PREPARED BY:
Ethical Environmental Policy Consortium
041719-OR HB 2623, 2019

PREPARED FOR:
Chair Senator Michael Dembrow, Vice-Chair Senator Alan Olsen, Senator Cliff Bentz, Senator Floyd Prozanski, Senator Arnie Roblan

SENATE COMMITTEE ON ENVIRONMENT & NATURAL RESOURCES

OR HB 2623, 2019: Potential Complications Associated with §2(2)(b)

17 April (2019)

Corporate entities which engage in unconventional oil and gas exploration (UOG) have contaminated aquifers, lakes, and streams (Soeder and Kappel 2009; Kargbo et al. 2010; Gregory et al. 2011; Vidic et al. 2013; Brittingham et al. 2014; Mauter et al. 2014; Gallegos et al. 2015), diminished air quality (Chalmers et al. 2012; Schneising et al. 2014; Omara et al. 2016), and have augmented the frequency and intensity of induced seismic events (Weingarten et al. 2015; USGS 2015; 2016; 2016b). *Currie et al.* has clearly demonstrated that infants birthed within 1km of an active hydraulically fractured (HF) well site will experience a 25% increase in the probability of low birth weight, and detrimental consequences arise when infant births occur within 3km (Currie et al. 2017). Increases in childhood hematologic cancer incidences have also been observed in close proximity to HF activities (Elliott et al. 2017; McKenzie et al. 2017).

The Ethical Environmental Policy Consortium (EEPC) is a 501(c)(3) public benefit corporation that collaborates with federal, state, and local policy makers, community organizations, corporate and business entities, and the general public, to assist with implementation of ethical environmental policy. Our mission is to reduce adverse ecological complications initiated by anthropogenic sources of pollution.

The EEPC was incorporated in June 2018 in Portland, OR and has recently received favorable support for our proposed recommendations from key federal congressional offices in the U.S. House of Representatives (IL-05 & FL-09) associated with H.R. 436, 116th Congress, 2019-2020 (Fracking Disclosure and Safety Act), formerly H.R. 6768, 115th Congress, 2018. The EEPC is currently collaborating with the initial sponsor of this legislation Congressman Darren Soto (FL-09) and his Legislative Director, in an effort to mitigate fugitive CH_4 and VOC emissions from active HF sites. Our bipartisan recommendations, if adopted, would provide immediate health benefits to the 17.6 million Americans residing within 1.6km (1 mile) of an active HF well site (Konkel 2017), and opportunities for industry to capture fugitive CH_4 for monetary gain.

We applaud the continuous effort of Chair Representative Helm, who proposed this legislative concept during multiple sessions. The EEPC immensely supports the passage of OR H.B. 2623, 2019 with one exception.

§2(2)(b) of OR H.B. 2623, 2019 provides an exemption for "*geothermal wells or activities related to exploration for geothermal energy.*"

The EEPC immensely endorses exploiting geothermal resources as a sustainable way to encourage our statewide transition to clean energy, yet believes that a multitude of unintended disadvantageous consequences may occur if drilling depth and cumulative water injection rates are not regulated responsibly.

A: *Proliferation of Anthropogenically Induced Seismicity:*

The increase in anthropogenically induced seismicity over the past decade has not only been triggered by UOG exploration, but also by geothermal production conducted in both igneous and sedimentary rocks (Tester et al. 2006; Majer et al. 2007).

The Energy Policy Act (EPAct) of 2005, 42 U.S.C. § 15801, P.L. 109-58 repealed the Public Utility Holding Company Act (PUHCA), 15 U.S.C. § § 79-79z(6), which was established in 1935 to aid individual states with their efforts to effectively regulate the energy sector following the Great Depression. Following the repeal of PUHCA, the Federal Regulatory Energy Commission (FERC) permitted immense outside capital investment into the US OG market, allowing for emerging new UOG extraction methods to flourish, such as horizontal drilling techniques. Natural resources situated in geologic formations that possess low permeability, which were once considered previously inaccessible and unprofitable, have now been exploited by utilizing horizontal drilling combined with HF (Wiseman 2008).

