Fracking, Disposal Wells and Induced Seismicity

By Robert A. Hefner V

A closer look at two energy issues being discussed today in America: Does hydraulic fracturing induce seismicity, and do Class II injection wells induce seismicity? This article will also briefly explore the environmental impacts of HF. This process lasts a matter of hours — not weeks or years. That is to say, HF doesn't continue on down the road and cause seismic events years later; you should see a correlation between HF and seismic activity almost instantly.

Part I: Hydraulic Fracturing

Historically, has HF caused (or induced) seismic activity?

Hydraulic fracturing has gained celebrity status among American political commentary to the point it has become quite divisive. Oklahoma in particular has been the celebrity, garnering national attention due to its number of felt earthquakes — far exceeding that of California. We've been published in the *LA Times*,[1] *Time Magazine*[2] and other major publications as well as news cycles like the "Today" show.[3] We will focus our attention here as a result.

HF was pioneered in 1947.[4] Since that time, this completion technique has been used in more than 1.2 million wells. From 1900 to 1928, Oklahoma was the world's largest producer of oil and gas, and subsequently Oklahoma remained one of the top-producing regions in the world. Geologically, Oklahoma is one of the oldest and most faulted states in the nation, giving ample amounts of opportunity for seismic activity.

Figure 1 shows Oklahoma appearing seismically dormant for nearly 30 years (1947-1980s); during that time over 291,000 wells were completed.

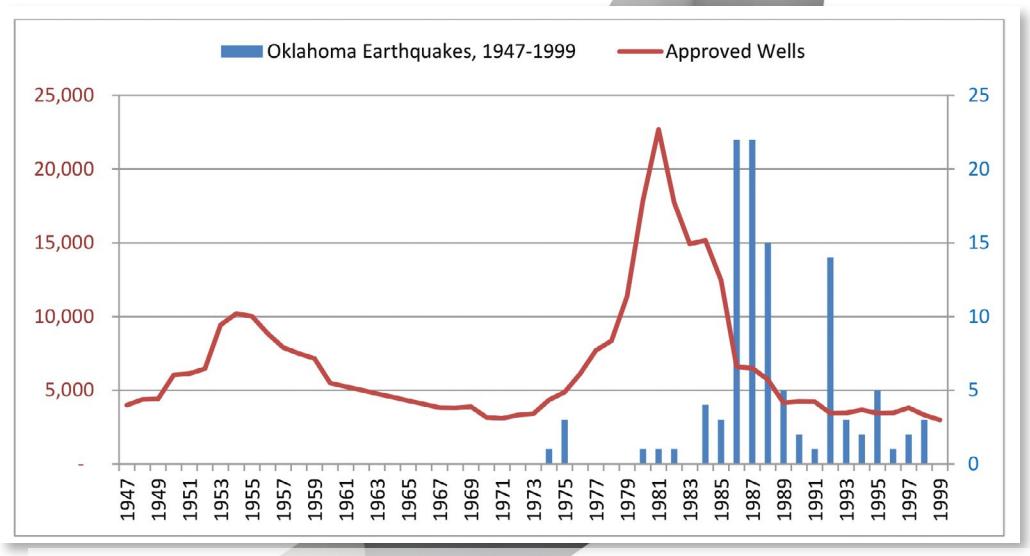


Figure 1: Historical Permitted Wells in Oklahoma vs. Seismic Events

Note: Seismographs were installed at some U.S. universities and at geomagnetic observatories of the U.S. Coast and Geodetic Survey in the early 20th century, and these recorded the larger U.S. earthquakes (typically magnitude 5 and above), but smaller shocks were still cataloged on the basis of macroseismic information. Seismographs got more sensitive and more numerous with time, so that by the 1960s shocks of M ~ 3.8 and larger in the conterminous U.S. would likely have been detected instrumentally and cataloged. Prior to the early 1970s, responsibility for this monitoring outside of California lay with agencies of the U.S. Department of Commerce (U.S. Coast and Geodetic Survey; National Oceanic and Atmospheric Administration), but in the early 1970s most civilian seismological monitoring by the U.S. government was consolidated in the USGS. Monitoring capability has improved since the 1970s, so that at present we are detecting earthquakes of 2.5 and larger in most of the conterminous U.S. In some areas, seismographs are situated densely enough that shocks of 1.5 and larger are systematically cataloged. SOURCE: USGS (seismic events), Railroad Commission of Texas (Barnett Permits) and DrillingInfo (Oklahoma Permits)

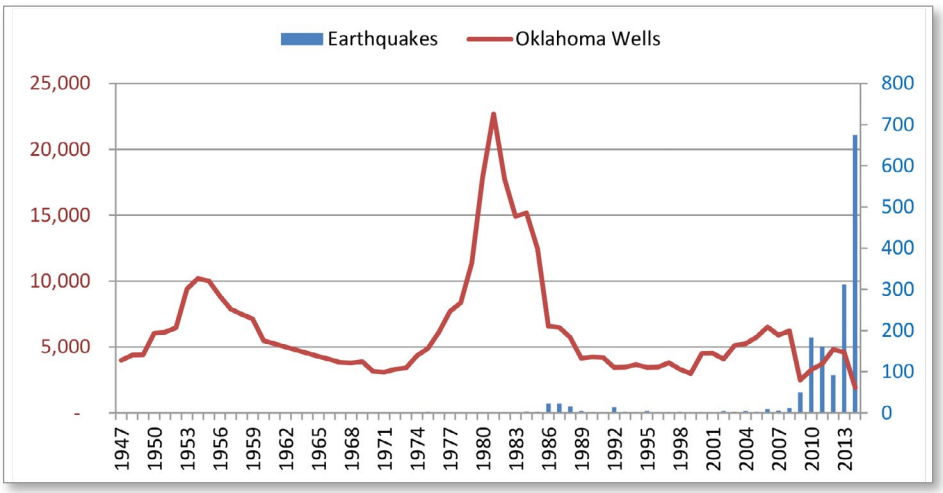


Figure 2: All Wells in Oklahoma vs. Seismic Events SOURCE: USGS (seismic events), Railroad Commission of Texas (Barnett Permits) and DrillingInfo (Oklahoma Permits)

