COMMENTS

Seismicity Induced by Hydraulic Fracturing and Wastewater Disposal Injection: A Comparison of Regulatory Frameworks

Katherine Davis*

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I. INTRODUCTION

Human-induced earthquakes, commonly referred to as "induced seismicity," are an important topic of global interest because of the increasing concern that activities associated with hydraulic fracturing may cause damaging earthquakes in regions that typically do not experience much seismic activity.[1] Beginning in the late 1990s, the use of horizontal drilling in hydraulic fracturing to extract oil and gas from tight shale formations has led to the development of new shale oil and gas fields in many parts of the central and eastern United States, western Canada, and the United Kingdom (U.K.).[2] With the expansion of unconventional oil

* © 2018 Katherine L. Davis. J.D. candidate 2019, Tulane University Law School; B.B.A. 2015, University of Georgia. She would like to thank Professor Robert Sloan for the inspiration for this topic and guidance with her research. She also thanks her friends and family for their love and encouragement over the years. She is especially indebted to Angela Davis and Andrew Blasio for their constant support.

1. William Ellsworth, *Injection-Induced Earthquakes*, 341 SCI. 1, 3 (July 12, 2013), http://www.sciencemag.org/content/341/6142/1225942.full.pdf.
2. *Id.*

and gas production in these countries, there have been significant recorded increases in seismic activity in areas near the hydraulic fracturing operations.[3] Research suggests a strong correlation between seismicity and both hydraulic fracturing and wastewater disposal injection.[4] The global development of oil and gas from shale will likely continue to expand because the resource potential is high in many parts of the world, and many countries aim to become more energy independent.[5] Induced seismicity associated with fracking activities has prompted a variety of responses in countries where it has been experienced, including research, moratoria, regulation, and litigation.[6]

This Comment analyzes the regulatory frameworks of three countries that have experienced notable induced seismicity associated with fracking activities, namely the United States, Canada, and the United Kingdom. In analyzing and comparing these regulations, it is important to consider an overarching question: What constitutes the ideal framework for confronting the risks of seismicity induced by hydraulic fracturing and wastewater disposal injection?

A. *What Is Fracking?*

Hydraulic fracturing, or "fracking," is a technique used in the extraction of oil and gas from tight shale rock formations by injecting fluids at a high pressure along horizontally drilled wells.[7] It was initially developed in the 1940s primarily to improve the output of aging oil and gas reservoirs.[8] In the late 1990s, horizontal drilling and technological

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3. Bryan Walsh, *The Seismic Link Between Fracking and Earthquakes*, TIME (May 1, 2014), http://time.com/84225/fracking-and-earthquake-link/; Gail Atkinson et al., *Hydraulic Fracturing and Seismicity in the Western Canada Sedimentary Basin*, 87 SEISMOLOGICAL RESEARCH LETTERS NO. 3, 1, 2 (2016); *Seismicity*, UKOOG, http://www.ukoog.org.uk/regulation/seismicity (last visited Mar. 18, 2018).

4. Ellsworth, *supra* note 1; Atkinson et al., *supra* note 3; *Fracking 'Probable' Cause of Lancashire Quakes*, GUARDIAN (Nov. 2, 2011), https://www.theguardian.com/environment/2011/nov/02/fracking-cause-lancashire-quakes.

5. Ellsworth, *supra* note 1, at 3.

6. Emery Richards, *Finding Fault: Induced Earthquake Liability and Regulation*, COLUM. J. ENVTL. L. 1, 6 (2015).

7. *The Process of Unconventional Natural Gas Production*, U.S. ENVTL. PROTECTION AGENCY, https://www.epa.gov/uog/process-unconventional-natural-gas-production (last visited Mar. 20, 2018).

8. MARY TIEMANN & ADAM VANN, CONG. RESEARCH SERV., HYDRAULIC FRACTURING AND SAFE DRINKING WATER ACT REGULATORY ISSUES 1 (2015) [hereinafter SDWA ISSUES].

advancements changed the future of fracking by allowing it to be used to extract natural gas and oil from shale rock formations.[9]

Oil and gas wells are drilled thousands of feet below the surface and may include horizontal or directional sections extending thousands of feet.[10] Fracking involves the "controlled injection of fluid" under enormous pressure to fracture the shale rock formation.[11] The fracturing fluid usually contains water, proppant, and chemicals.[12] The proppants, usually sand, ceramic pellets or other small incompressible particles, are included in the mixture to hold open the newly created fractures to allow the oil or gas to flow freely out of the formation and into a production well.[13] A single production well may be fracked multiple times, using between 500,000 and 10 million gallons of water, along with proppant and chemicals.[14] When the injection process is completed, the fluid is pumped back up to the surface.[15] This fluid, now called "flowback," combined with naturally occurring materials, such as brines, metals, radionuclides, and hydrocarbons that are pumped to the surface, is collectively called "produced water."[16] Produced water is commonly "stored on site in tanks or pits before treatment, disposal or recycling."[17] Often, it is injected deep underground for disposal.[18] The increase of fracking activities has led to an increase in the volume of wastewater requiring disposal and demand for more deep disposal wells.[19]

