious

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140. Richards, *supra* note 39, at 30-31.

141. *See id.* at 32-33.

142. *Id.* at 30.

143. *Id.* at 31; GOLD, *supra* note 23, at 26.

144. Richards, *supra* note 39, at 30.

145. *See* Bergman Memorandum, *supra* note 9, at ES-3.

146. *See* GOLD, *supra* note 23, at 296-97 (explaining that "the forces arrayed in favor and against don't speak the same language."). *See also* Ehrman, *supra* note 4, at 426–27 (arguing that "environmental issues, industry lobby efforts, and intentional relations have all prevented a comprehensive national energy policy that would address current and potential supply along with corresponding reductions in demand.").

147. *See* Ehrman, *supra* note 4, at 464 (asserting that "without compromise regarding our energy future we may face a decrease in industrial growth and an increase in environmental harm."); YERGIN, *supra* note 3, at 723.

regulatory monitoring and community engagement.[148] The best approach is to "broadly align government policy and market forces" in order to create new best practices and mitigation strategies in the context of induced seismicity.[149] Within this collaborative framework, various entities take on different roles: geoscientists investigate the link between oil and gas production and increasing seismic activity and also demystify false assumptions regarding the science; courts and regulators hold companies accountable when they ignore the risks of induced seismicity; and the oil and gas industry tailor their operations to decrease their role in inducing earthquakes.[150]

148. *See* Ehrman, *supra* note 4, at 464.

149. *See* GOLD, *supra* note 23, at 307.

150. Bergman Memorandum, *supra* note 9, at ES-2. The EPA stresses the use of this multidisciplinary approach. *Id.*