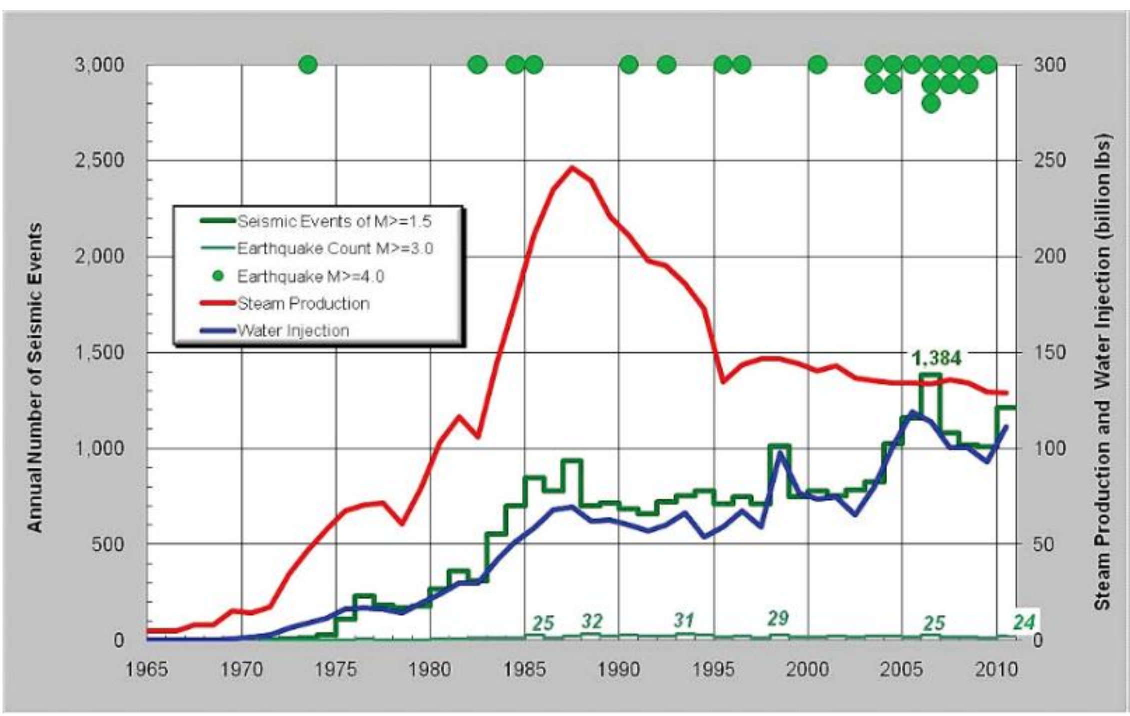
In 2011, after the vast rise of UOG exploration, widespread unanticipated seismic activity occurred in Prague, OK (Mw=5.6), Trinidad, CO (Mw=5.3), Timpson, TX (Mw=4.8), and Guy, AR (Mw=4.7) (USGS 2015). During the time period from 1973–2008, an average of 21 earthquakes of Mw = >3 were experienced in central and eastern US annually. In 2015 that number rose to over 1,000 (USGS 2016). HF water injection can have far-reaching seismic effects (Yek et al. 2016). Recorded pressure increases from cumulative wastewater injection from as far as 90km away, has been recently confirmed by the Kanas Geological Survey (KGS) to induce seismicity, as a direct result of far-field pressure diffusion (Peterie et al. 2018).

A recent analysis of seismic data obtained from the state of OK, compared to data from additional major US UOG regions (Bakken, Eagle Ford, Permian) has revealed that HF injection rates, including cumulative produced water volume, along with the proximity to the crystalline basement (which consists of rock formations beneath a platform of sedimentary rocks that are metamorphic or igneous) are the fundamental drivers initiating induced seismicity in OK (Scanlon et al. 2018). This study also discovered that transferring produced wastewater injection operations into nonproducing geologic zones possessing low-permeability, will substantially increase the number of anthropogencially induced earthquakes.

During the process of enhanced geothermal systems (EGS), fluids are injected under high pressure into rock formations to create reservoirs, similar to the methods employed by the OG industry. As a result of the emergence of experimental HF techniques applied in EGS, the regularity of anthropogenically induced seismicity has increased. The fundamental method exercised for performing EGS and deep drilling geothermal exploration is HF.

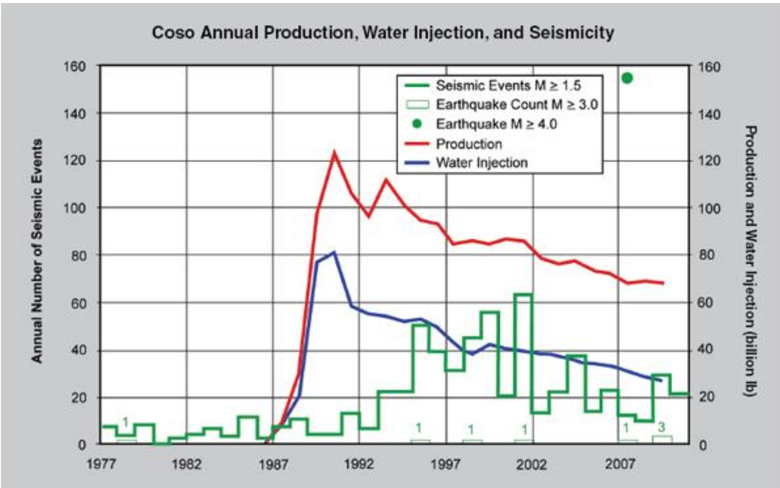
B: *Seismicity is Dependent Upon Cumulative Water Injection Rates:*