The practice of fracking is highly controversial, with much debate surrounding the perceived benefits and drawbacks.[20] Some benefits may include job creation, a smaller carbon footprint, less costly oil and gas extraction, and the possibility for a country to become more energy

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9. *See id.*; Ellsworth, *supra* note 1, at 3.
10. *The Process of Unconventional Natural Gas Production*, *supra* note 7.
11. Ellsworth, *supra* note 1, at 3.
12. *The Process of Unconventional Natural Gas Production*, *supra* note 7.
13. *Id.*; SDWA ISSUES, *supra* note 8, at 1.
14. SDWA ISSUES, *supra* note 8, at 2.
15. *Id.* at 1.
16. *The Process of Unconventional Natural Gas Production*, *supra* note 7.
17. *Id.*
18. *Id.*
19. BC OIL & GAS COMM'N, INVESTIGATION OF OBSERVED SEISMICITY IN THE MONTNEY TREND, 2014, at 1 (Can.) [hereinafter MONTNEY TREND]; PETER FOLGER & MARY TIEMANN, CONG. RESEARCH SERV., HUMAN-INDUCED EARTHQUAKES FROM DEEP-WELL INJECTION: A BRIEF OVERVIEW 1 (2016) [hereinafter DEEP-WELL INJECTION].
20. *See generally* John Wihby, *Pros and Cons of Fracking: 5 Key Issues*, YALE CLIMATE CONNECTIONS (May 27, 2015), https://www.yaleclimateconnections.org/2015/05/pros-and-cons-of-fracking-5-key-issues/.

independent.[21] Fracking arguably has several environmental risks including contamination of aquifers and drinking water, air and noise pollution, negative impacts on the communities near fracking operations, and induced seismicity—the focus of this Comment.[22]

B. *Induced Seismicity Basics*

It is well established that certain human activities induce earthquakes.[23] For instance, mining activities, construction of dams and water reservoirs, oil and gas production, geothermal energy production, and injection of fluids into subsurface formations are historic causes of human activity-induced earthquakes.[24] The determination of whether or not a seismic event was induced is often complex; it involves considering background seismicity, distance from hydraulic fracturing or disposal operations, and the timing of the event compared to the timing of operations.[25]

Two types of induced seismicity are associated with fracking: hydraulic fracturing-induced seismicity and wastewater disposal-induced seismicity.[26] As previously discussed, fracking involves the high-pressure injection of fluid to intentionally crack the rock formation to enhance production.[27] This practice routinely induces "micro-earthquakes" below magnitude 1, which are too small to be felt on the surface.[28]

The second type of induced seismicity associated with fracking involves the injection of wastewater from fracking activities into deep disposal wells.[29] The U.S. Environmental Protection Agency (EPA) has identified three key components contributing to injection-induced seismicity:

> (1) an increase in the formation pore pressure from disposal activities; (2) a fault (or zone of multiple faults and fractures) optimally oriented for movement, located in a critically stressed region, of sufficient size, and

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21. *See id.*
22. *Id.*
23. U.S. ENVTL. PROT. AGENCY, DISTRIBUTION OF FINAL WORK PRODUCT FROM THE NATIONAL UNDERGROUND INJECTION CONTROL (UIC) TECHNICAL WORKGROUP 1 (2015), [hereinafter PRACTICAL APPROACHES]; DEEP-WELL INJECTION, *supra* note 19, at 1.
24. DEEP-WELL INJECTION, *supra* note 19, at 1.
25. MONTNEY TREND, *supra* note 19, at 11; *see* DEEP-WELL INJECTION, *supra* note 19, at 4.
26. *See* MONTNEY TREND, *supra* note 19, at 7.
27. Ellsworth, *supra* note 1, at 3.
28. *Id.*
29. *Id.*

> possessing sufficient accumulated stress/strain, such that fault slip and movement would have the potential to cause a significant earthquake (Fault of Concern); and (3) a permeable avenue (matrix or fracture permeability) allowing the pore pressure increase to reach the fault.[30]

For both types of induced seismicity, "the trigger mechanism is essentially the same—fluid is injected into or near an underground fault at high enough pressures for driving stresses to overcome normal stresses, resulting in fault movement."[31] However, there are several notable differences. For instance, injection into disposal wells occurs for an extended period of time, months or years, while injection for fracking is a short-term event.[32] Also, after fracking a well, much of the injected fluid is pumped back up to the surface, decreasing the pressure within the formation.[33] The injected fluid volume in disposal wells is not commonly flowed back.[34] Further, the distance of triggered events is different.[35] Injection into disposal wells can trigger distant fault movement miles away from the injection point.[36] In contrast, events triggered by fluid injection during fracking are usually very close to the injection point.[37]

The risks associated with earthquakes include, among other things, death, injury, destruction of infrastructure, landslides, and flooding.[38] There is debate among experts about whether fracking or wastewater disposal injection poses a greater risk of inducing destructive earthquakes.[39] In the United States, the significant increase in the rate of earthquakes of magnitude 3 or greater in the central states has been attributed to the injection of wastewater into disposal wells.[40] Thus, much of the concern about earthquakes and fracking centers on the injection of wastewater.[41] However, studies in Canada and the United Kingdom have found a high level of correlation between seismicity and fracking, rather than disposal well injection.[42]

