FRACK ATTACK

Cracking the Case against Hydraulic Fracturing

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Cracking the Case against Hydraulic Fracturing

Executive Summary

The debate over hydraulic fracturing ("fracking") has suffered from misinformation.

Colorado Governor John Hickenlooper—a geologist—said it best: "There's no science here. This is all hyperbole and a lot of anxiety. . . ."[1]

Before succumbing to hyperbole and anxiety, the public should consider the following:

- Fracking is not new. It is an old, proven technology. The recent excitement over fracking is due to the same *old* technology being applied to *new* types of rock layers.

- Fracking is essential to oil and natural gas production in Colorado. A ban on fracking is a *de facto* ban on an industry that accounts for 6 percent of total employment in Colorado and 7.3 percent of the state's economy.[2]

- Both the physical laws of nature and economic incentives make the possibility of contamination very small.

- Fracking is consistently and mistakenly blamed for contamination that results from poor drilling practices and surface spills.

- Colorado and other states have regulations in place that effectively protect public health and the environment from oil and gas activity, including fracking.

- The most feared chemicals correctly or incorrectly linked to fracking are often non-toxic or are natural parts of the everyday environment.

- Claims that fracking will deplete water supplies, create unmanageable wastes, and cause damaging earthquakes are based on assumptions that do not reflect reality.

Table of Contents

Background

The first step to understand fracking is to know that fracking is used to extract both oil and natural gas.[3] In fact, oil and natural gas are just hydrocarbons at different stages in the same process: the natural breakdown of hydrocarbons. Over time, oil breaks down into natural gas, the most mature hydrocarbon. Consequently, when a company "strikes oil," the company has found a mixture of hydrocarbons. Most of the hydrocarbons are still in the liquid stages, and only some are in the gaseous stages of the process. As a result, there is no such thing as an "oil drilling rig" or a "natural gas fracking procedure." The same equipment and procedures are used for both.

> ***Fracking is an extraction method that helps produce oil and natural gas that otherwise could not be produced.***

What is Fracking?

Fracking is an extraction method that helps produce oil and natural gas that otherwise could not be produced. A liquid or gaseous mixture (a "fracking fluid") is injected into the well, under high pressure, to create fractures in a specific rock layer. Before fracking, the well is sealed with steel pipe and cement ("casing"). Holes are then punched through the casing at the targeted depth to create a controlled point of entry for the fracking fluid. Typically, the targeted formations are thousands of feet below potential sources of drinking water. Figure 1 shows an overall perspective of fracking. Figure 2 shows a typical equipment layout for a fracking operation.

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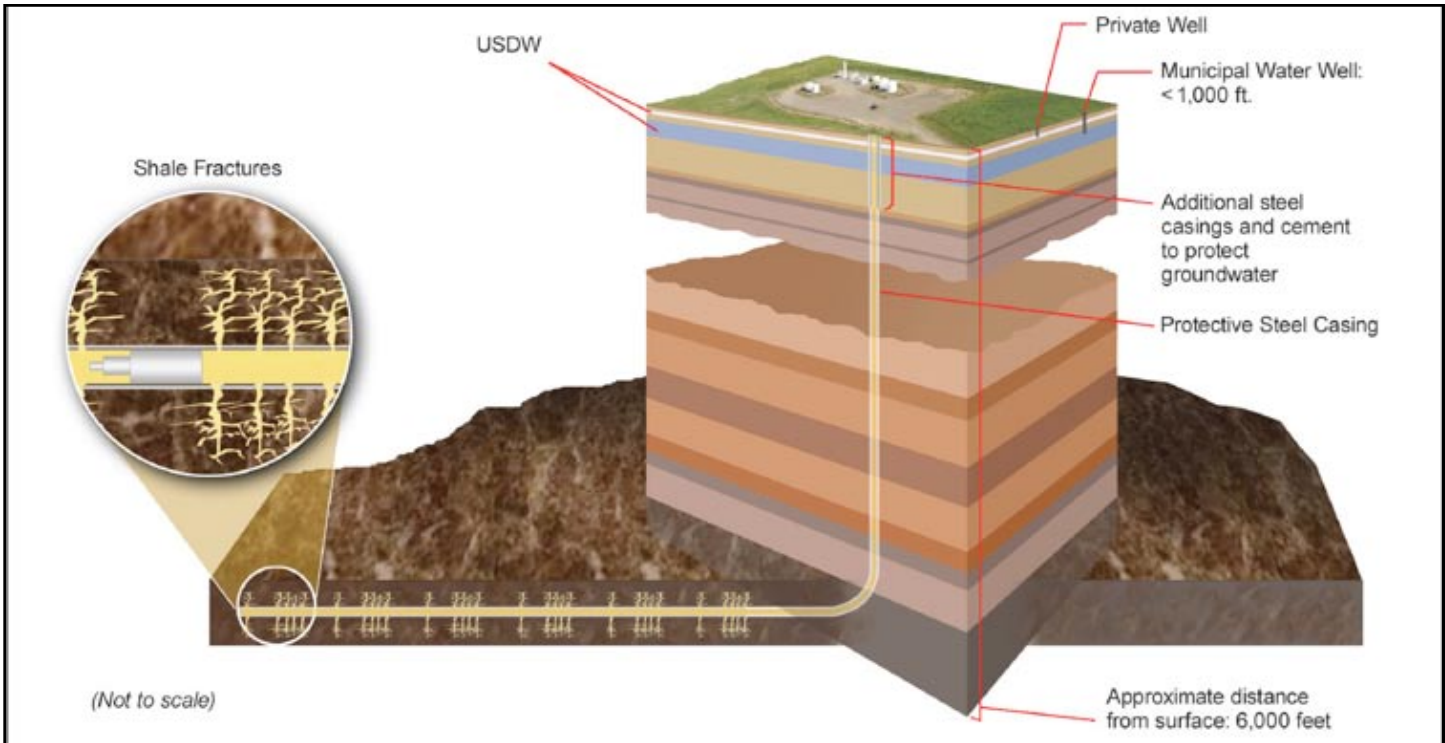
The fracking fluid is a mixture of a base fluid, a "proppant," and chemical additives. The base fluid acts like a giant fluid piston, transferring pressure and energy from the surface down to the rock layer where the fractures are created. The base fluid is often water, but it can also be other liquids or gases. The base fluid makes up 90 to 100 percent of the mixture.