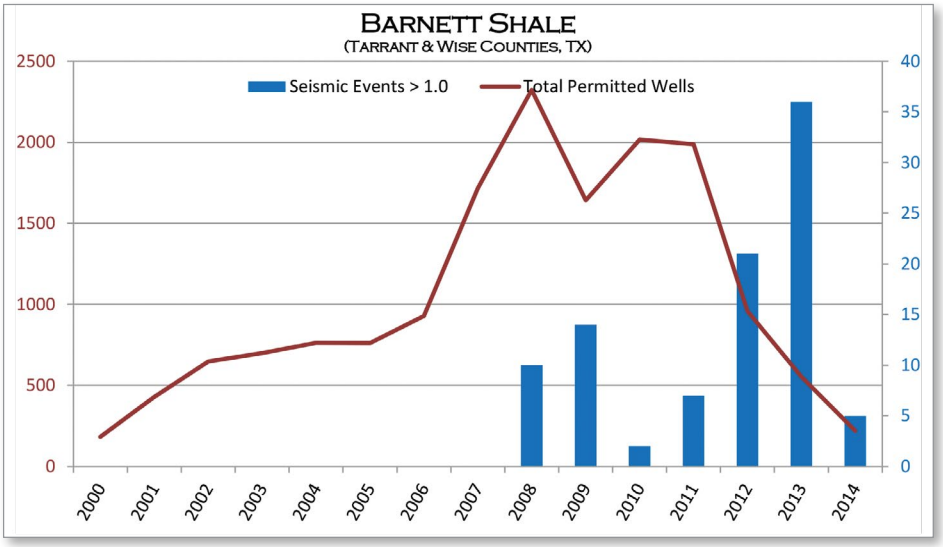


Figure 3: Barnett Shale Permitted Wells vs. Seismic Events SOURCE: USGS (seismic events), Railroad Commission of Texas (Barnett Permits) and DrillingInfo (Oklahoma Permits)

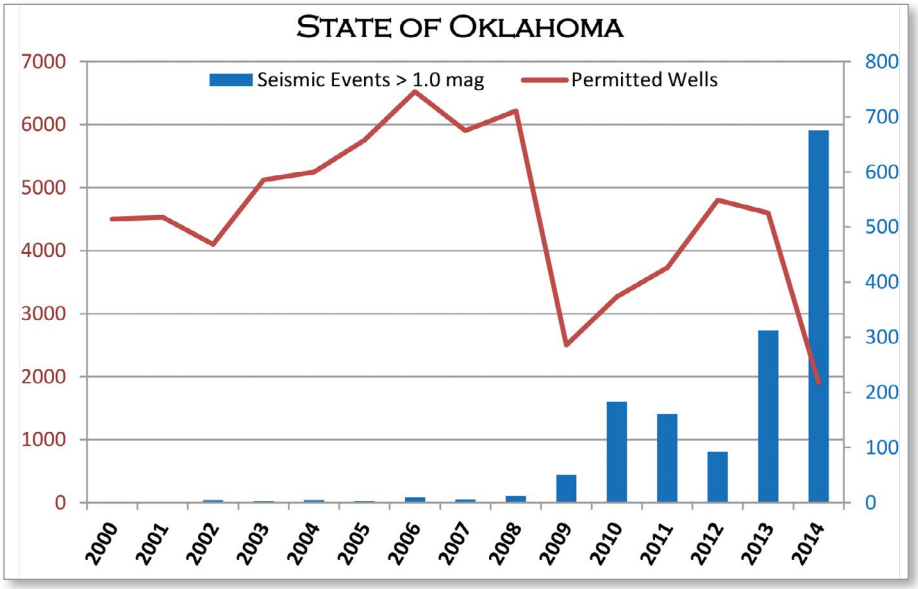


Figure 4: Total Well Permits Awarded in Oklahoma vs. Seismic Events SOURCE: USGS (seismic events), Railroad Commission of Texas (Barnett Permits) and DrillingInfo (Oklahoma Permits)

Some might argue a delayed correlation but, as noted earlier, HF only lasts hours, not weeks or years. Further, the scale of seismic events is greatly skewed in comparison when you add in the 2000s. Properly put into proportion, the trend looks quite a bit different **(Figure 2)**. Oklahoma is now completing less than one-quarter the amount of wells from its peak in 1981, and seismic activity is all of a sudden spiking without any real rhyme or reason. Historically, it doesn't appear that HF caused seismic activity.

Has HF caused (or induced) seismic activity during the modern era?

The modern era can be defined post-Devon Energy's acquisition of Mitchell Energy in 2002 and shortly before. As chronicled in *The Frackers*,[5] George Mitchell's company spent the better part of the '90s attempting to utilize fracture stimulation to unlock shale gas in the Barnett before stumbling upon the "slick water frack" and, thus, beginning the Shale Revolution as we know it today. A star was born when Oklahoma City's Devon Energy realized its potential and took it to the next level, combining horizontal drilling with the new slick water fracks designed by Mitchell's team. Since the modern era began with George Mitchell's Barnett Shale in North Texas, let's quickly look for a correlation between HF and seismic activity there.

As you already knew, or now know, every well drilled into the Barnett formation from 2000 to 2008 utilized fracture stimulation as part of the completion technique. Ironically, there are zero seismic events during those eight years **(Figure 3)**; there was actually an inverse (negative) relationship between the number of wells and seismic events from 2000 to 2007 and 2009 to 2013 — only one year, 2008, showed any potential correlation (increase in number of wells and increase in number of seismic events). As with the Oklahoma example, there doesn't appear to be a strong correlation between HF and induced seismicity.

Let's look at Oklahoma again, this time only during the modern era. **Figure 4** illustrates the number of total permits awarded in Oklahoma during the same time frame as the Barnett Shale graph *(Figure 3)*. As you can see, there is no correlation between wells permitted and seismicity. Again, we see inverse relationships nearly every year.