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30. PRACTICAL APPROACHES, *supra* note 23, at 9.
31. MONTNEY TREND, *supra* note 19, at 7.
32. PRACTICAL APPROACHES, *supra* note 23, at 2.
33. *See id.*
34. MONTNEY TREND, *supra* note 19, at 7.
35. *Id.*
36. *Id.*
37. *Id.*
38. *See generally* Wihby, *supra* note 20.
39. Ellsworth, *supra* note 1, at 3; Atkinson et al., *supra* note 3, at 2.
40. Atkinson et al., *supra* note 3, at 1.
41. Ellsworth, *supra* note 1, at 3.
42. *See* Atkinson et al., *supra* note 3, at 2.

II. ANALYSIS OF REGULATORY FRAMEWORKS REGARDING INDUCED SEISMICITY BY COUNTRY

A. United States

The United States is the global leader in fracking, currently boasting over 300,000 hydraulically fractured wells, compared to about 23,000 in the year 2000.[43] Fracking made up less than two percent of American oil production in 2000, but currently it accounts for more than half of all U.S. oil output.[44] It has created an oil and gas boom in the country, which is now affecting global markets.[45] As of 2014, the United States is the world's top producer of petroleum and natural gas hydrocarbons.[46] However, as fracking has grown in the United States, so has the number of earthquakes, particularly in the central and eastern states that conduct fracking activities.[47] More than 100 quakes of magnitude 3.0 or larger were recorded each year between 2010 and 2013, compared to an average of twenty-one per year over the preceding three decades.[48] Although, only a small fraction of the more than 30 thousand wastewater disposal wells in the country have been associated with induced seismicity.[49]

Since the dawn of fracking in the United States, there has been much debate between industry and environmentalists over whether and how the practice should be regulated.[50] Under the current framework, the federal government has little power to regulate fracking, and much authority rests with the states.[51] The Safe Drinking Water Act (SDWA) of 1974 is "the principal law authorizing federal regulation of underground injection activities."[52] The SDWA authorizes the EPA to regulate the underground injection of fluids to prevent underground injection that endangers drinking water sources.[53] The SDWA directs the EPA to "promulgate

43. Matt Egan, *Oil Milestone: Fracking Fuels Half of U.S. Output*, CNN MONEY (Mar. 16, 2018), http://money.cnn.com/2016/03/24/investing/fracking-shale-oil-boom/index.html.

44. *Id.*

45. *See id.*

46. *U.S. Remained World's Largest Producer of Petroleum and Natural Gas Hydrocarbons in 2014*, U.S. ENERGY INFO. ADMIN., https://www.eia.gov/todayinenergy/detail.php?id=20692 (last visited Mar. 20, 2018).

47. *See* Walsh, *supra* note 3.

48. *Id.*

49. Richards, *supra* note 6, at 3.

50. *See generally* DEEP-WELL INJECTION, *supra* note 19.

51. *See id.* at 16. The Energy Policy Act of 2005, a federal law, revised the scope of what would be regulated to explicitly exclude fracking.

52. *Id.*

53. SDWA ISSUES, *supra* note 8, at 7.

regulations for state underground injection control (UIC) programs."[54] While the EPA may regulate the injection of fluids for disposal, it lacks authority under SDWA to regulate the underground injection of fluids for hydraulic fracturing of oil or gas production wells.[55] Consequently, the EPA cannot regulate injection used for hydraulic fracturing itself, except where diesel fuels are used.[56]

The SDWA authorizes states and Indian tribes to assume primary enforcement authority, or "primacy," for the UIC program.[57] "Primacy allows states to permit facilities, inspect wells, enforce against violations, and otherwise regulate underground injection activity within the state."[58] If a state chooses not to assume program responsibility or if its UIC program plan is not approved, then the EPA must implement the UIC program in that state.[59]

In implementing the UIC program, the EPA has established six classes of underground injection wells based on categories of materials injected by each class.[60] Class II wells are wells used to inject fluids associated with oil and gas production.[61] More than 180,000 Class II wells are in operation in the United States.[62] Class II wells are divided into three categories, including disposal wells, enhanced recovery wells, and hydrocarbon storage wells.[63] Disposal wells are used to inject produced water and other fluids associated with oil and gas production for permanent disposal.[64] Approximately twenty percent of Class II wells are disposal wells.[65]

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54. *See* Safe Drinking Water Act, 42 U.S.C. § 300 (1996); DEEP-WELL INJECTION, *supra* note 19, at 16.

55. DEEP-WELL INJECTION, *supra* note 19, at 16. The Energy Policy Act of 2005 revised the SDWA term "underground injection" to explicitly exclude the injection of fluids and propping agents (except diesel fuels) used for hydraulic fracturing purposes.

56. *See id.*

57. *Id.*

58. Richards, *supra* note 6, at 8.

59. DEEP-WELL INJECTION, *supra* note 19, at 17.

60. *Id.*

61. *Class II Oil and Gas Related Injection Wells*, ENVTL. PROTECTION AGENCY, https://www.epa.gov/uic/class-ii-oil-and-gas-related-injection-wells (last visited Mar. 20, 2018).