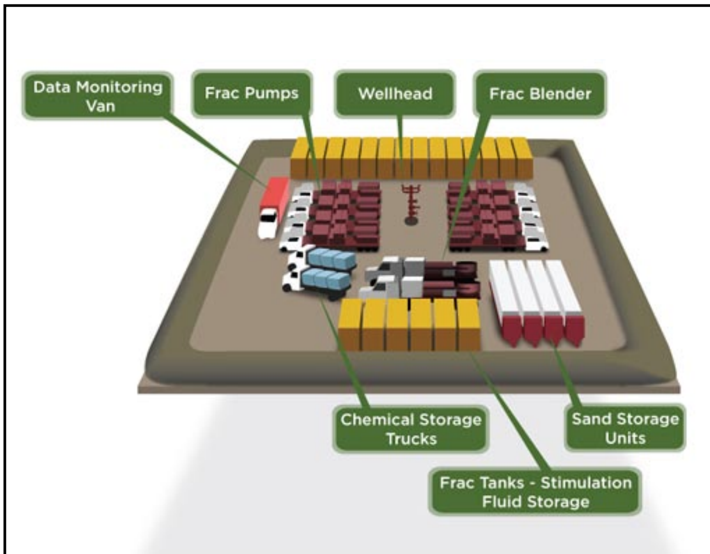
The proppant is a granular substance, usually sand, that can withstand high pressures without the individual grains being crushed. The base fluid carries the proppant into the fractures, where the

Figure 1. *General perspective view of fracking. "USDW" stands for Underground Source of Drinking Water. Source: United States Department of Energy, http://www.fe.doe.gov/programs/oilgas/shalegas/hydraulicfracturing.html.*



Steel casing lines the well and is cemented in place to prevent any communication up the wellbore as the fracturing job is pumped or the well is produced. Shallow formations holding fresh water that may be useful for farming or public consumption are separated from the fractured shale by thousands of feet of rock.

Figure 2. *Typical equipment layout during a fracking operation. Source: HydraulicFracturing.org.*



proppant acts like a door stop, propping the fractures open after the fracking process is finished. The proppant can make up anywhere from 0 to 10 percent of the fracking fluid (sometimes none is used at all).

The chemical additives serve a variety of specific purposes. Combined, they make up 0.5 to 1 percent of the fracking fluid. Hundreds of different chemicals are available for use in fracking fluids. However, typically only 5 to 20 different chemicals will be used in a single fracking fluid mixture.

The time required to frack varies from well to well, primarily because wells are fracked in multiple stages and some have more stages than others. A vertical well, with only one or two stages, can be fracked in a few hours. A horizontal well, with 10 or more stages, can take several days to complete. Fracking is a standard practice in Colorado. According to David Neslin, former director of the Colorado Oil & Gas Conservation Commission (COGCC):

> Hydraulic fracturing ... is almost ubiquitous across Colorado, and 90 percent of the wells are hydraulically fractured across the nation.[4]

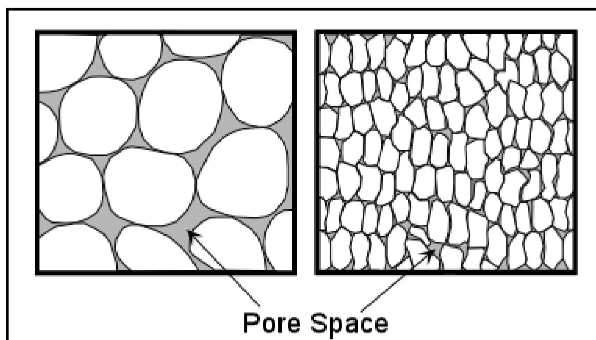
Brief videos of the fracking process can be found at the URLs listed below. The first video shows the entire process (drilling and fracking) in general. The second video shows the fracking process in greater detail. These videos are not necessary for understanding this paper, but they provide helpful perspective.

- http://www.youtube.com/watch?v=O0kmskvJFt0
- http://www.youtube.com/watch?v=73mvWl5cgg&feature=related

Why Frack?

Contrary to popular belief, hydrocarbons are not found in underground lakes or caverns. Instead, they exist inside solid layers of rock, filling the tiny void spaces ("pores") between the rock grains (figure 3). The pores form an interconnected network that allows the hydrocarbons to flow through the rock layers (a quality known as "permeability").

Figure 3: *Oil, natural gas, and many other fluids are found inside the pores of sedimentary rocks. The white blobs in the figure are the mineral grains that make up the rock. Source: Stephen A. Nelson, Tulane University, http://www.tulane.edu/~sanelson/eens1110/groundwater.htm*



A distinct layer of rock (a "formation") that is filled with hydrocarbons *and* has a high permeability (i.e., a well-connected pore network) is called a "conventional formation." If, on the other hand, the formation has low permeability (i.e., a poorly-connected pore network), it is called an "unconventional formation." Unconventional formations can store vast amounts of hydrocarbons—even as much as conventional formations. However, since they have a low permeability, they cannot produce the hydrocarbons unless fracking or some other technique is used to increase their overall permeability.[5] Figure 4 shows the difference between conventional and unconventional formations from a geologic perspective.