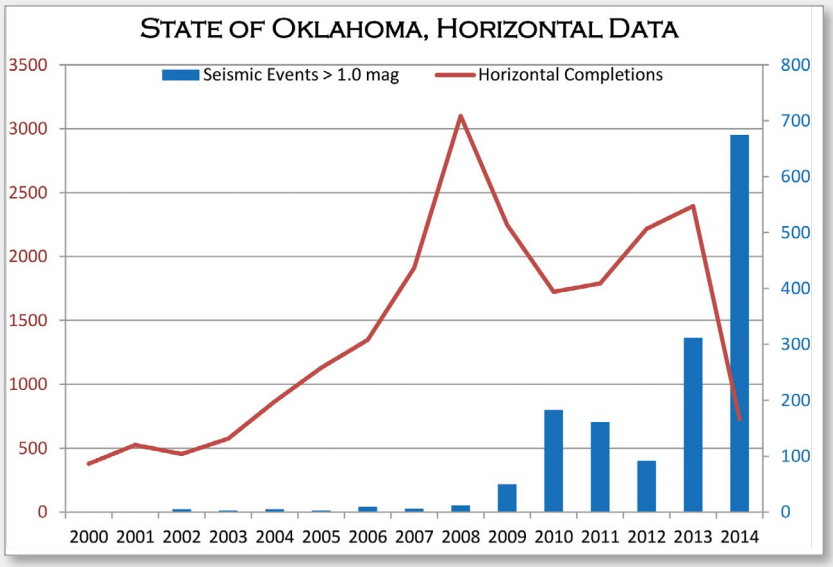


Figure 5: Horizontally Permitted Wells in Oklahoma vs. Seismic Events

Note: The charts are including all recorded earthquakes greater than 1.0 magnitude, which is very generous to opponents of HF. The earthquake magnitude scale is logarithmic; that is to say, the magnitude scale is really comparing amplitudes of waves on a seismogram, not the strength (energy release) of the earthquakes, which is really the more relevant comparison. For every degree of magnitude, the quake is 31.622 times stronger. So, a 4.0 magnitude earthquake is 31,622 times more powerful than a 1.0 magnitude earthquake — you would need 31,622 magnitude 1.0 quakes to equal the energy release of one single 4.0, or 1,000 magnitude 1.0 earthquakes to equal one single 3.0 earthquake (which most people can't even feel). A 3.9 or lesser magnitude earthquake will produce roughly the same amount of damage as an EF1 tornado (a reference most Midwesterners will understand). SOURCE: USGS (seismic events), Railroad Commission of Texas (Barnett Permits) and DrillingInfo (Oklahoma Permits)

Figure 5 focuses only on horizontally completed wells in Oklahoma. This time, the chart indicates a seemingly delayed correlation. We'll discuss that a little later in Part II: Disposal Injection Wells.

Now, this is not to say that there is no correlation between HF and felt seismic activity because there certainly is. As Columbia University's Roger Anderson states, "Hydrofracking by its nature causes tiny earthquakes, because it involves fracturing of rock — but these are largely imperceptible, as the process takes place in relatively weak, shallow shales that crack before building up much strain."

The Oklahoma Geologic Survey, for example, has suggested two separate events were triggered by HF: the Eagleton No. 1-29 (2013)[6] and the Picket Unit B No. 4-18 (2011).[7] More recently, Skoumal, et al. published research directly linking HF to seismic events in Poland Township, Ohio (2015).[8] The authors of the study, Skoumal and Brudzinski, subsequently published in the *National Review Online* "The Fracking Fracas over Earthquakes,"[9] aimed to calm the sensationalized response. As they state: "An outright ban [on fracking] wouldn't be appropriate. If you're right on top of it [a 3.0 earthquake], it's like a milk jug falling off a counter, and that's it. A 3.0 is not a danger to anybody." As noted, it would take 1,000 of these earthquakes to equal the energy release of one single 4.0 magnitude earthquake. It is, thus, readily acknowledged herein that HF has been linked to rare cases — so rare that earthquake expert Cliff Fohlich told *National Review Online* he is aware of "maybe 10 other instances on the planet" where HF triggered an earthquake. The science has certainly begun to mount to that end. So much so that Harvard University's chair of Earth & Planetary Sciences Department[10] stated: "[f]racking is probably not a direct cause of associated earthquakes." As the Barnett and Oklahoma charts illustrate, those rare exceptions aren't the rule.

We've chosen to focus on Oklahoma and Texas for relevant case studies to show that HF isn't to blame for increased seismic activity — at least generally. What about all those areas in the United States absent of oil and gas activity? What is causing their significant increases?

Idaho — not exactly an oil and gas powerhouse — has seen a significant increase in seismic activity. Idaho ranks 42nd in energy production by EIA's most recent data, yet we are reading

Side Notes

1 - http://www.latimes.com/science/sciencenow/la-sci-sn-oklahoma-earthquakes-fracking-science-20140703-story.html
2 - http://time.com/84225/fracking-and-earthquake-link/
3 - http://newsok.com/today-show-whats-causing-hundreds-of-oklahoma-earthquakes/article/4920654
4 - http://www.geosociety.org/criticalissues/hydraulicfracturing/history.asp
5 - http://www.amazon.com/The-Frackers-Outrageous-Billionaire-Wildcatters/dp/1591846455
6 - http://wichita.ogs.ou.edu/documents/OF2-2014.pdf
7 - http://www.ogs.ou.edu/pubsscanned/openfile/OF1_2011.pdf
8 - http://www.bssaonline.org/content/early/2015/01/01/0120140168.abstract?sid=93c90be0-cb9d-4406-88a9-61031b203c85
9 - http://www.nationalreview.com/article/396805/fracking-fracas-over-earthquakes-jillian-kay-melchior
10 - http://news.harvard.edu/gazette/story/2015/03/staying-power-for-shale-gas/
11 - http://rt.com/usa/central-idaho-rocked-hundreds-earthquakes-992/