Figure 1: The Geysers (*Geothermal*), CA 1965-2010

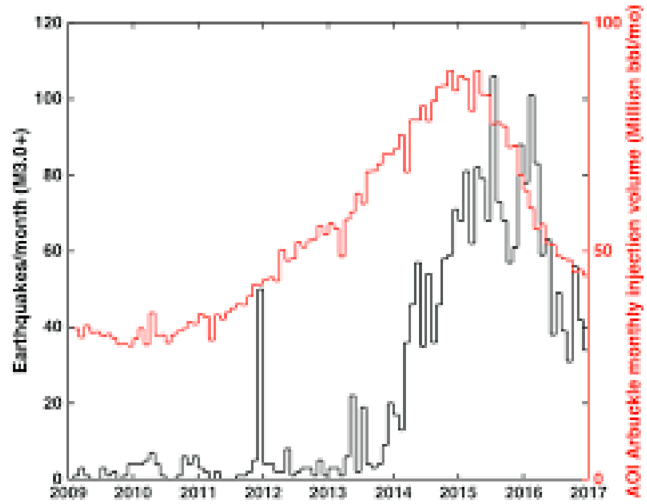


(NRC 2013)

Figure 2 & 3: Coso Field (*Geothermal*), China Lake, CA v. Arbuckle Formation (*Oil & Gas*), OK



(Figure 2: NRC 2013)

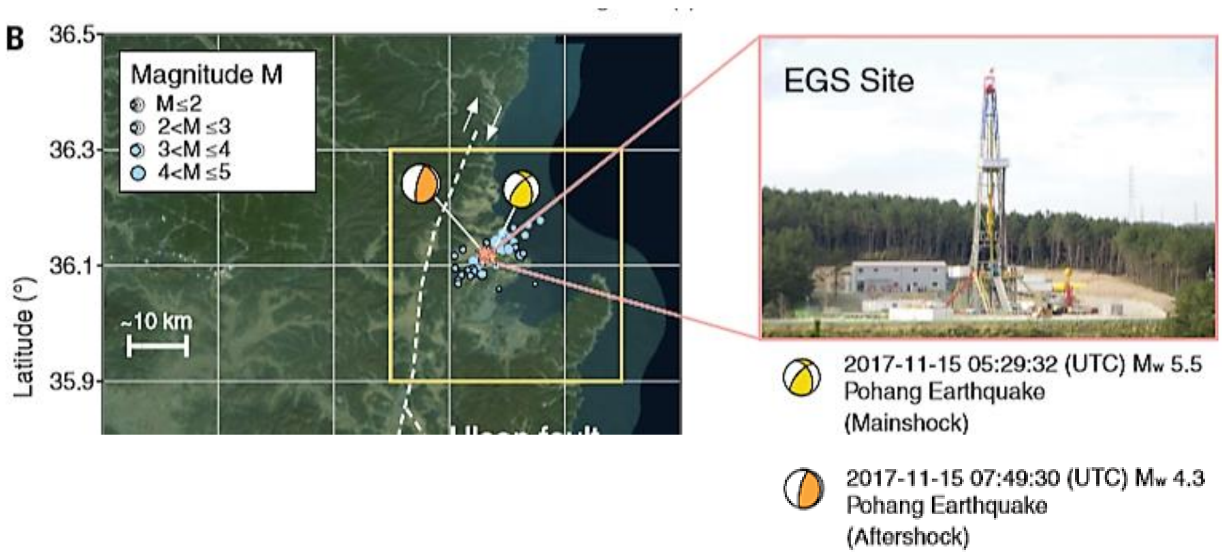


(Figure 3: OGS 2017)

Deep geothermal systems have the potential to generate the same induced seismic conundrum fabricated by the OG industry, since these projects also inject fluids into the subsurface to increase permeability (Giardini 2009; Ellsworth 2013; Diehl et al. 2017; Grigoli et al 2017).