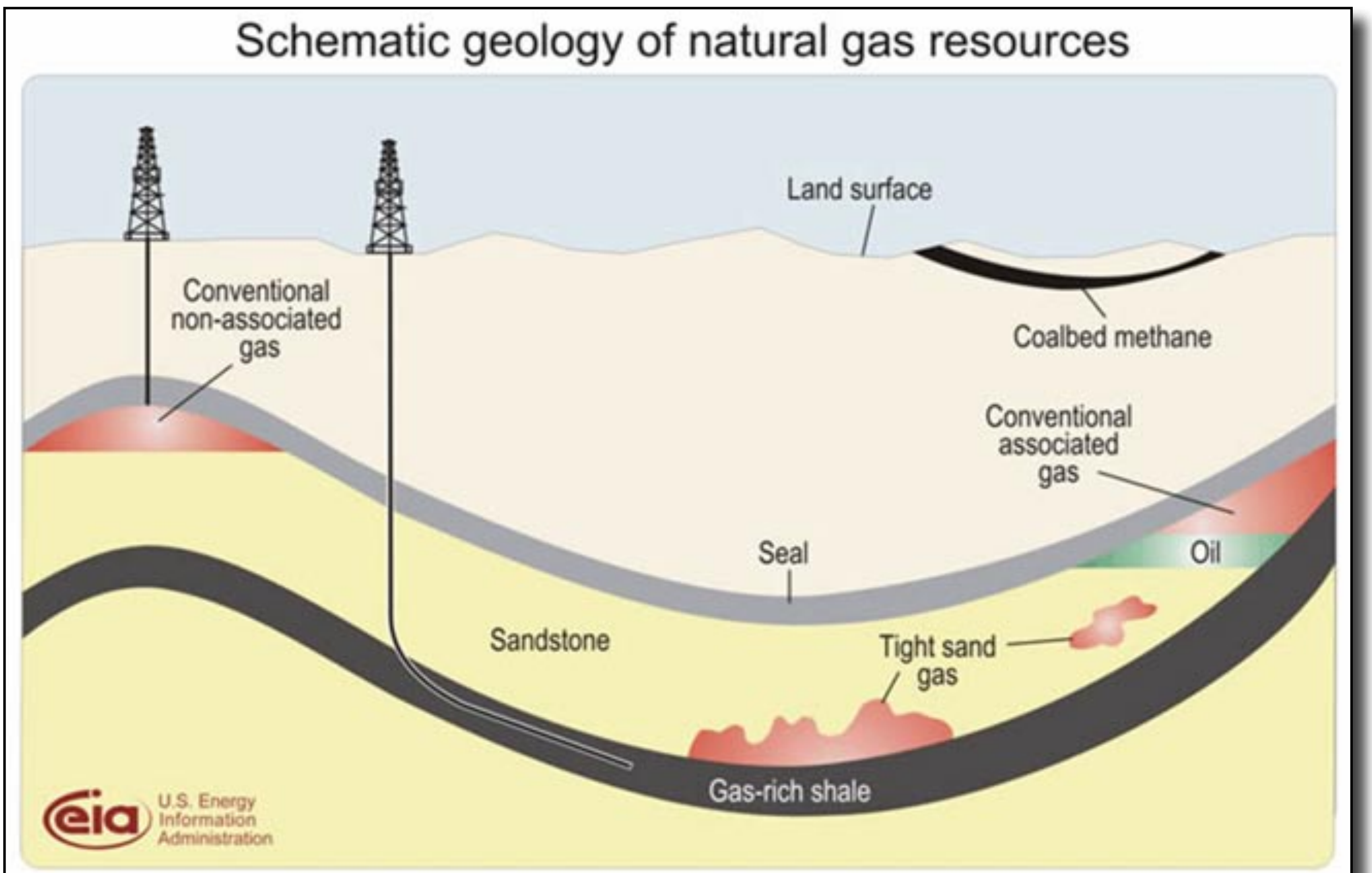
To unlock trapped hydrocarbons, fracking does not actually connect all the tiny pores with fractures (that would be impossible). Instead, after a fracking operation is finished and the pressure is released, the fractures—held open by the proppant—serve as low-pressure zones. By extending the low-pressure zone from the well out into the formation, the pressure-drive becomes stronger and better able to pull the hydrocarbons through the poorly-connected pore network.

In this sense, fracking is like bringing a negatively-charged wire close to a positively charged wire so electrons can jump across the gap (in the form of a spark). The wires do not actually have to touch (and neither do fractures and pores), but bringing the wires close enough together increases the force just enough to pull the electrons through the air. Hydrocarbons behave similar to electrons when they move across a poorly-connected pore network into nearby fractures.

The Unconventional Revolution

Fracking was first used by the oil and gas industry in the 1940s.[6] However, up until the 1990s, fracking was only used on *conventional* formations. These formations were able to produce without fracking, but the technique was used to improve and accelerate their production. Meanwhile, unconventional formations were considered worthless. Engineers and geologists knew that unconventional formations held vast amounts of hydrocarbons, but they were convinced that nothing, not even fracking, would ever make them profitable.

Figure 4. *In conventional formations, oil and gas migrate through permeable sandstone formations and accumulate when they encounter an impermeable formation (called a "seal"). In unconventional formations (like the "Gas-rich Shale" in the diagram), the oil and gas have never left the original formation in which they were created—they are trapped inside the pores. Source: Energy Information Administration. http://www.eia.gov/energy_in_brief/images/charts/NatGasSchematic-large.jpg*



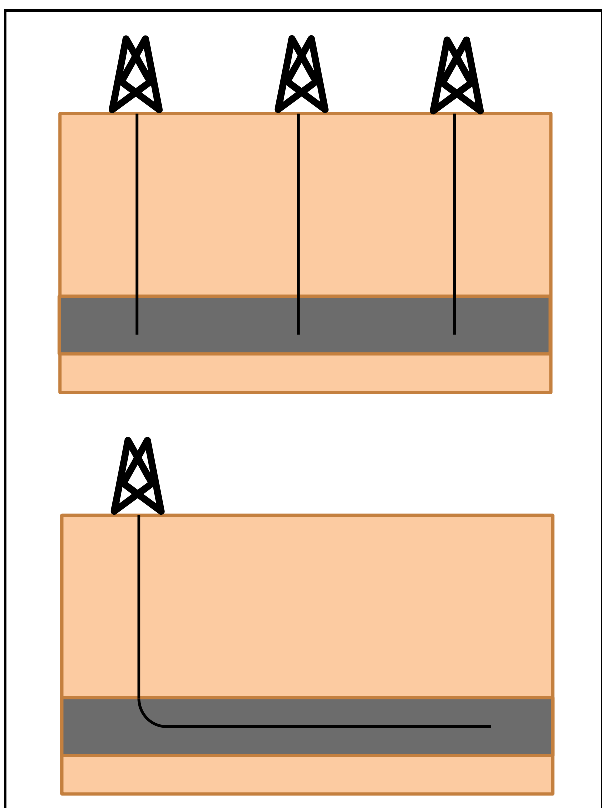
The unconventional revolution began in the late 1990s. For the first time ever, an unconventional formation produced enough natural gas to recover the costs that had been spent to drill and frack it. The Barnett Shale, in Texas, was transformed from a worthless formation into a highly prolific one. This event made fracking more than just a method for enhancing conventional production. Fracking was now a way to create production where it had never existed, where it had never been thought possible.[7]

Horizontal Drilling

While fracking was the key to physically unlocking unconventional formations, horizontal drilling was the key to making it profitable.