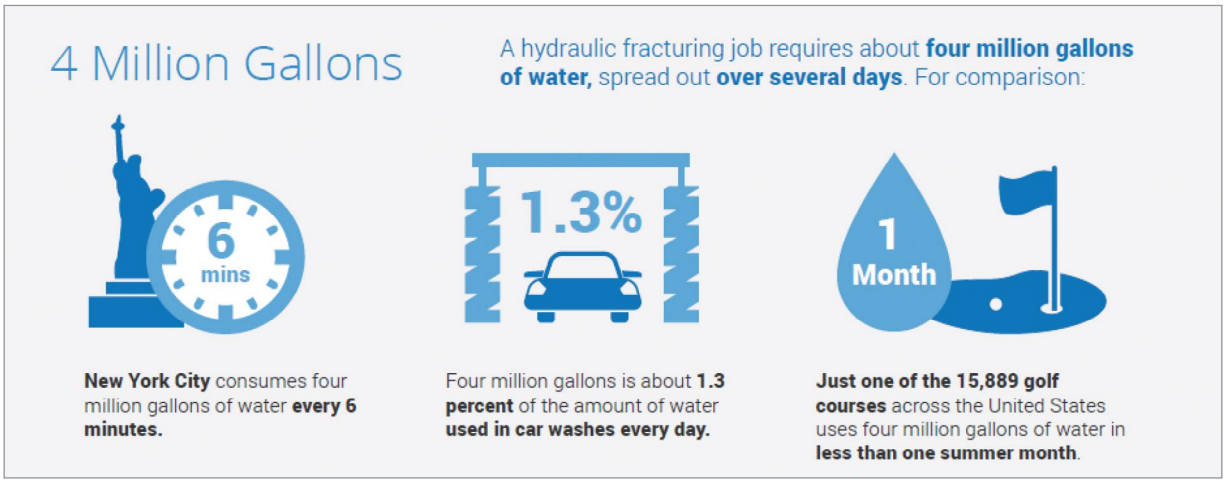
"Central Idaho Rocked by Hundreds of Earthquakes."[11] We even saw an abnormally large 8.0 magnitude earthquake[12] rock Alaska's Aleutian Islands (you'd need 32 million earthquakes the size of the one reported in Poland Township, Ohio, to equal the energy release of that single earthquake). Again, no oil and gas activity is present in either area, so it's more likely we are experiencing a greater trend — Earth is waking up and becoming more tectonically active.

A Quick Tangent: Environmental Impacts of HF

Whether intentionally or not, media outlets routinely strike fear into their uneducated, innocent readership when discussing fracture stimulation. They list the ingredients of HF as "water, chemicals and sand" without providing any basis for what that mixture actually looks like. While technically truthful, the reality is that 99.5 percent of the mixture is made up of water and sand, with a very small 0.1 to 0.5 percent being chemical in nature. Admittedly, *The Wall Street Journal* — a pro-free market paper — still gets this grossly wrong in its article, "Energy Companies Try New Methods to Address HF Complaints."[13]

Freshwater Use

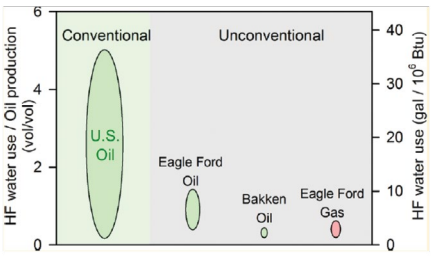
Further, some media use phrases like "millions of gallons" without providing any context. As reported by *Energy In Depth*, "The Facts on Hydraulic Fracturing and Water Use,"[14] a single frack uses about 4 million gallons of water. In comparison, New York City uses 4 million gallons of water every 6 minutes and golf courses in the United States use 2.1 billion gallons of water *per day* — that's equivalent to 525 oil and gas wells being fracked in a single day. *Energy In Depth*[15] also published a fantastic two-part story on fresh water use in California. It points out that HF operations in California used about as much water as a single California golf course, and there are 800 to 1,100 golf courses, depending on who you ask. So, oil and gas uses a miniscule amount of fresh water compared to other, nonessential industries like recreation. **Let that sink in: Freshwater use for all HF wells in California equals freshwater use for a single California golf course.**



SOURCE: *Energy In Depth*

Wastewater

As you'll see later in this article, Duke University demonstrates the ratio of energy per unit of wastewater has dramatically increased due to hydraulic fracturing (i.e., hydraulic fracturing has decreased the amount of wastewater produced while increasing the amount of energy harvested). Not only is this an environmental success, it hints that hydraulic fracturing might also decrease the amount of freshwater needed to recover each unit of energy — another environmental success. A study from the American Chemical Society[16] published Sept. 18, 2014, shows that conventional oil production, which yields less oil per well, requires more water usage than unconventional oil wells. Environmentalists should, thus, be singing its praises.



SOURCE: *Environmental Science & Technology (see end note 16)*

Groundwater Contamination

With respect to groundwater contamination, the Environmental Protection Agency's Lisa Jackson[17] herself admitted in May 2011, "[I am] not aware of any proven case where the HF process itself affected water." Since that time there have been no links of freshwater contamination to HF, only poor cement jobs and circumstantial gas seepage in active areas.

A group of "often accused anti-HF" researchers from Duke University released a definitive study on this very subject Sept. 15, 2014. The Duke study[18] set out to answer two questions (a) "Are elevated levels of hydrocarbon gases in drinking-water aquifers near gas wells natural or anthropogenic?" and (b) "If fugitive gas contamination exists, what mechanisms cause it?"

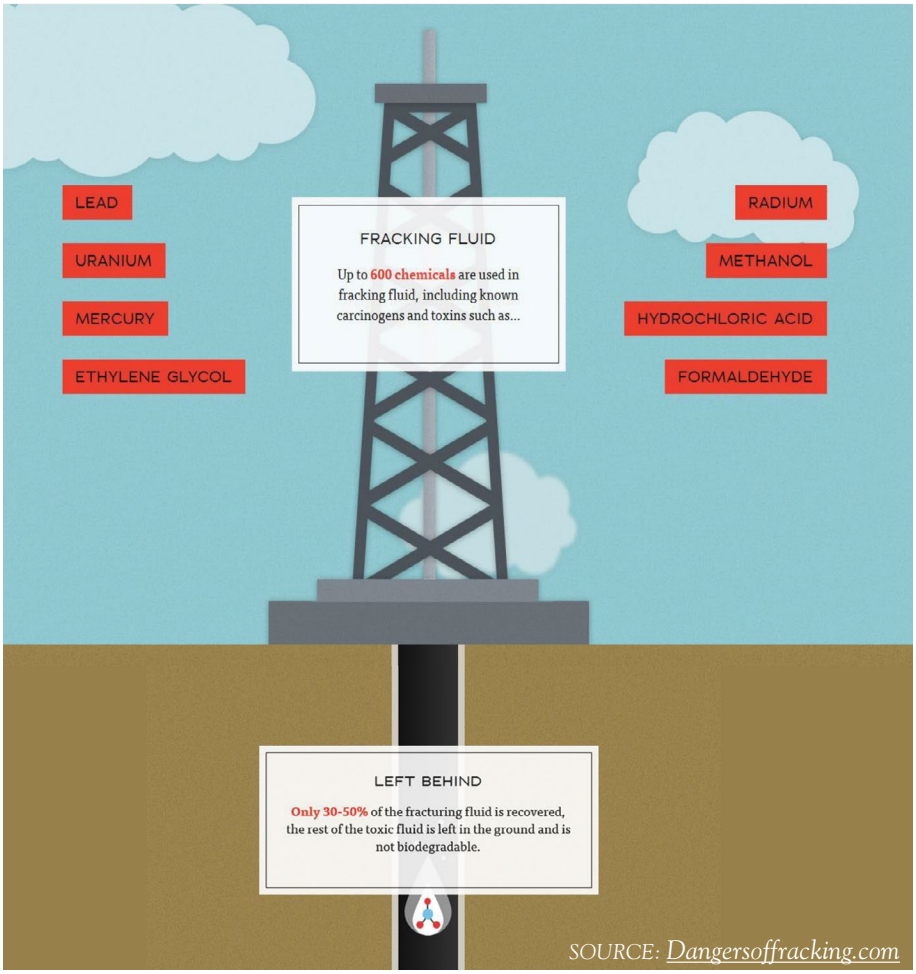
After studying 113 Marcellus wells and 20 Barnett Shale wells, the study's very straightforward answer was that "our data do not suggest that horizontal drilling or hydraulic fracturing has provided a conduit to connect deep Marcellus or Barnett formations directly to surface aquifers."