- On November 15, 2017 a Mw=5.5 induced earthquake occurred in close proximity to an EGS site in Pohang, South Korea, injuring 70 people, and also caused substantial structural damage to the city (Grigoli et al. 2018). This seismic event was followed by a Mw=4.3 aftershock that transpired in a physiographic province considered to be seismically stable. This induced earthquake was subsequent an additional Mw=5.5 earthquake occurring just one year earlier in the same region. These two seismic events are considered the largest magnitude earthquakes ever recorded in South Korean history, since seismic monitoring was adopted in 1903 (Kim et al. 2017). By utilizing seismological and geodetic analyses, geophysicists were able to confirm that the activated fault triggered was situated below the EGS site (Figure 4), and determined that the depth of the Pohang earthquake and aftershock was shallow, approximately 4.0km-4.5km below the Earth's surface, distinguishing these events as anthropogenically induced rather than naturally occurring.

Figure 4: Pohang Earthquake Sequence 2017 (Mw=5.5 + Mw=4.3)



(Grigoli et al. 2018 with permission)

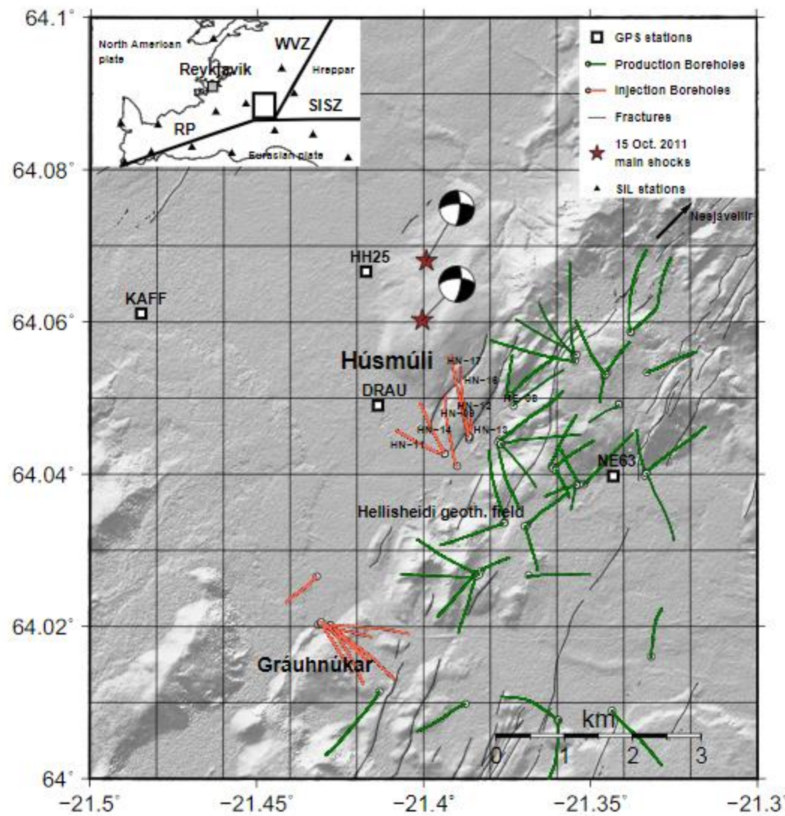
- During 2006 in Basel, Switzerland a $60 million EGS deep drilling project was eliminated due to public outrage and extensive damage sustained from an induced earthquake that produced structural damage to the nearby community costing millions to repair (Meier et al. 2015).

- In St. Gallen, Switzerland 340 induced seismic events were triggered by geothermal reservoir stimulation during a deep geothermal drilling project conducted in July 2013. A Mw=3.5 earthquake was felt from as far away as 10km–15km from the epicenter (Diehl et al. 2017).

- Earthquakes can be initiated by thermal stressors and significant pressure decreases resulting from expansions in geothermal energy production, as demonstrated in the April 1, 2000 Mw=4.5 induced event in Tuscany, Italy (Castello et al. 2006; Rovida et al. 2011). Vaporization combined with the reinjection of fluids can initiate thermal stressing of rocks (Dahm et al. 2015). This earthquake arose from a shallow depth in close proximity to the geothermal plant, and caused structural damage to more than 50 buildings (Braun et al. 2016).

- Intense geothermal wastewater injection performed at the Husmuli injection site, located in the Hellisheidi Geothermal Field in Iceland, initiated two Mw=4 earthquakes (Figure 5) on October 15, 2011 (Flovenz et al. 2015; Gunnarsson et al. 2015; Juncu et al. 2018). The pressure alterations due to fluid injection resulted in surface deformation and increased stress on local active faults.