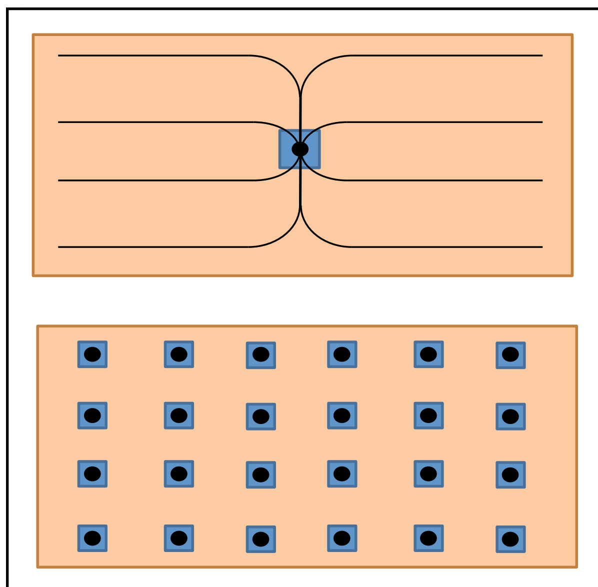
When wells have to be fracked, they are more expensive. Horizontal drilling helps to offset these costs by reducing overall drilling costs. One horizontal well can replace three or more vertical wells at a fraction of the total cost (figure 5). Thus, horizontal drilling represents an economy of scale in drilling and fracking operations.

Figure 5. *Horizontal drilling makes it possible to replace three or more vertical wells with a single horizontal well. Source: Donovan D. Schafer* (author).



Horizontal drilling also makes "pad-drilling" possible, which results in even more cost savings. Pad-drilling is a field development technique in which several horizontal wells are drilled in different directions from a single surface location (known as a "well-pad"). One well-pad can be used for eight horizontal wells, each of which replaces three or more vertical wells. In short, one well-pad can now replace what would have been 24 distinct well-pads in the past (figure 6). Taking into account the slightly larger well-pads required for pad-drilling, the end result is a 90 percent reduction in overall surface impacts.[8]

Figure 6. *The upper diagram is a top-down view of pad-drilling, where multiple horizontal wells (black lines) are drilled to spread outward from a single well-pad (blue square).The bottom diagram is a top-down view showing the equivalent number of vertical well-pads that would be required to drain the same area. As a result of pad-drilling, the same area can be drained with a much smaller surface impact. Source: Donovan D. Schafer (author).*



One problem with horizontal drilling and pad-drilling is that they give the false impression that impacts from oil and gas operations are getting bigger and bigger. If one compares a single well-pad from the past, having one vertical well, to a well-pad today, having eight or more horizontal wells, the latter will look much larger. It is easy to forget (or never know in the first place) that the larger well-pads are replacing 24 of the smaller well-pads. Horizontal drilling similarly distorts our perceptions of fracking operations. While a horizontal well can use as many as 5 million gallons to frack, the operation replaces three or more frack-jobs that would have been done on separate vertical wells in the past.

Fracking in Colorado

Colorado oil and gas is a $24 billion industry, accounting for 137,000 jobs (6 percent of employment) and 7.3 percent of the state's economy.[9] It cannot exist without fracking. Tisha Schuller, president of the Colorado Oil and Gas Association (COGA), explains:

> In Colorado, we don't have resources that we could tap without using hydraulic fracturing. . . . It's hydraulic fracturing that makes these resources available to us.[10]

No fracking = no production = no industry.

Colorado is no stranger to oil and gas. More than 60,000 wells have been drilled and produced within the state (figure 7). Weld County long has been the center of attention with more than 40 percent of the state's active wells.[11]

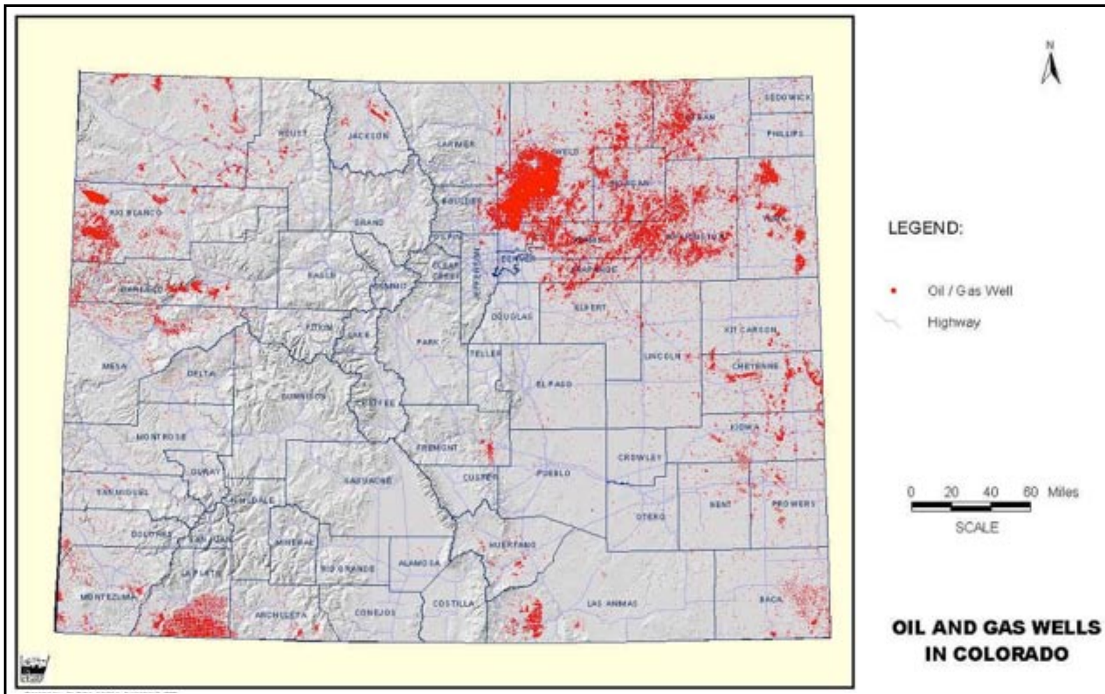


Figure 7. *Map showing the more than 60,000 oil and gas wells that have been drilled and produced in Colorado. Source: Colorado Oil and Gas Conservation Commission, http://cogcc.state.co.us/General/AtAGlance.html*