62. *Id.*

63. *Id.*

64. DEEP-WELL INJECTION, *supra* note 19, at 19.

65. *Class II Oil and Gas Related Injection Wells*, *supra* note 61.

The SDWA does not directly address seismicity,[66] and the EPA's regulations governing Class II wells do not contain seismicity-related requirements.[67] However, the Class II UIC program "includes discretionary authority that allows additional conditions to be added to the injection permit on a case-by-case basis, along with additional requirements for construction, corrective action, operation, monitoring, or reporting (including closure of the injection well) as necessary to protect USDWs."[68] In 2015 the EPA released a guidance document with technical recommendations and best practices for minimizing the impacts of induced seismicity from Class II disposal wells.[69] The purpose of the guidance document is to identify practical approaches "to minimize and manage injection-induced seismicity."[70]

Because most oil and gas producing states today exercise primary enforcement authority for Class II wells,[71] the regulatory frameworks for injection wells among states with primacy vary considerably.[72] For instance, "[s]ome states regulate injection wells through a single agency, such as an oil and gas commission, and other states divide the regulatory authority between several agencies, such as those with oversight over protecting the environment and public health."[73] Similarly, states with primacy have varying requirements for Class II wells.[74] Induced earthquakes have prompted a variety of responses in the states where they have been experienced, including research, moratoria, litigation, and strengthened regulations and oversight.[75] Because state regulations vary considerably, I have highlighted only a few notable state regulations below.

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66. DEEP-WELL INJECTION, *supra* note 19, at 3. SDWA's primary purpose is to prevent endangerment of underground sources of drinking water.

67. PRACTICAL APPROACHES, *supra* note 23, at 3-4; *see* DEEP-WELL INJECTION, *supra* note 19, at 20. However, EPA's UIC regulations for two classes of injection wells, Class I hazardous waste disposal wells and Class VI wells for geologic sequestration of CO2, do specifically address evaluation of seismicity risks with siting and testing requirements.

68. PRACTICAL APPROACHES, *supra* note 23, at 3-4.

69. *See generally id.*

70. *Id.* at 4.

71. SDWA ISSUES, *supra* note 8, at 15.

72. Richards, *supra* note 6, at 8.

73. *Id.*

74. *Id.* at 11.

75. *Id.* at 6.

Oklahoma is arguably the state that has experienced the most induced seismicity associated with fracking activities and disposal wells.[76] Earthquake rates in the state have spiked, with over 900 recorded earthquakes of magnitude 3 or greater in 2015, compared to an average of two quakes that size a year before 2009.[77] Several quakes in the state have caused injury and damage, including a 5-magnitude quake in Prague in 2011 and a 5.8-magnitude quake recorded in Pawnee in 2016, the largest in the state's history.[78]

Oklahoma has primacy for the UIC Class II, which is administered by the Oklahoma Corporation Commission (OCC).[79] To address injection-induced seismicity concerns, in 2013 the OCC initiated a "traffic light" permitting system for Class II disposal wells operators.[80] The system requires that disposal well permit applications are reviewed for proximity to faults and seismicity in the area.[81] All proposed disposal wells, regardless of location, must conduct a seismicity review.[82]

> For applications for new wells, regulators must determine whether a location of a proposed well is within three miles of a stress fault, within six miles of a seismic cluster, or within another "area of interest." If so, the well operator is asked to demonstrate level of risk of induced seismicity and to provide more technical data, and a public hearing must be held on the permit application.[83]

The "yellow light" permitting system applies to disposal wells that are in areas with seismicity concerns but do not meet the automatic "red light" criteria.[84] Yellow light permit requirements are often more stringent; for instance, "[w]ells must shut down every 60 days and take bottom hole pressure readings."[85]

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76. *See Induced Earthquakes: Myths and Misconceptions*, USGS https://earthquake.usgs.gov/research/induced/myths.php (last visited Mar. 19, 2018).
77. Bill Whitaker, *Oklahoma's Rise in Quakes Linked to Man-Made Causes*, CBS NEWS (Sept. 11, 2016), https://www.cbsnews.com/news/60-minutes-oklahoma-rise-in-quakes-linked-to-man-made-causes-2/.
78. *Id.*
79. Richards, *supra* note 6, at 24.
80. DEEP-WELL INJECTION, *supra* note 19, at 27.
81. *Oklahoma Corporation Commission*, EARTHQUAKES IN OKLA., http://earthquakes.ok.gov/what-we-are-doing/oklahoma-corporation-commission/ (last visited Mar. 19, 2018) [hereinafter *OCC*].
82. *Id.*
83. DEEP-WELL INJECTION, *supra* note 19, at 27.
84. *Id.*; *OCC*, *supra* note 81.
85. *OCC*, *supra* note 81.