Even Harvard University's chair of Earth & Planetary Sciences Department[19] made statements to this effect: "fracking itself probably does not release fluids into the water [aquifers]."

Then, there is always the EPA's nearly 1,000-page study on the relationship between groundwater and HF, which stated that HF has "not led to widespread, systematic impacts to drinking water resources." EID[20] published a fun Top 10 on the study so you don't have to read it all, the biggest of which greatly expands the definition of HF from the EPA's own definition provided on page 1.

Harmful Chemicals

Finally, the University of Colorado published first-of-its-kind research[21] on the chemicals used in HF fluids, which many proponents of HF bans throughout the country rely upon to support their notion that HF is bad for the environment. This graphic from DangersofFracking.com illustrates how proponents of HF bans illustrate the "facts":



SOURCE: Dangersoffracking.com

12 - http://news.yahoo.com/local-tsunami-warning-issued-quake-hits-off-alaskas-213927220.html;_ylt=AwrBEiEUoKhTgzUAfuHQtDMD
13 - http://www.wsj.com/news/articles/SB10001424052702304831304579544092287190238
14 - http://energyindepth.org/national/infographic-the-facts-on-hydraulic-fracturing-and-water-use/
15 - http://energyindepth.org/california/clearing-up-confusion-water-energy-development-california/
16 - pubs.acs.org/doi/pdf/10.1021/es502506v
17 - https://www.youtube.com/watch?v=im-yJhCHhCo
18 - http://www.pnas.org/content/111/39/14076.abstract
19 - http://news.harvard.edu/gazette/story/2015/03/staying-power-for-shale-gas/
20 - http://energyindepth.org/national/ten-important-things-to-know-from-epas-1000-page-groundwater-study/
21 - http://www.colorado.edu/news/releases/2014/11/12/major-class-fracking-chemicals-no-more-toxic-common-household-substances

Earthworksaction.org takes the fear-mongering to the ultimate level making statements such as, "Many fracturing fluid chemicals are known to be toxic to humans and wildlife, and several are known to cause cancer."

What did the University of Colorado's first-of-its-kind research say? The University of Colorado analyzed surfactants from HF fluids found from Colorado, Louisiana, Nevada, Pennsylvania and Texas. "The results showed that the chemicals found in the fluid samples were also commonly found in everyday products, from toothpaste to laxatives to detergent to ice cream." They go on to further state, "What we have learned in this piece of work is that the really toxic surfactants aren't being used in the wells we have tested." The science is continuing to mount on the side of hydraulic fracturing being a safe technology.

HF Conclusion

Keeping in mind HF operations last a matter of hours and seismic activity should ensue shortly (days, not years) thereafter, I believe we can now put to bed the idea that HF is causing felt seismic activity.

22 - http://spectator.org/articles/59554/fracking-banin-louisiana

23 - http://www.forbes.com/sites/realspin/2014/12/22/careful-review-of-health-studies-used-by-cuomo-administration-to-justify-fracking-ban/

24 - http://breakingenergy.com/2015/01/14/new-york-fracking-ban-throws-peer-review-under-the-bus/

25 - http://www.wsj.com/articles/new-york-fracking-cases-echo-past-gas-boom-1402969695

26 - http://www.pbs.org/newshour/rundown/upstate-new-york-towns-look-secession-right-frack-pennsylvania/

27 - http://www.tribtalk.org/2014/10/03/why-denton-shouldnt-ban-fracking/

28 - http://www.dentonrc.com/local-news/local-news-headlines/20150527-fracking-battle-in-texas-not-over.ece

29 - http://blogs.kqed.org/science/2015/01/02/interior-secretary-local-fracking-bans-are-wrong-way-to-go/

30 - http://stateimpact.npr.org/texas/tag/earthquake/

31 - http://time.com/84225/fracking-and-earthquake-link

32 - http://www.sciencemag.org/content/161/3848/1301.short

33 - http://water.epa.gov/type/groundwater/uic/regulations.cfm

Even though we can conclude with a large degree of certainty that HF doesn't induce seismic events, the anti-fracking hysteria is spreading across the United States. Republicans in Louisiana have moved to ban HF,[22] and New York has banned HF using debunked research[23] — one study cited was immediately disavowed by the executive director of the publishing organization well in advance of New York's decision, touting peer-reviewed science that also appears to be in violation of ethical conduct.[24] New York now faces a major lawsuit, which could find punitive damages in favor of mineral owners' rights being infringed upon[25] and the Southern Tier trying to secede from New York[26] and be absorbed by Pennsylvania as they fight for their economic life — admittedly a long shot.