Figure 5: Husmuli Injection Site (Hellisheidi Geothermal Field), Iceland

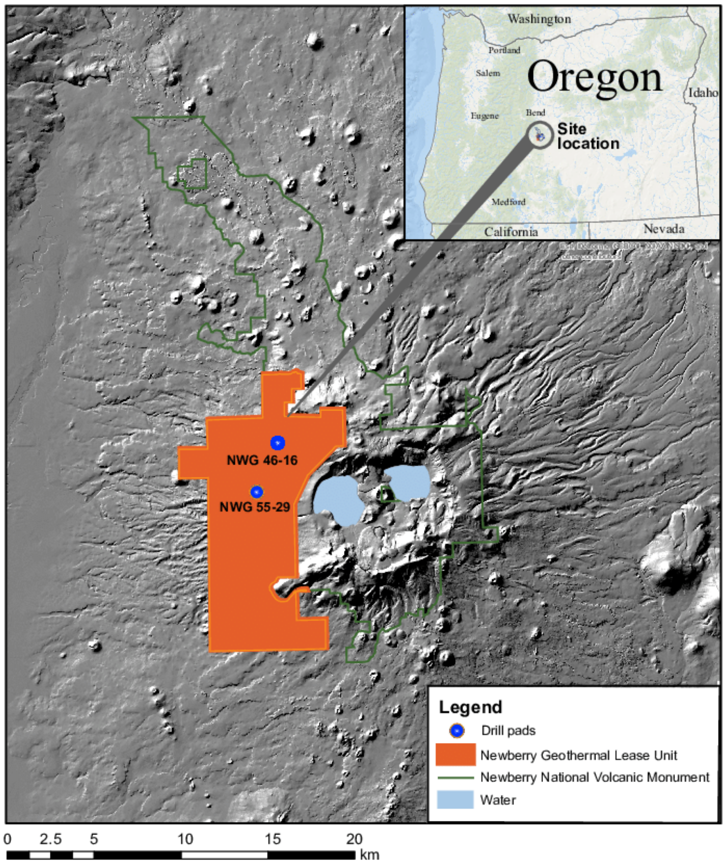


(Juncu et al. 2018)

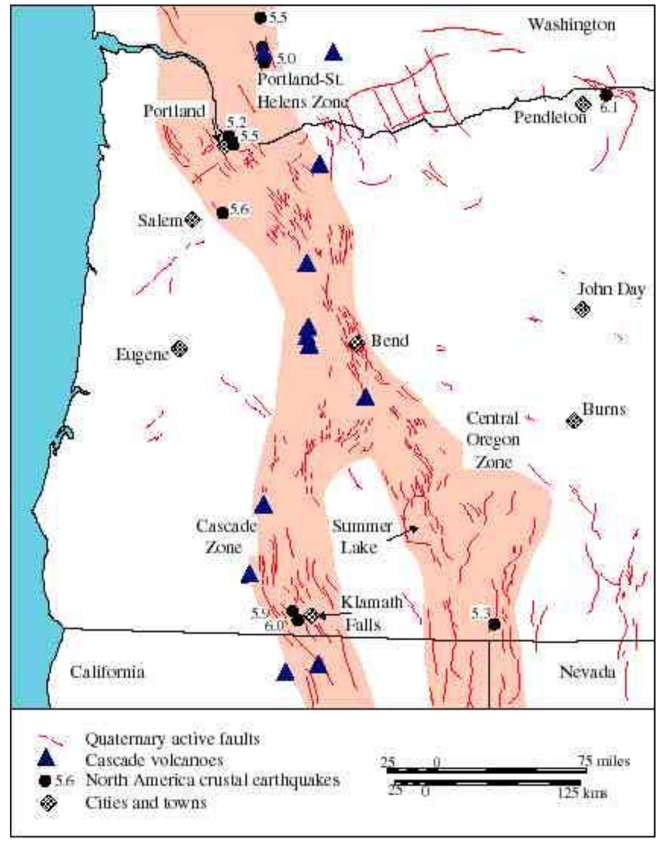
Super Hot Rock (SHR) EGS research is currently being conducted at the Newberry Volcano in OR (Figure 6), one of the largest geothermal heat reservoirs in the nation (Cladouhos et al. 2011). SHR possessing a temperature > 400°C will produce a super-critical fluid (SCF), which has the potential to generate 5 x more energy than water at 200°C. The Newberry Deep Drilling Project (NDDP) will be operated in an idle geothermal exploration well (NWG 46-16) that is 3.5km deep, and will be extended an additional 1km-1.5km to access temperatures reaching 500 °C.

The EEPC supports the implementation of the experimental NDDP to obtain SCF for energy generation, but believes that this research should be confined to the NWG 46-16 well site until proven safe.