Ohio boasts having the most stringent Class II injection well regulations in the country, but unlike Oklahoma it has not adopted the traffic light approach.[86] In recent years Ohio has experienced an increase in seismicity, which many researchers associate with wastewater injection activities, particularly in Youngstown.[87] Ohio assumed primacy for Class II injection wells in 1983, and the Ohio Department of Natural Resources (ODNR) regulates the state's program.[88] In response to the 2011 Youngstown earthquakes the ODNR "prohibited all drilling into the Precambrian basement rock and added new permit requirements for Class II disposal wells to improve site assessment and collection of more comprehensive information."[89] ODNR can require a variety of tests in permit applications to determine if a fault exists in an area where a disposal well is planned.[90] These tests may include pressure fall-off testing, geological evaluation of potential faulting, seismic monitoring program, minimum geophysical logging suite, and radioactive tracer or spinner surveys.[91] Further, "[f]or all new Class II permit applications, ODNR requires installation of monitoring technologies, including a continuous pressure monitoring system and an automatic shutoff system."[92] ODNR also performs unannounced inspections.[93]

B. Canada

Canada is the second largest developer of shale gas and shale oil resources in the world, behind only the United States.[94] It is currently the fourth largest producer and fifth largest exporter of natural gas.[95] Fracking has enabled Canada to produce shale gas and oil where it previously could not, and there is hope that these resources will form a key part of Canada's

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86. *See States Well Ahead of EPA on Underground Wastewater Disposal Regulations*, ENERGY DEPTH (Mar. 20, 2018), https://www.energyindepth.org/states-well-ahead-of-epa-on-underground-wastewater-injection-regulations/?154 [hereinafter *States Well Ahead of EPA*].

87. *FAQ's on Induced Seismicity*, OHIO DEP'T NAT. RESOURCES http://www2.ohiodnr.gov/Portals/oilgas/pdf/induced-seis-faq.pdf (last visited Mar. 22, 2018). A magnitude 4 earthquake occurred in Youngstown on New Year's Eve 2011.

88. Richards, *supra* note 6, at 12.

89. DEEP-WELL INJECTION, *supra* note 19, at 25-26.

90. *States Well Ahead of EPA*, *supra* note 86.

91. DEEP-WELL INJECTION, *supra* note 19, at 25-26; *see States Well Ahead of EPA*, *supra* note 86.

92. DEEP-WELL INJECTION, *supra* note 19, at 26.

93. *States Well Ahead of EPA*, *supra* note 86.

94. Atkinson et al., *supra* note 3, at 1-2.

95. *Natural Gas Facts*, NAT. RESOURCES CAN., https://www.nrcan.gc.ca/energy/facts/natural-gas/20067 (last visited Mar. 20, 2018).

energy future.[96] Development has been focused within the Western Canada Sedimentary Basin (WCSB), primarily in the provinces of British Columbia and Alberta.[97] Key areas of oil and gas development within the WCSB include the Montney Play Trend, Horn River Basin, Duvernay Formation, and Cardium Formation.[98] As unusual oil and gas development has increased in these areas in recent years, so has the number of earthquakes.[99] For instance, in northeastern British Columbia, the number of earthquakes increased "from about 20 a year in 2002 to nearly 200 by 2011."[100] Although the majority of these earthquakes have been small, a 4.6-magnitude earthquake in northeastern British Columbia in 2015 and a 4.8-mangitude earthquake in Alberta in 2016 have both been linked to fracking.[101]

A recent statistical study of seismicity in the WCSB indicated that "most of the seismic activity in the WCSB since 1985 seems to be associated with oil and gas activity, although only a small portion of fracking operations appear to be linked to seismic activity."[102] It found that the "spatiotemporal relationship of the increased incidence of seismicity with HF wells implies that within the WCSB a greater fraction of induced seismicity (since 2010) is linked to hydraulic fracturing than to wastewater injection."[103] The study also found that "[h]azard and exposure are key elements to consider in guiding regulatory policy and field-development strategies so as to balance risks and benefits in the

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96. *See id.*; *see also* Karen Graham, *Canada Prepares for Its Own Shale Oil and Gas Revolution*, DIGITAL J. (Jan. 29, 2018), http://www.digitaljournal.com/news/world/canada-prepares-to-become-the-next-frontier-for-shale-oil-and-gas/article/513419.

97. *Id.*

98. *See Petroleum Geology*, BRITISH COLUMBIA, https://www2.gov.bc.ca/gov/content/industry/natural-gas-oil/petroleum-geoscience/petroleum-geology (last visited Mar. 19, 2018); *see also* Atkinson et al., *supra* note 3, at 7.

99. *See generally* Atkinson et al., *supra* note 3.

100. Sunny Dhillon, *Study Fortifies Link Between Fracking and Earthquakes in British Columbia*, GLOBE & MAIL (Apr. 17, 2017), https://www.theglobeandmail.com/news/british-columbia/study-fortifies-link-between-fracking-and-earthquakes-in-british-columbia/article34731280/.

101. *B.C. Oil Commission Confirms 4.6-Magnitude Earthquake in August Caused by Fracking*, FIN. POST (Dec. 16, 2015), http://business.financialpost.com/commodities/energy/b-c-oil-commission-confirms-4-6-magnitude-earthquake-in-august-caused-by-fracking; Karen Graham, *Groundbreaking Study Shows Link to Fracking and Earthquakes*, DIGITAL J. (Nov. 18, 2016), http://www.digitaljournal.com/tech-and-science/science/new-study-links-earthquakes-to-fracking-in-fox-creek-alberta/article/479904.