The city of Denton, Texas, also passed a HF ban Nov. 4, 2014. This ban is somewhat unique to all others since it was originally placed on the ballot as an initiative by those who took issue with how close gas wells were to their homes. Of course, after it was found on the ballot, environmental and earthquake fears began to swirl. The Denton HF ban led to economic damage, loss of property rights and legal problems that proved to be very costly to Denton taxpayers, as the head of the Barnett Shale Energy Education Council[27] suggested it would prior to the election. Regardless, the vote was overwhelmingly passed (60 to 40 percent in favor) and it only cost $70,000 to strike that kind of fear into the hearts

of innocent constituents — not even $700,000 backed by numerous university studies could sway them. The Denton City Council voted 6-1 to repeal their fracking ban, which has cost the taxpayers between $500,000 and $1 million depending on whom you ask — *The Denton RC*[28] for example.

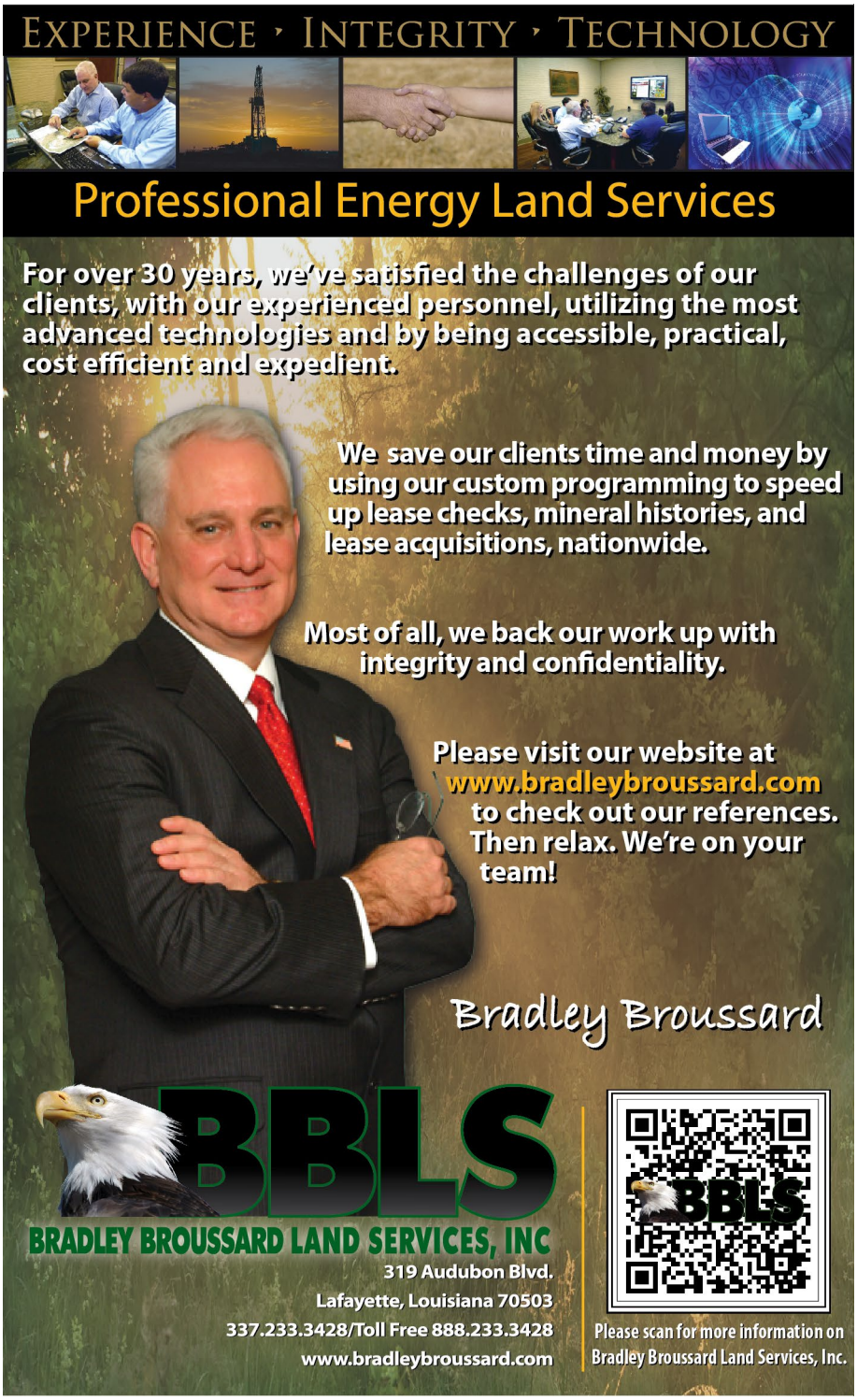
What's the bottom line? Fear is a powerful motivator, and you don't have to spend very much money to strike fear into the public regardless of what the science says. Secretary of Interior Sally Jewell, nominated by President Obama, might sum it up best, "There is a lot of misinformation about fracking. I think localized efforts or statewide efforts in many cases don't understand the science behind it. … [Bans are] the wrong way to go."[29]

There is a seemingly delayed correlation in *Figure 5: Horizontally Permitted Wells in Oklahoma vs. Seismic Events*, which needs to be evaluated, however. It's one that implicates a potential culprit for increased seismic activity — disposal injection wells.

Part II: Disposal Injection Wells

For those not familiar, disposal injection wells and HF are completely separate events in completely separate wells. Unfortunately, most reporting you see on the subject — similar to *StateImpact*[30] and *Time Magazine*[31] — report "disposal of drilling wastewater used in HF has now been scientifically linked to earthquakes" and suggest that disposal and HF are so closely tied together they are one and the same. They also write about disposal wells as if they are something new — they are not. Disposal wells, or Class II injection wells, have been directly linked to seismic events as early as 1968 in Denver.[32] It's nothing new and we've learned a great deal already about their impacts.

Disposal wells exist due to EPA Regulations[33] of the oil and gas industry. The EPA requires the oil and gas industry to dispose of all produced



fluids (fluid that comes out of the well) and treat it as hazardous waste. So, when fluid comes to the surface (out of a formation underground), the oil and gas industry trucks or pipes it to a disposal well where it's re-injected back into the earth to be disposed of safely and prudently. Of course, new technologies like Ecosphere[34] could possibly antiquate this practice if the EPA would update its rules to the 21st century. While the fluid injected back into the earth does contain some frack fluid, the majority comes from existing fluid residing within the reservoir prior to drilling and completion (i.e., nonfrack fluid). So, HF is a process used while completing an oil or gas well, and a disposal well is a completely separate well that is used to dispose of produced fluids from multiple oil and gas wells. In many cases, a single disposal well services multiple oil and gas wells.