Figure 6 & 7: Location of Experimental Geothermal Well NWG-46-16 & Quaternary Active Faults in OR



(Figure 6: Bonneville et al. 2018)



(Figure 7: Langridge 2018)

RECOMMENDATIONS FOR REGULATING EGS:

- Establish net fluid budgets for HF and wastewater injection for all EGS production and exploration activities.
- Restrict well drilling depths and water injection levels from encroaching the crystalline basement.
- Eliminate wastewater injection into nonproducing geologic zones, primarily regions possessing low-permeability.
- Create a state inventory of geologic boundaries that address every region where engineered geothermal exploration is plausible, and designate specific tectonic subprovinces in each physiographic province, to properly distinguish where it is safe to conduct EGS and deep drilling geothermal projects.
- Implement a cautious Induced Seismicity Traffic Light Protocol (IS-TLP): Green = $M_L \leq 1.5$ (proceed with operations); Yellow = $M_L \geq 1.5$ (reduce injection rates); Red = $M_L \geq 2.0$ (suspend operations).

As stated earlier in our testimony, the EEPC immensely supports the passage of OR H.B. 2623, 2019, but recommends devising strategies to safeguard communities residing in close proximity to EGS and deep drilling geothermal projects.

Since both the OG and geothermal industry utilize similar drilling methods for exploiting natural resources, we must regulate these experimental EGS methods cautiously, to restrict the potential for triggering large anthropogenically induced seismic events in tectonically active physiographic provinces located in OR.

Once the exploratory techniques employed at NWG 46-16 are proven to be safe for at least a decade, perhaps similar strategies can be adopted statewide to harness clean geothermal energy.

Thank you for your time.

Sincerely,

Alexander Krokus
Executive Director & Senior Policy Advisor: EEPC

E
E P
C

Ethical Environmental Policy Consortium
5555 N. Wilbur Ave.
Portland, OR 97217
Phone: (503) 954-0002
Email: alexander.krokus@eepc-usa.org
info@eepc-usa.org
www.eepc-usa.org

References:

Bonneville A, Cladouhos T, Petty S, Schultz A, Carsten S, Hiroshi A, Frioleifsson G, Jaupart C, De Natale G. 2018. The Newberry deep drilling project (NDDP) workshop. *Scientific Drilling*, 24: 79-86. https://www.researchgate.net/publication/328431175_The_Newberry_Deep_Drilling_Project_NDDP_workshop

Braun T, Dahm T, Krüger F, Ohrnberger M. 2016. Does geothermal exploitation trigger earthquakes in Tuscany? *Eos*, 97. https://doi.org/10.1029/2016EO053197

Brittingham M, Maloney K, Farag A, Harper D, Bowen Z. 2014. Ecological risks of shale oil and gas development to wildlife, aquatic resources and their habitats. *Environ. Sci. Technol*, 48(19): 11034–11047.

Castello B, Selvaggi G, Chiarabba C, Amato A. 2006. CSI Catalogo della sismicità italiana 1981–2002, versione 1.1, Centro Naz. Terremoti, Ist. *Naz. di Geofis*. e Vulcanol., Rome. http://csi.rm.ingv.it/

Chalmers GR, Bustin RM, Power IM. 2012. Characterization of gas shale pore systems by porosimetry, pycnometry, surface area, and field emission scanning electron microscopy/transmission electron microscopy image analyses. *AAPG Bulletin*, (96)1099–1119.

Cladouhos T, Petty S, Callahan O, Osborn W, Hickman S, Davatzes N. 2011. The role of stress modeling in stimulation planning at the Newberry volcano egs demonstration project. Proceedings, *36th Workshop on Geothermal Reservoir Engineering Stanford University*, Stanford, California, January 31 - February 2, 2011. SGP-TR-191. https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2018/Cladouhos.pdf

Currie J, Greenstone M, Meckel K. 2017. Hydraulic fracturing and infant health: new evidence from Pennsylvania. *Science Adv*, 3:e1603021. 13 December 2017. http://advances.sciencemag.org/content/3/12/e1603021

Dahm T, Cesca S, Hainzl S, Braun T, Krüger F. 2015. Discrimination between induced, triggered, and natural earthquakes close to hydrocarbon reservoirs: a probabilistic approach based on the modeling of depletion-induced stress changes and seismological source parameters. *Geophy. Res. Lett.,* 120(4): 2491–2509.