102. DEEP-WELL INJECTION, *supra* note 19, at 14; *see* Atkinson et al., *supra* note 3, at 13.

103. Atkinson et al., *supra* note 3, at 13.

exploitation of oil and gas resources."[104] It also noted that, unlike in the United States, the increase in fracking activities in Canada has not resulted in a sharp increase in the number of disposal wells.[105]

The National Energy Board (NEB) is Canada's federal energy regulatory agency, and it regulates, among other things, oil and gas exploration and production activities in specified areas that are not regulated under joint federal/provincial accords.[106] "Each province and territory maintains its own regulatory regime for approving energy-related projects. The majority of oil and gas-related activities under provincial jurisdiction are located in the provinces of Alberta and British Columbia."[107]

Alberta is considered Canada's energy province.[108] The Alberta Energy Regulator (AER) is empowered to regulate development of oil, natural gas, oil sands, and coal, as well as the delivery pipelines within Alberta's borders.[109] Because the government of Alberta owns about eighty percent of the province's petroleum and natural gas mineral rights, companies must purchase rights to develop the resources.[110] Regulation of the development of oil and gas is executed "through two core functions: adjudication and regulation, and information and knowledge."[111] The Alberta Geological Survey is part of the AER, and it provides geological information and expertise to government, industry, and the public about Alberta's resources and geology.[112] Seismologists with the Alberta Geological Survey monitor seismicity within the province using an extensive network of more than fifty seismic monitoring stations.[113] Due to the recent increase in seismicity in the Fox Creek area, the AER enacted

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104. *Id.*
105. *Id.* at 2.
106. *Who We Are*, NAT'L ENERGY BOARD, https://www.neb-one.gc.ca/bts/whwr/index-eng.html (last visited Feb. 20, 2018).
107. Shawn Denstedt et al., *Regulatory Approval for Energy Projects*, OSLER (Dec. 2014), https://www.osler.com/en/resources/cross-border/2014/regulatory-approval-for-energy-projects.
108. *Oil and Gas*, ALBERTA CAN., http://www.albertacanada.com/business/industries/oil-and-gas.aspx (last visited Mar. 19, 2018).
109. *How Does the AER Regulate the Oil and Gas Industry?*, ALBERTA ENERGY REGULATOR, https://www.aer.ca/about-aer/spotlight-on/unconventional-regulatory-framework/how-does-the-aer-regulate-the-oil-and-gas-industry (last visited Mar. 20, 2018).
110. *Id.*
111. *Id.*
112. *See About the AGS: Who We Are*, ALBERTA ENERGY REGULATOR, https://ags.aer.ca/about-the-ags/who-we-are.htm (last visited Mar. 27, 2018).
113. *Seismic Activity*, ALBERTA ENERGY REGULATOR, https://www.aer.ca/providing-information/by-topic/seismic-activity (last visited Mar. 20, 2018).

"Subsurface Order No. 2," which imposes new seismic monitoring and reporting requirements in the Fox Creek area of the Duvernay Zone.[114] The order requires an operator conducting fracking operations to assess the potential for induced seismicity that may result from its activities and to establish and be "immediately prepared to implement a plan to monitor for, mitigate, and respond to induced seismicity that may occur or result from its completion operations."[115] Further,

> Operators will be required to monitor for seismic activity and follow a "traffic light" process with staged action thresholds. If there are no seismic events observed, operations can proceed as part of the AER's usual requirements. Operators must immediately report any seismic events of 2.0 local magnitude (ML) or greater in the vicinity of their operations and invoke their response plans. If operators observe a seismic event of 4.0 ML or greater, they must immediately cease operations and report it to the AER. They will not be allowed to resume operations without AER approval.[116]

British Columbia's Oil and Gas Activities Act (OGAA) covers the majority of oil and gas activities in British Columbia, and the Oil and Gas Commission (OGC) is primarily responsible for the regulation of oil and gas activities and pipelines in British Columbia.[117] The OGC "has the legislative authority to make decisions on proposed oil and gas activities."[118] "Companies looking to explore, develop, produce, and market oil and gas resources in B.C. must apply to the Commission. The Commission reviews, assesses and makes decisions on these applications."[119] The Commission regulates induced seismicity using well permit conditions.[120] Also, seismicity is addressed in industry recommended practices.[121] CAPP has published industry "guidance on minimum requirements for assessing, monitoring, responding to, and mitigating anomalous induced seismicity for hydraulic fracturing."[122]

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114. *Id.*

115. Alberta Energy Regulator, *Subsurface Order No. 2* (Feb. 19, 2015), https://www.aer.ca/documents/orders/subsurface-orders/SO2.pdf.

116. *Seismic Activity*, *supra* note 113.

117. Denstedt et al., *supra* note 107.

118. *Induced Seismicity*, BCOGC, https://www.bcogc.ca/node/13092/download (last visited Oct. 16, 2018).

119. *Id.*

120. ERNST & YOUNG, REVIEW OF BRITISH COLUMBIA'S HYDRAULIC FRACTURING REGULATORY FRAMEWORK 106 (2015).

121. *Id.* at 106-07.