While some cases have been directly linked to disposal wells, they are a relatively small percentage. Out of more than 140,000 currently active Class II injection wells,[35] only a handful of wells have been associated with induced seismic activity. Not all of those injection wells are disposal wells; approximately 60 percent of the active injection wells in Oklahoma are wells used for enhanced oil recovery, not disposal. Further, Oklahoma's oil and gas regulatory body, the Oklahoma Corporation Commission, has stated: "In most of the cases examined thus far [since 2011], there have been either no injection wells operating in the area of interest [seismic activity], or the focus of the events were at depths that varied greatly from the operational depths of the injection wells in question." Columbia University's 2012 report[36] placed a probability on the chance of an injection well causing a seismic event in a dormant fault at 1:200 or 0.5 percent chance. An examination of another major producing shale play, the Bakken, indicates that not all states are created equal because unlike in other oil-producing states, North Dakota experiences little or no seismic activity.[37]

Still, steps are actively being taken on the state level to ensure seismic events are more closely monitored and located off-fault. Of course, not all the faults in the United States are known, which is one reason why some wells have caused seismic activity. Ohio, for example, experienced a cluster of seismic events due to injection wells drilled into unknown, dormant faults. Since then, Ohio has put into place new permit conditions: Companies that drill within three miles of a known fault or area of seismic activity

greater than 2.0 magnitude are required to install seismic monitors that are linked to the Ohio Department of Natural Resources.[38]

ODNR even published a study back in 2012 that stated the ingredients that must be present to induce a seismic event:

- "a fault must exist within the crystalline basement rock,"
- "that fault must already be in a near-failure state of stress,"
- "an injection well must be drilled deep enough and near enough to the fault and have a path of communication to the fault," and
- "the injection well must inject a sufficient quantity of fluids at a high enough pressure and for an adequate period of time to cause failure, or movement, along that fault (or system of faults)."

What was the ODNR's conclusion?[39] "All the evidence indicates that properly located Class II injection wells will not cause earthquakes" since "[g]eologists believe it's very difficult for all conditions to be met to induce seismic events."

Southern Methodist University released a report as well, in conjunction with The University of Texas at Austin, on the link between injection wells and "earthquakes." The report[40] indicates there are more than 2,400 injection wells in the Fort Worth Basin (Barnett Shale area) and the vast majority do not have seismic activity associated with them. Still, researchers were reluctant to rule disposal wells out of the equation even though Texas' regulatory body, the Railroad Commission of Texas, found no data that linked hydraulic fracturing to earthquakes and no significant correlation between seismic activity and injection wells.

More recently (July 4, 2014), geologists from Cornell University, together with the University of Colorado and the U.S. Geological Society, issued a study titled "Sharp Increase in Central Oklahoma Seismicity since 2008 Induced by Massive Wastewater Injection."[41] This peer-reviewed study states: "fluid migration from high-rate disposal wells in Oklahoma is *potentially* responsible for the largest swarm," and, "Our earthquake relocations and pore pressure *models* indicate that four high-rate disposal wells are *capable* of increasing pore pressure above the reported triggering threshold throughout the Jones swarm. Although thousands of wells operate aseismically, four of the highest-rate wells are capable of inducing 20 percent of 2008-2013 central U.S. seismicity." This study doesn't come to any direct, concrete conclusion that these four, high-rate wastewater injection wells are to blame for increased seismic events in Oklahoma other than in title of the study, which doesn't appear to be appropriately named. Of course, the *LA Times*[42] and others write headlines like, "Study Links Oklahoma Earthquake Swarm With HF Operations." First, nowhere does the study say anything about HF being linked to wastewater injection wells. Second, the study shows that four wells *potentially* triggered a swarm of seismic activity with no clear, definitive statement that this is the case.

Of note, the Cornell-Colorado-USGS study did indicate that fluid migration from disposal injection wells could travel up to 19 miles from the well site and documented that the 2010 earthquake swarm ruptured an "unmapped" fault.

34 - http://www.ecospheretech.com

35 - http://water.epa.gov/type/groundwater/uic/class2/

36 - http://www.ldeo.columbia.edu/news-events/seismologists-link-ohio-earthquakes-waste-disposal-wells

37 - http://www.inforum.com/news/3701357-unlike-other-oil-producing-states-nd-experiences-little-or-no-seismic-activity

38 - http://www.cantonrep.com/article/20140411/Business/140419802

39 - http://oilandgas.ohiodnr.gov/portals/oilgas/downloads/northstar/reports/northstar-executive_summary.pdf

40 - http://keranews.org/post/what-s-causing-texas-earthquakes-smu-study-explores-injection-wells-drilling

41 - http://www.sciencemag.org/content/early/2014/07/02/science.1255802.full.pdf?keytype=ref&siteid=sci&ijkey=3dn.4mOXpb5fM

42 - http://www.latimes.com/science/sciencenow/la-sci-sn-oklahoma-earthquakes-fracking-science-20140703-story.html

We will need time to understand fluid migration. These are two important annotations because they get to the crux of the problem: We don't understand underground fluid migration quite yet, and we don't have every fault mapped across the United States.

Since the study, the evidence has continued to mount, however, that disposal injection wells are the cause of much seismicity — at least in Oklahoma. The Oklahoma Geological Society[43] updated its statement on earthquakes appropriately in April to state two key findings:

1. "Based on observed seismicity rates and geographical patterns of migrating seismicity in Oklahoma, which follow major oil and gas plays with large amounts of produced water, these rates and patterns of seismicity are very *unlikely to represent naturally occurring rate change and process*."
2. "It is often stated that disposed water is waste-water or 'flow-back water' from hydraulic fracturing. While there are large amounts of waste-water generated from hydraulic fracturing, this volume represents a small percentage of the total volume of waste-water injected in disposal wells in Oklahoma."