Diehl T, Kraft T, Kissling E, Wiemer S. 2017. The induced earthquake sequence related to the St. Gallen deep geothermal project (Switzerland): Fault reactivation and fluid interactions imaged by microseismicity. *Journal of Geophysical Research: Solid Earth*, 112(9). https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2017JB014473

Donat F, Gisler M, Jaggi B, Kästli P, Lutz T, Masciadri V, Matt C, Mayer-Rosa D, Rippmann D, Schwarz-Zanetti G, Tauber J, Wenk T. The 1356 Basel earthquake: an interdisciplinary revision. *Geophysical Journal International*, 178(1): 351–374. https://doi.org/10.1111/j.1365-246X.2009.04130.x

Elliott E, Trinh P, Ma X, Leaderer B, Ward M, Deziel N. 2017. Unconventional oil and gas development and risk of childhood leukemia: assessing the evidence. *Sci. Total Environ*, 576: 138–147.

Ellsworth W. 2013. Injection-induced earthquakes. *Science*, 341(6142): 1225942, doi:10.1126/science.1225942

Flóvenz O, Ágústsson K., Guðnason E, Kristjánsdóttir S. 2015. Reinjection and induced seismicity in geothermal fields in Iceland. *Proceedings World Geothermal Congress*, Melbourne, Australia, 19–25 April 2015. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/23013.pdf

Gallegos T, Varela B, Haines S, Engle M. 2015. Hydraulic fracturing water use variability in the United States and potential environmental implications. US Geological Survey, Eastern Energy Resource Center. *Water Resour. Res*, (51): 5839-5845.

Giardini D. 2009. Geothermal quake risks must be faced. *Nature*, 462(7275): 848–849, doi:10.1038/462848a.

Gregory K, Vidic R, Dzombak D. 2011. Water management challenges associated with the production of shale gas by hydraulic fracturing. *Elements*, 7(3): 181–186.

Grigoli F, Cesca S, Priolo E, Rinaldi A, Clinton J, Stabile T, Dost B, Fernandez M, Wiemer S, Dahm T. 2017. Current challenges in monitoring, discrimination, and management of induced seismicity related to underground industrial activities: a European perspective. *Rev. Geophys.*, (55): 310–340. doi:10.1002/2016RG000542.

Gunnarsson G, Kristjánsson B, Gunnarsson I., Júlíusson B. 2015. Reinjection into a fractured reservoir-induced seismicity and other challenges in operating reinjection wells in the Hellisheidi field, sw-Iceland. *Proceedings World Geothermal Congress* , Melbourne, Australia, 19-25 April 2015. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/23011.pdf

Juncu D, Arnadottir T, Geirsson H, Guomundsson G, Lund B, Gunnarsson G, Hooper A, Hreinsdottir S, Michalczewska K. 2018. Injection-induced surface deformation and seismicity at the Hellisheidi geothermal field, Iceland. *Journal of Volcanology and Geothermal Research*, xxx (2018) xxx-xxx. https://reader.elsevier.com/reader/sd/pii/S0377027317304080?token=040217535EB57FD1C5BB6DAB8E8BABC6EBBE190DB05B87D7D24927DD13D0B411BBF43CAF10DED07159F667F1D40594E2

Kargbo D, Wilhelm R, Campbell D. 2010. Natural gas plays in the marcellus shale: challenges and potential opportunities. *Environ. Sci. Technol*, 44(15): 5679–5684.

Kim K, Kim J, Han M, Kang S, Son M, Kang T, Rhie J, Kim Y, Park Y, Kim H, You Q, Hao T. 2017. Deep fault plane revealed by high-precision locations of early aftershocks following the 12 september 2016 ml 5.8 Gyeongju, Korea, earthquake. *Bull. Seismol. Soc. Am.*, (108): 517–523. doi:10.1785/0120170104

Konkel L. 2017. In the neighborhood of 18 million: estimating how many people live near oil and gas wells. *Environmental Health Perspectives*, 125(8): 124003-1. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5963578/pdf/EHP2553.pdf

Langridge R. 2018. Fault maps of Oregon. University of Oregon. https://pages.uoregon.edu/millerm/faultmaps.html

Majer E, Baria R, Stark M, Oates S, Bommer J. 2007. Induced seismicity associated with enhanced geothermal systems. *Geothermics*, (36): 185-222.

Mauter M. 2014. Regional variation in water-related impacts of shale gas development and implications for emerging international plays. *Environ. Sci. Technol*, 48(15): 8298–8306.