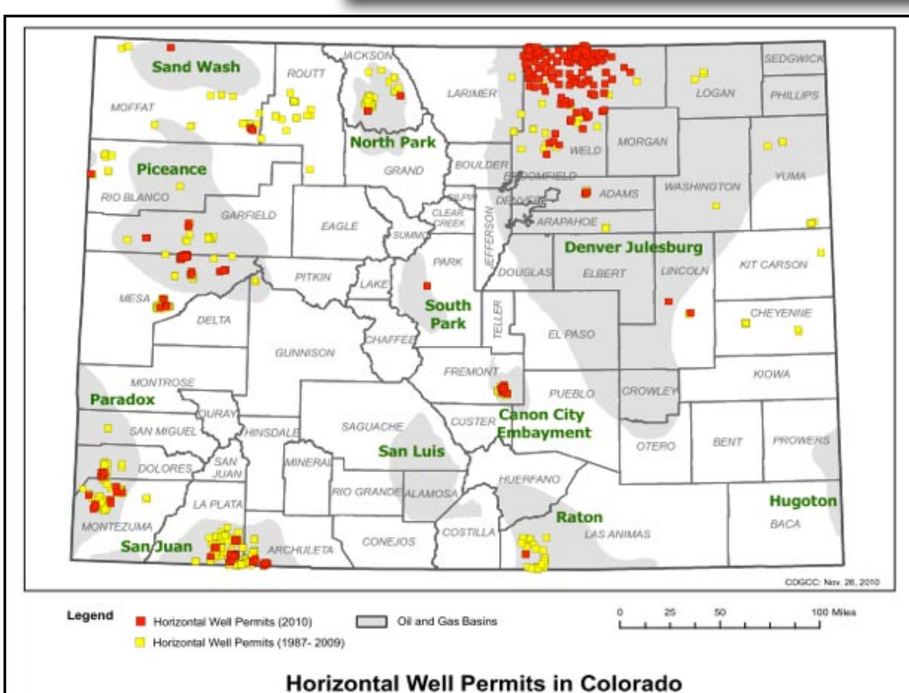


Figure 8. *Map showing recent horizontal well permits and the productive basins in Colorado. Source: Colorado Oil and Gas Conservation Commission, http://cogcc.state.co.us/Library/Presentations/ColoradoHorizontalWells_Nov29_2010v1.pdf*

But, as figure 8 shows, Weld County has seen a recent increase in horizontal well permits. More than 90 percent of these permits, issued in 2010, had the Niobrara Shale formation listed as their target.[12] The Niobrara is the cause for the recent buzz surrounding the Wattenberg Field. (In oil and gas terminology, "field" refers to a geographical area under which there can be one or more productive formations stacked vertically.)

Figure 9 provides a side-view of the Niobrara and its relation to the deepest aquifer in the field, the Laramie Fox Hills aquifer. Throughout the field, the two formations are separated by more than 4,000 feet of rock.

Garfield and Mesa counties also have received a lot of attention. After Weld, they had the most permits issued during the first quarter of 2011.[13] In these areas companies are targeting the Williams Fork formation, which ranges from 5,000 to 7,000 feet deep.[14]

Archuleta, La Plata, and Las Animas are the next most active counties. Most of the wells drilled in these counties are for coal bed methane (CBM) production. While CBM can involve small fracking operations, the overall process and circumstances are significantly different from what will be covered in the bulk of this paper. However, because CBM is an important part of natural gas production in Colorado, a section in this paper ("Coal Bed Methane") is dedicated solely to the unique considerations of fracking as it is used for CBM duction.

Contamination Concerns

Before going any further, it should be stated clearly that freshwater sources can, in fact, be contaminated by oil and gas activity. However, as explained in the following sections, the contamination is not a result of the actual fracking process. Instead, it is caused by poor drilling practices and surface spills.

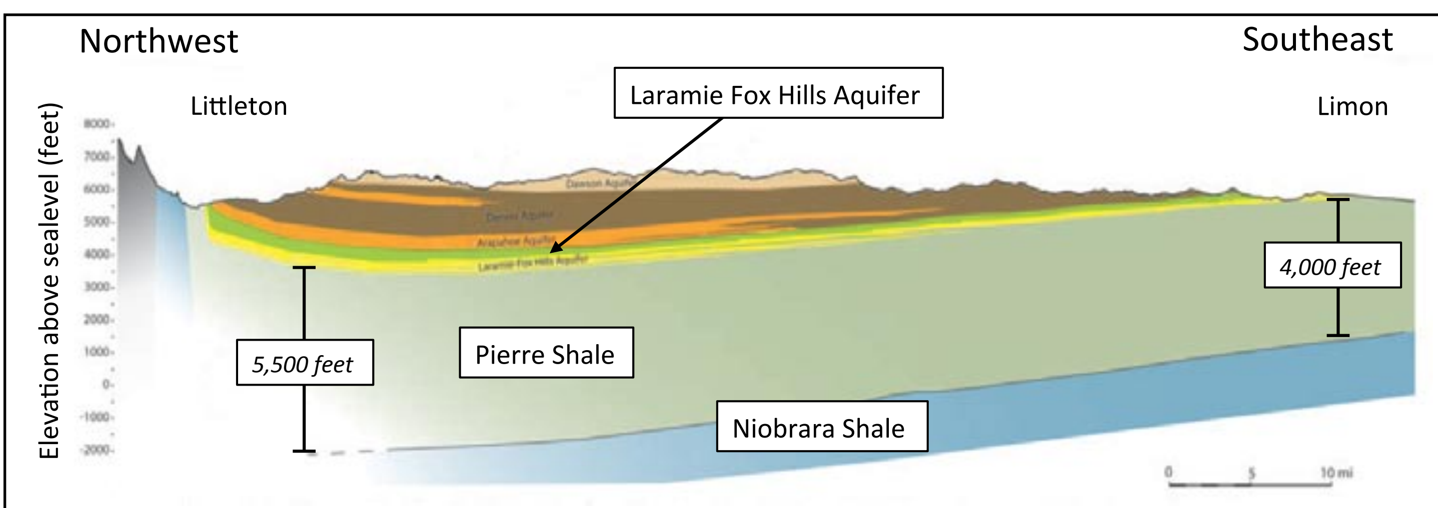
Many environmental groups have come to this realization. Matt Watson, with the Environmental Defense Fund, was recently quoted in the *Denver Post* saying:

> "The term 'fracking' is being used for all the things in the process that can cause problems. Most of those problems have nothing to do with the actual fracking."[15]

The Physics of Fracking

In most cases fracking takes place in formations many thousands of feet below sources of drinking water (figure 10).[16] Thus, the belief that fracking can directly cause contamination requires the belief that fracking can create fractures extending thousands

Figure 9. *Side-view of the Niobrara Shale formation in relation to the Laramie Fox Hills aquifer, the deepest freshwater source in the Wattenberg Field. The Pierre Shale that separates the Niobrara and the aquifers is actually a collection of many distinct rock layers, but it is often displayed and referenced as one formation for convenience. Source: Colorado Geological Survey,* http://geosurvey.state.co.us/pubs/Documents/rtv13n1%204-15-11%20B.pdf *(modified by author to improve legibility).*



of feet upward, through many rock layers, and into freshwater aquifers. Fractures, however, have a natural bias to spread outward and not upward.

Underground stresses, rock properties, and the layered nature of the earth's crust work together to blunt the upward growth of fractures. When fractures spread upward, they must pass through multiple rock layers, each having different internal stresses and properties. When fractures encounter an interface (between one layer and the next), the sudden change in stresses and properties can cause a variety of things to happen, all of which inhibit upward propagation.[17] The overall effect is a blunting of fractures when they hit an interface. Multiply this by the many distinct layers, and the countless non-distinct layers, and the result is a powerfully protective barrier.

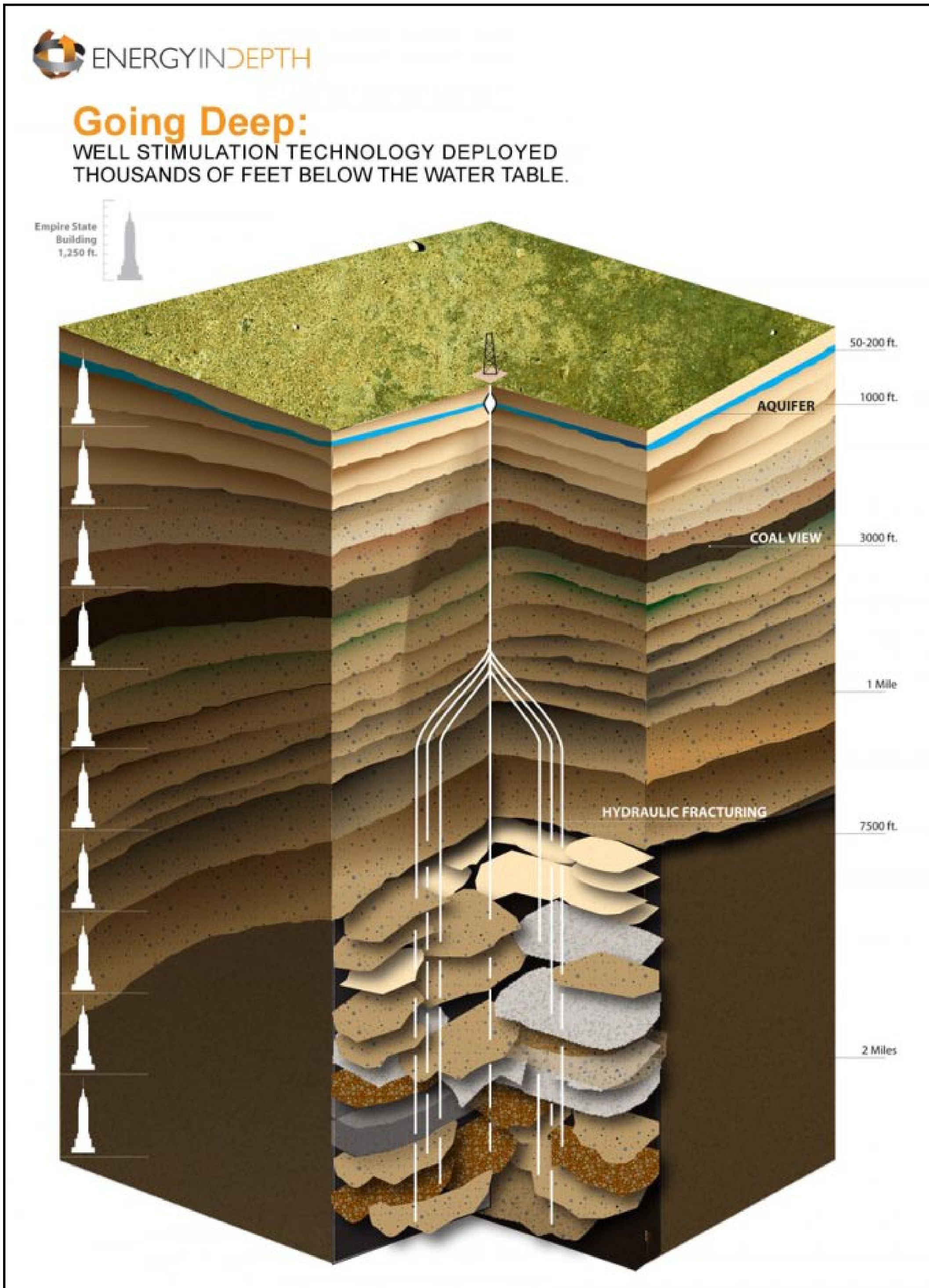


Figure 10. *Scale drawing of typical reservoir depth relative to typical aquifer depths. The separation is shown in lengths of the Empire State Building on the left-hand side. Source: Energy In Depth.*