122. *Id.* at 107.

The Commission engages in ongoing research and published studies in 2012 and 2014 to investigate the increase in seismic events in the Horn River Basin and Montney Trend, respectively.[123] The studies concluded that the seismic events in these areas were triggered by fluid injection during hydraulic fracturing, more so than by disposal.[124] For example, the 2014 Montney Trend Report "found that during this period 231 seismic events in the Montney were attributed to oil and gas operations—38 induced by wastewater disposal and 193 by hydraulic fracturing operations."[125]

As a result of these studies, the Commission has recently increased monitoring requirements to better address the risks of induced seismicity.[126] As of January 2018, oversight includes "the immediate suspension of drilling activities if a magnitude 4.0 or greater event is recorded, as well as the mandatory reporting of felt events"; permit conditions "require the presence of ground motion monitoring during hydraulic fracturing activities for areas where previous seismic activity occurred, as well as reporting of event"; "risk assessments are required for disposal wells, which operate under strict pressure and reporting conditions"; and "nine new seismograph stations [must be] installed in northeast B.C."[127]

C. United Kingdom

In April 2011, shortly after fracking began in Blackpool, an earthquake registering 2.3 on the Richter scale was felt in the area.[128] Although there was little damage, the tremor was felt by residents in the area and cracked ceilings were reported.[129] A month later, a 1.4-magnitude earthquake in the same area followed.[130] These two earthquakes led to a nationwide eighteen-month ban on the use of fracking because of

123. *Induced Seismicity*, *supra* note 118.
124. *Id.*
125. *Montney Trend*, *supra* note 19, at 6.
126. *Induced Seismicity*, *supra* note 118.
127. *Id.*
128. Susanna Twidale, *Six Years After Tremors Halted Fracking, Britain Ready to Try Again*, REUTERS (Nov. 2, 2017), https://uk.reuters.com/article/uk-britain-fracking/six-years-after-tremors-halted-fracking-britain-ready-to-try-again-idUKKBN1D20H8.
129. *Id.*
130. *Id.*

speculation that they were caused by Cuadrilla's fracking operations in the area.[131]

No well has been fracked in the U.K. since 2011 due to the moratorium and fracking regulatory changes, including the introduction of a traffic-light system to address induced seismicity.[132] However, 2018 might be a year of change for the fracking industry in the U.K.[133] Several companies, including Cuadrilla and Third Energy, have stated that they expect to begin fracking in England before the end of this year.[134] Proponents argue that fracking will allow the country to become less dependent on importing natural gas.[135] The security of Britain's energy supplies has been a big concern since the vote to leave the European Union.[136] While it is impossible to know how much shale gas is underground before fracking, the "British Geological Survey estimates shale gas resources in northern England alone could contain 1,300 trillion cubic feet (tcf) of gas, 10 percent of which could meet the country's demand for almost 40 years."[137] However, public opposition across the U.K. is very strong, especially among environmental groups. Recently the Scottish government extended the moratorium on fracking due to overwhelming public opposition and climate concerns.[138]

The Oil and Gas Authority (OGA) regulates the oil and gas industry in the U.K.[139] It also regulates the risk of induced seismicity from onshore fracking operations in the U.K.[140] In this regard, the OGA is responsible for ensuring that operators put in place measures to control the level of induced seismicity from hydraulic fracturing.[141] "The Environment

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131. *Id.*

132. *See* Adam Vaughan, *Fracking—The Reality, the Risks and What the Future Holds*, GUARDIAN (Feb. 26, 2018), https://www.theguardian.com/news/2018/feb/26/fracking-the-reality-the-risks-and-what-the-future-holds.

133. *Id.*

134. *Twidale*, *supra* note 128.

135. *Id.*

136. *Id.*

137. *Id.*

138. Severin Carrell, *Scottish Government Bans Fracking After Public Opposition*, GUARDIAN (Oct. 3, 2017), https://www.theguardian.com/uk-news/2017/oct/03/scottish-government-bans-fracking-scotland-paul-wheelhouse; *see* Twidale, *supra* note 128.

139. *What We Do*, OIL & GAS AUTHORITY, https://www.ogauthority.co.uk/about-us/what-we-do/ (last visited Feb. 20, 2018).

140. *Overview*, OIL & GAS AUTHORITY, https://www.ogauthority.co.uk/onshore/overview/ (last visited Mar. 20, 2018).

141. ENV'T AGENCY, ONSHORE OIL AND GAS SECTOR GUIDANCE, 2016, Version 1, at 48 (UK).

Agency is responsible for regulating environmental impacts including those that may occur as a result of induced seismicity. Operators must satisfy the Environment Agency that they have appropriate safeguards in place to avoid impacts on geological structure and infrastructure where this could put the environment at risk."[142]

The OGA has been given a range of regulatory powers from the legislature through several Acts.[143] For instance, while all rights to the U.K.'s petroleum resources belong to the Crown, OGA has the authority to grant licenses to the petroleum as they see fit.[144] The OGA currently has two main policies in place to manage the risk of induced seismicity from fracking.[145] First, the OGA requires the operator to conduct detailed geological studies before drilling to prevent operations from taking place near preexisting geological faults.[146] Second, the operator must prepare a Hydraulic Fracturing Plan (HFP) for OGA approval before drilling can commence.[147] The OGA will assess the risks of induced seismicity and must be satisfied that sufficient controls are in place before granting approval.[148] Controls typically included in the HFP are monitoring of background seismicity, a real-time traffic light scheme for monitoring seismicity during injection, detailed operational precautions, and a decision tree.[149]