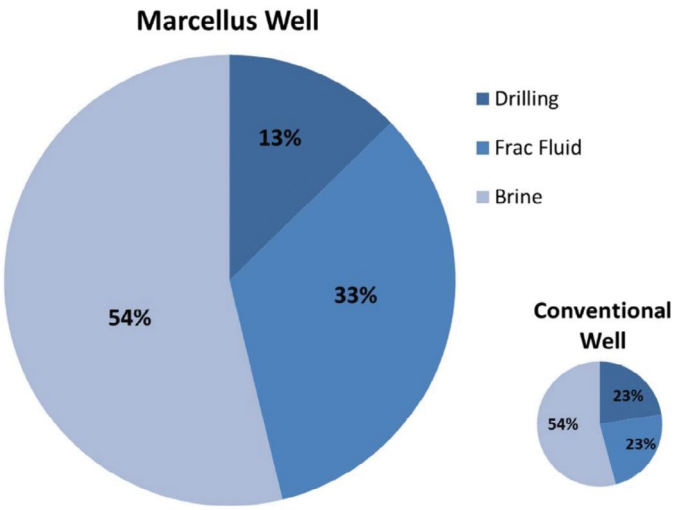
Stanford University[44] released the most recent study (June 18) in *Science Magazine* to more precisely state: "In three study areas that encompass the vast majority of the recent seismicity, we show that the increases in seismicity follow 5- to 10-fold increases in the rates of saltwater disposal. Adjacent areas where there has been relatively little saltwater disposal have had comparatively few recent earthquakes."

Oklahoma's earthquakes appear to be due to disposal injection wells located in the Arbuckle formation, overlying the crystalline basement, and the Arbuckle formation appears to be "in hydraulic communication with potentially active faults in crystalline basement, where nearly all the earthquakes are occurring."[45]

Regardless, we are beginning to see some clear conclusions from all these studies: (a) don't inject into known faults, (b) increased monitoring of wells in areas of known seismic activity is a good idea and (c) don't inject too close to the crystalline basement whereby you could possibly have hydraulic communication. It wouldn't be crazy to suggest shutting down Class II injection wells that end up drilling into unmapped faults either — a recommendation that has now been put into effect in Oklahoma and other states.

HF increases wastewater disposal volumes, so we should stop HF, right?

This argument has started to surface lately: HF increases wastewater volumes that are pumped into disposal injection wells, a handful of disposal injection wells induced seismic



SOURCE: Duke University's Figure 13–A: A four-year profile of waste production from Marcellus and conventional wells.

events and therefore HF is bad. From the studies done on wastewater thus far, this couldn't be further from the truth. In 2012, Duke University[46] released an extensive report on wastewater generation and disposal from natural gas wells in Pennsylvania.

As Duke's study states, "overall waste *volume* is very different between Marcellus wells and conventional wells, while waste *composition* is only slightly different if both well types are hydraulic fractured." If composition really isn't any different, does the volume associated present negative impacts?

According to the Duke study, "In ***Figure 13-A***, the pie charts are sized to show the difference in the amount of waste production, with Marcellus wells producing approximately 11.3 times more waste per well than conventional wells. However, Marcellus wells also produce approximately 40 times more gas in 4 years on average than conventional wells. As a result Marcellus wells are significantly more efficient than conventional wells in terms of waste production, with about three times as much gas produced for each gallon of wastewater. This ratio may go down slightly over time as gas production from hydraulically fractured wells decreases, but even with no gas production beyond the fourth year and steady brine production mirroring the fourth year brine values, Marcellus wells remain more efficient than conventional wells. Pennsylvania dramatically increased its production of natural gas producing 10 times more natural gas in 2011 than 2004, with only 4 times more waste production."[47]

Thus, modern wells have actually increased the efficiency by which oil and gas companies extract gas per unit of waste. As a result, less water will be injected back down into disposal injection wells than without the coupling of horizontal drilling and HF. The environmental movement should be praising the oil and gas community for such a development.

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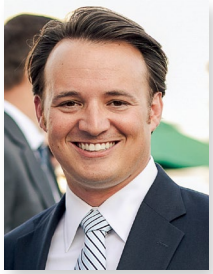
In Summary

This article has explored seismic activity in relation to oil and gas operations across the United States, with a focus on the most active states. More specifically, we explored HF operations in areas of increased seismic activity, HF's environmental impact and disposal injection wells in areas of increased seismic activity. We have quashed the argument that "HF causes earthquakes" (a conclusion that Stanford University's Mark Zoback[48] has plainly stated on CNBC), shown that HF's use of freshwater is environmentally dwarfed in comparison to other nonessential industries like recreation (a conclusion the EPA[49] came to as well), only a statistical few disposal injection wells have induced seismic activity and hydraulic fracturing actually decreases the amount of wastewater that needs to be disposed of via injection wells per unit of oil and gas produced. We also realized non-energy states like Idaho are seeing significant increases in seismic activity that obviously can't be linked to oil and gas activity, while other major energy producing states like North Dakota have been devoid of statistical increases in seismic activity. So, what do we do?

Arkansas and New York have displayed exactly what not to do: Arkansas banned disposal injection wells altogether while New York banned HF altogether. Denton, Texas, gave us a perfect example of legislative oversteps and the undue financial burden it places upon taxpayers. It should be noted that famed environmentalist Gov. Jerry Brown[50] of California even refuses to subject California to such a ban, saying, "It doesn't make a lot of sense."

I'm proud to say Oklahoma is taking a very reasonable approach. The Oklahoma Corporation Commission, Oklahoma's oil and gas regulatory body, says it is "keeping an open mind" about ongoing research, correctly stating, "We are having to manage *perceived* risks." Meanwhile, Oklahoma Gov. Mary Fallin signed into law a bill that requires operators of injection wells to report daily, instead of monthly, injection volumes — a measure that took effect in September 2014. Subsequently, the OCC implemented a traffic light system[51] in March that applies to 347 of the approximately 900 disposal wells in Oklahoma located in the Arbuckle formation — a formation that sits on top of basement rock. So far, the traffic light system has shut down more than 50 disposal wells and reduced injection rates of approximately 150 wells.[52] In July, the OCC updated the March directive[53] and operators have a matter of days to prove they are not injecting below the Arbuckle formation where the well could be in communication with basement rock. There is, thus, clear evidence that regulators are paying attention and taking real, proactive steps to ensure the public's safety while balancing delicate economic considerations. Oklahoma should be proud.

about the AUTHOR



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