Figure 11. *Fracture mapping of frack-jobs done in the Marcellus Shale in Ohio, Pennsylvania, and West Virginia. The blue lines at the top represent the deepest aquifers. The red line represents the depth of the Marcellus formation, and the jagged lines that are extending from it represent the greatest upward and downward extents of the fractures. Reproduced with permission from Kevin Fisher, http://www.halliburton.com/public/pe/contents/Papers_and_Articles/web/A_through_P/AOGR%20Article-%20Data%20Prove%20Safety%20of%20Frac.pdf*

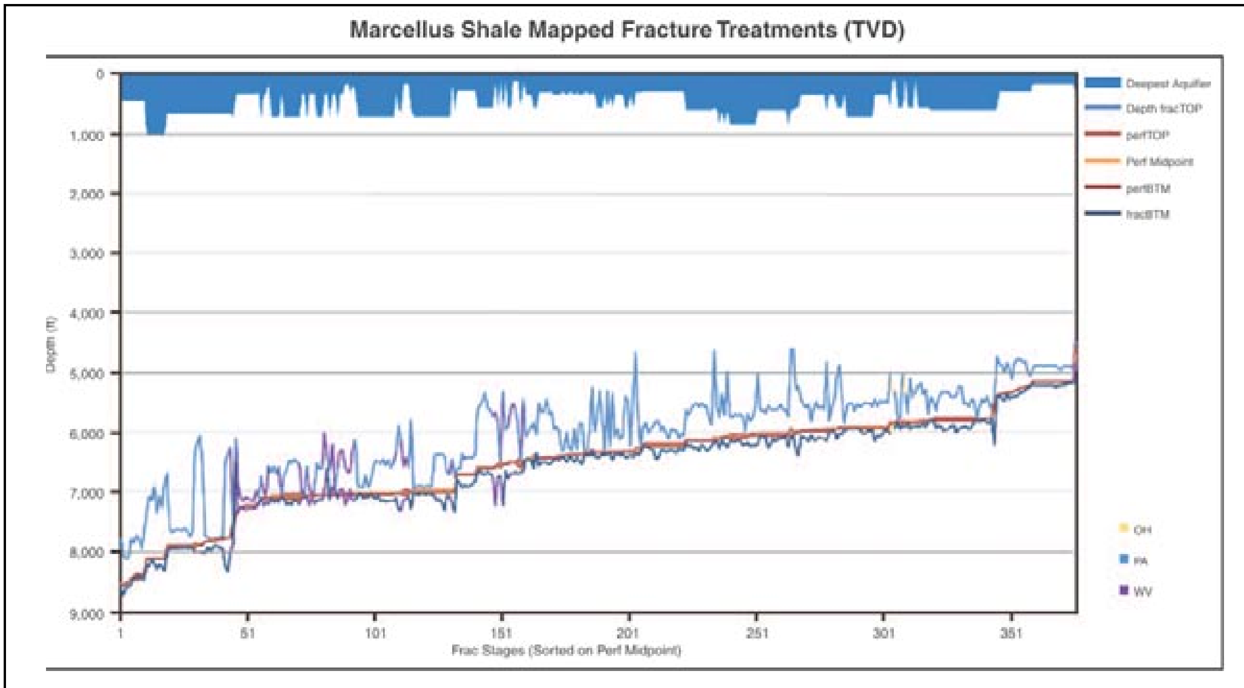
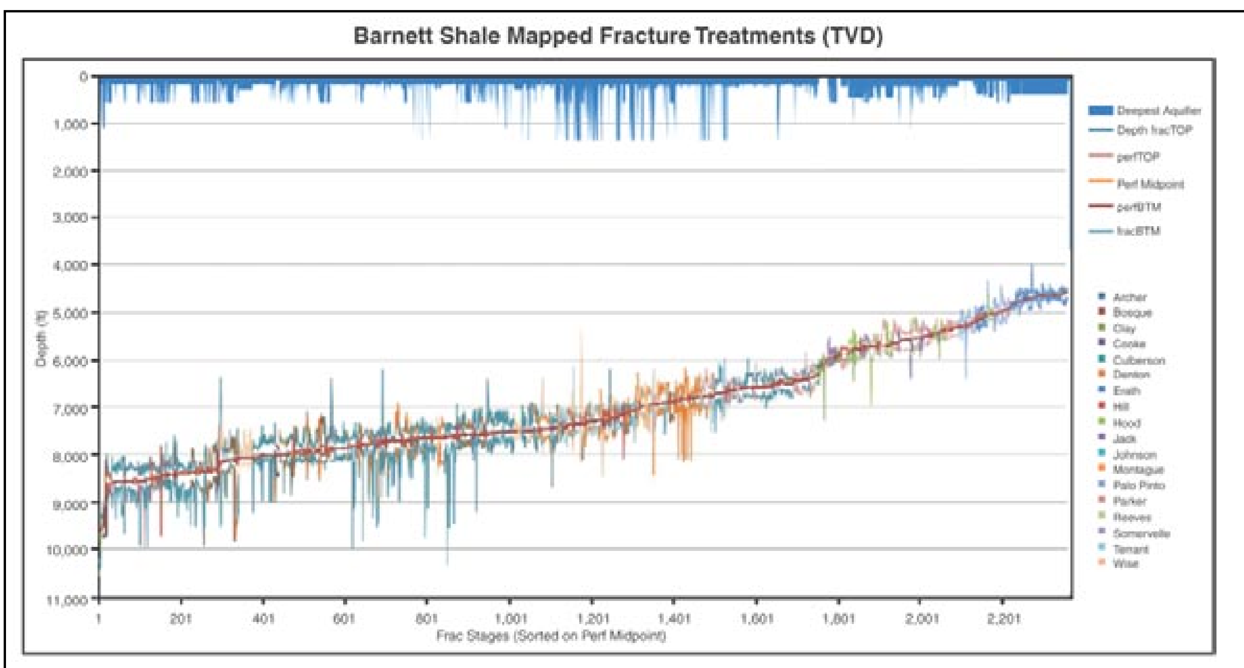