The traffic light system, aforementioned in this Comment, monitors "local seismicity so that operations can be quickly paused and reviewed if unexpected levels of seismic activity are detected."[150] Currently, the action level for a "red light" in the U.K. traffic light system is set at a magnitude of 0.5ML.[151] If any site records a seismic event of magnitude greater than 0.5ML, injection is suspended immediately and pressures are reduced.[152] This magnitude is well below the level that could be felt at the surface, yet

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142. *Id.*

143. *Legislative Context*, OIL & GAS AUTHORITY, https://www.ogauthority.co.uk/regulatory-framework/legislative-context/ (last visited Mar. 20, 2018). Acts giving regulatory power include the Petroleum Act 1998, Infrastructure Act 2015, Energy Act 2011, and Energy Act 2016.

144. *Licensing Regime*, OIL & GAS AUTHORITY, https://www.ogauthority.co.uk/regulatory-framework/licensing-regime/ (last visited Mar. 20, 2018).

145. OIL & GAS AUTH., CONSOLIDATED ONSHORE GUIDANCE 30 (2017).

146. *Id.*

147. *Id.*

148. *Id.* at 28.

149. *Id.* at 30.

150. *Id.*

151. *Id.* at 31.

152. *Id.*

"greater than the level expected to be generated by the fracturing of the rock itself."[153] The operator must then review the possible causes of the event and determine whether the seismicity is in accordance with the expectations provided in the HFP.[154] If the magnitude and ground motion levels confirm the predictions in the HFP, then operations may resume.[155]

Unlike in the United States, the U.K.'s Environment Agency does not permit the injection of flowback fluids from shale gas activities into deep disposal wells.[156] Although, the Agency's 2016 Guidance seems to create a loophole by stating that "[t]he re-injection of flowback fluid for disposal is not necessarily prohibited and may be permissible where, for example, it is injected back into formations from which hydrocarbons have been extracted and will have no impact on the status of water bodies or pose any risk to groundwater."[157] However, the Agency makes it clear that this (disposal wells) is not the preferred method, and the other available alternatives, such as disposal at permitted waste disposal facilities or by the use of onsite wastewater treatment facilities, are the better environmental option.[158]

III. CONCLUSION

As mentioned above, the global development of oil and gas from shale will likely continue to expand because the resource potential is high in many parts of the world, and many countries hope to become more energy independent.[159] So far, the earthquakes that seem to have been induced by activities associated with fracking have not been devastating.[160] However, that could change as fracking extends to new places, including areas already prone to earthquakes. For instance, China is exploring shale gas in the seismically active province of Guizhou.[161] The southwest region of China is prone to large earthquakes, including a

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153. *Id.*

154. *Id.*

155. *Id.* at 32.

156. ENV'T AGENCY, ONSHORE OIL AND GAS SECTOR GUIDANCE 46 (2016).

157. Megan O'Donnell et al., *Corrected—UK Failing to Learn U.S. Lessons on Fracking Waste Water*, ENERGY & CARBON BLOG (Jan. 22, 2016), http://energyandcarbon.com/uk-failing-lessons-fracking-waste-water/; ENV'T AGENCY, *supra* note 141, at 46-47.

158. ENV'T AGENCY, ONSHORE OIL AND GAS SECTOR GUIDANCE 46-47 (2016).

159. *Ellsworth*, *supra* note 1, at 3.

160. *Id.*; Walsh, *supra* note 3.

161. John Daly, *China Embraces Fracking in Seismically Active Province—Quakes to Follow?*, OIL PRICE (Feb. 26, 2012), https://oilprice.com/Energy/Natural-Gas/China-Embraces-Fracking-in-Seismically-Active-Province-Quakes-to-Follow.html.

3.4 magnitude quake in 2010 that killed at least seven people and a 7.9 magnitude quake in 2008 that left almost 90,000 people dead or missing.[162]

Figuring out how to frack and dispose of wastewater from oil and gas production in a way that avoids significant earthquakes is imperative, or the fracking revolution may be short-lived.[163] It is an issue of global interest that is finally a topic of discussion among regulators, governments, and seismologists. For example, the Seismological Society of America's 2017 annual meeting had a panel discussing the assessment and management of hazards from seismicity induced by hydraulic fracturing.[164] It is clearly in everyone's best interest, including the industry, to have regulations in place that address induced seismicity, but are the current regulations doing enough to prevent a significant quake? This circles back to the question mentioned above: What constitutes the ideal framework for confronting the risks of seismicity induced by hydraulic fracturing and wastewater disposal injection?

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162. *Id.*
163. *See* Walsh, *supra* note 3.
164. *See Special Sessions*, SEISMOLOGICAL SOC'Y AM., https://meetings.seismosoc.org/special-sessions/ (last visited Mar. 20, 2018).