McKenzie L, Allshouse W, Byers T, Bedrick E, Serdar B, Adgate J. 2017. Childhood hematologic cancer and residential proximity to oil and gas development. *PLoS ONE*, 12(2): e0170423. https://doi.org/10.1371/journal.pone.0170423

Meier P, Rodriguez A, Bethmann F. 2015. Lessons learned from Basel: new egs projects in Switzerland using multistage stimulation and a probabilistic traffic light system for reduction of seismic risk. Proceedings World Geothermal Congress 2015. Melbourne Australia, April 2015. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/31023.pdf

NRC (National Research Council). 2013. Induced seismicity potential in energy technologies. Washington, DC: *The National Academies Press*. https://doi.org/10.17226/13355

OGS (Oklahoma Geological Survey). 2017. OGS statement on 2017 USGS assessment of continued seismic hazard in Oklahoma. 1 Mar 2017. http://wichita.ogs.ou.edu/documents/OGS_Statement_USGS_Hazard_Map_2017.pdf

Omara M, Sullivan M, Subramanian R, Robinson A, Presto A. 2016. Methane emissions from conventional and unconventional natural gas production sites in the Marcellus shale basin. *Environ Sci Technol*, 50(4): 2099-2107.

Peterie S, Miller R, Buchanan, DeArmond B. 2018. Fluid injection wells can have a wide seismic reach. *Eos*, 99, https://doi.org/10.1029/2018EO096199

Preiss J, Walter S, Oppenheimer D. 1996. Seismicity maps of the Santa Rosa 1deg by 2deg quadrangle, California for the period 1969-1995. U.S. Geological Survey Miscellaneous Investigations Series. https://pubs.usgs.gov/of/2002/of02-209/

Rovida A, Camassi R, Gasperini P, Stucchi M. 2011. CPTI11, the 2011 version of the parametric catalogue of Italian earthquakes, Ist. *Naz. di Geofis*. e Vulcanol., Milan, Italy. http://emidius.mi.ingv.it/CPTI

Scanlon B, Weingarten M, Murray K, Reedy R. 2018. Managing basin-scale fluid budgets to reduce injection-induced seismicity from the recent U.S. shale revolution. Seismol. Res. Lett., 90(1): 171-182. https://pubs.geoscienceworld.org/ssa/srl/article-abstract/90/1/171/566121/managing-basin-scale-fluid-budgets-to-reduce?redirectedFrom=fulltext

Schneising O, Burrows J, Dickerson R, Buchwitz M, Reuter M, Bovensmann H. 2014. Remote sensing of fugitive methane emissions from oil and gas production in north American tight geological formations. *Earth's Future*, 2: 548-558. doi: 10.1002/2014EF000265.

Soeder D, Kappel W. 2009. Water resources and natural gas production from the marcellus shale: fact sheet. US Geological Survey, Baltimore, MD. 2009-3032.

Tester J, Anderson B, Batchelor A, Blackwell D, DiDippo R. The future of geothermal energy: impact of enhanced geothermal systems (EGS) on the United States in the 21st century. Rep. INL/EXT-06-11746, Massachusetts Institute of Technology and Department of Energy, Natl. Lab., Idaho Falls. https://www1.eere.energy.gov/geothermal/pdfs/future_geo_energy.pdf

USGS (United States Geological Survey. 2018. Natural hazards: why are there so many earthquakes in the Geysers area in northern California? https://www.usgs.gov/faqs/why-are-there-so-many-earthquakes-geysers-area-northern-california?qt-news_science_products=0#qt-news_science_products)

---.2016. A rare moderate-sized (Mw 4.9) earthquake in Kansas: rupture process of the Milan, Kansas, earthquake of 12 November 2014 and its relationship to fluid injection. *Seismol. Res. Letters*, (87): 1-9.

---. 2016b. Induced earthquake magnitudes are as large as (statistically) expected. *Journal of Geophysical Research: Solid Earth*, 121(6): 4575–4590. http://www.its.caltech.edu/~pagem/InducedMmax.pdf

---. 2015. Efforts to monitor and characterize the recent increasing seismicity in central Oklahoma. *The Leading Edge*, 34(6): 628-639. doi: 10.1190/tle34060628.1. https://scits.stanford.edu/sites/default/files/tle340606282e1.pdf

Vidic R, Brantley S, Vandenbossche J, Yoxtheimer D, Abad J. 2013. Impact of shale gas development on regional water quality. *Science*, 340(6134).

Weingarten M, Ge S, Godt W, Bekins B, Rubinstein J. 2015. High-rate injection is associated with the increase in U.S. mid-continent seismicity. *Science*, 348(6241). http://science.sciencemag.org/content/348/6241/1336

Wiseman H. 2008. Untested waters: the rise of hydraulic fracturing in oil and gas production and the need to revisit regulation. *Fordham Law Review*, (20): 115-169.

Yeck W, Weingarten M, Benz M, McNamara D, Bergman E, Herrmann R, Rubinstein J, Earle P. 2016. Far-field pressurization likely caused one of the largest injection induced earthquakes by reactivating a large preexisting basement fault structure. *Geophy. Res. Lett.*, 43(19): 10198-10207. https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2016GL070861