Figure 12. *Fracture mapping of frack-jobs done in the Barnett Shale in Texas. The blue lines at the top represent the deepest aquifers. The red line represents the depth of the Barnett formation, and the jagged lines that are extending from it represent the greatest upward and downward extents of the fractures. Reproduced with permission from Kevin Fisher, http://www.halliburton.com/public/pe/contents/Papers_and_Articles/web/A_through_P/AOGR%20Article-%20Data%20Prove%20Safety%20of%20Frac.pdf*



Professor Michael Economides, author of several textbooks on hydraulic fracturing, expressed the general frustration of geophysicists and engineers when he said:

> There is no physics to support connectivity between the induced fracture, done thousands of feet underground, that would contaminate drinking water aquifers, found at a few hundred feet depth.[18]

Vast amounts of data also support the same conclusion. Figures 11 and 12 display the fracture mapping results from microseismic monitoring for more than 15,000 frack-jobs done in the Barnett Shale in Texas and the Marcellus Shale in Ohio, Pennsylvania, and West Virginia.[19] None of the fractures come within 3,500 feet of a freshwater aquifer.[20] The depths of these formations are comparable to the Niobrara and Williams Fork formations in Colorado.

Economic Incentives

In addition to the actual physics of fracking, there are also economic considerations that make contamination even more unlikely. People often assume industrial activity and environmental protection are inherently at odds. Yet in the case of fracking, the exact opposite is true.

People often assume industrial activity and environmental protection are inherently at odds. Yet in the case of fracking, the exact opposite is true.

Unlike coal plant emissions and manufacturing wastes, fracking fluids are an expensive resource that exploration and production (E&P) companies pay large amounts of money to acquire and use. They do not want to waste these fluids. If fractures spread above or below the targeted formation, in any amount whatsoever, the company fracking the well wastes its resources and diminishes its potential profits.

Further, just as residents do not want hydrocarbons in their water, E&P companies do not want water in their hydrocarbons. Stagnant, undrinkable saltwater ("brine") makes up 55 percent of the earth's groundwater. Unlike freshwater, which is generally found in only the first thousand feet, brine is spread throughout the earth's crust. Thus brine is much closer to the targeted formations, and a much greater threat to oil and gas operations.

When brine infiltrates oil and gas formations, it can clog up pores and cut off the flow of hydrocarbons. The brine responds to the same forces that pull on hydrocarbons. It actively competes with oil and gas for the best flow paths through the fractures and into the well. Eventually, the brine overwhelms the oil and gas, causing large amounts of oil or gas to be left behind and never produced. Therefore, to avoid brine contamination, E&P companies go to great lengths to keep fractures from spreading beyond their targeted formations. (Think of the brine formations as a virtual mine-field surrounding the targeted formation, greatly incentivizing E&P companies to keep their fractures "in-zone." These formations provide a pretty good safety margin when aquifers are additional thousands of feet away.)

One of the ways companies ensure that fractures stay within the targeted formations is by tracking fractures through microseismic monitoring. Microseismic monitoring uses hypersensitive geophones to detect fractures as they are generated, and then locate them on a 3D map. Similar to radar, microseismic monitoring is able to locate the fractures with a high degree of accuracy even when they occur thousands of feet below the ground.

Drilling Contamination

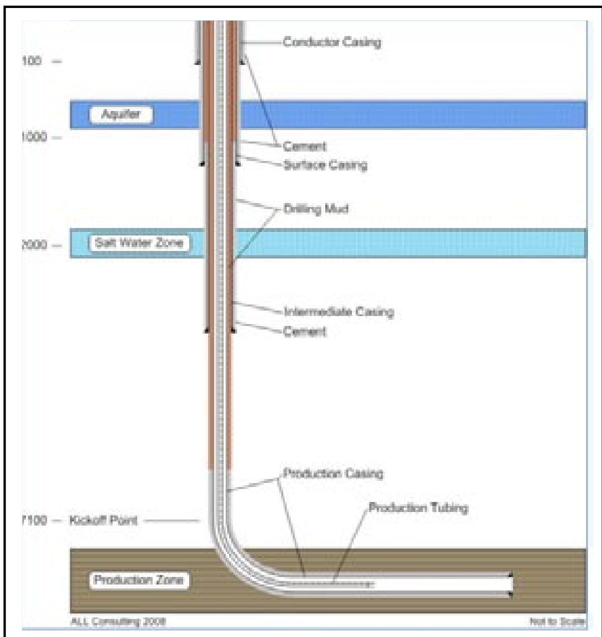
The most common cause of groundwater contamination—mistakenly blamed on fracking—is poor drilling practices.

The most common cause of groundwater contamination—mistakenly blamed on fracking—is poor drilling practices.

The process of drilling is actually two repeated processes, known separately as drilling and casing. First, a well is drilled to a pre-determined initial depth. Next, the drilling rig lowers steel pipe to the bottom. Then, cement is pumped down the inside of the pipe, out the end, and back up the *annulus* (the small gap between the pipe and the exposed rock). Lastly, a squeegee-like device is pushed to the bottom—by pumping water behind it—in order to clear cement from the inside of the pipe. When a casing operation is finished, the inside of the pipe is filled with water, and the annulus is filled with cement.

After each casing operation, a smaller drill bit is lowered to the bottom in order to drill to the next casing point. The process is repeated several times using a narrower pipe and a smaller drill bit each time. When finished, the upper portion of the well has a structure that resembles a telescope looking upward (figure 13). In horizontal wells, the final length of casing runs all the way to the end of the horizontal section. (While it is hard to imagine how steel pipe can make a 90-degree turn, the turn is actually spread out over 900 feet, making it only 10 degrees per 100 feet).

Figure 13. *Typical well casing diagram. Image courtesy of ALL Consulting, http://www.netl.doe.gov/technologies/oil-gas/publications/epreports/shale_gas_primer_2009.pdf*



The URL below is for a video that shows the drilling and casing process in detail:
http://www.youtube.com/watch?v=AYQcSz27Xp8&feature=relmfu

Casing serves two purposes. First, it provides structural support, like wood supports in a mine shaft. Second, it forms a waterproof seal to keep water and other fluids out of the well.

Keeping water and fluids from infiltrating the well is important to E&P companies, because invading fluids can alter the properties of the special drilling fluid (known as "drilling mud") used to cool the drill bit and remove cuttings during the drilling process.

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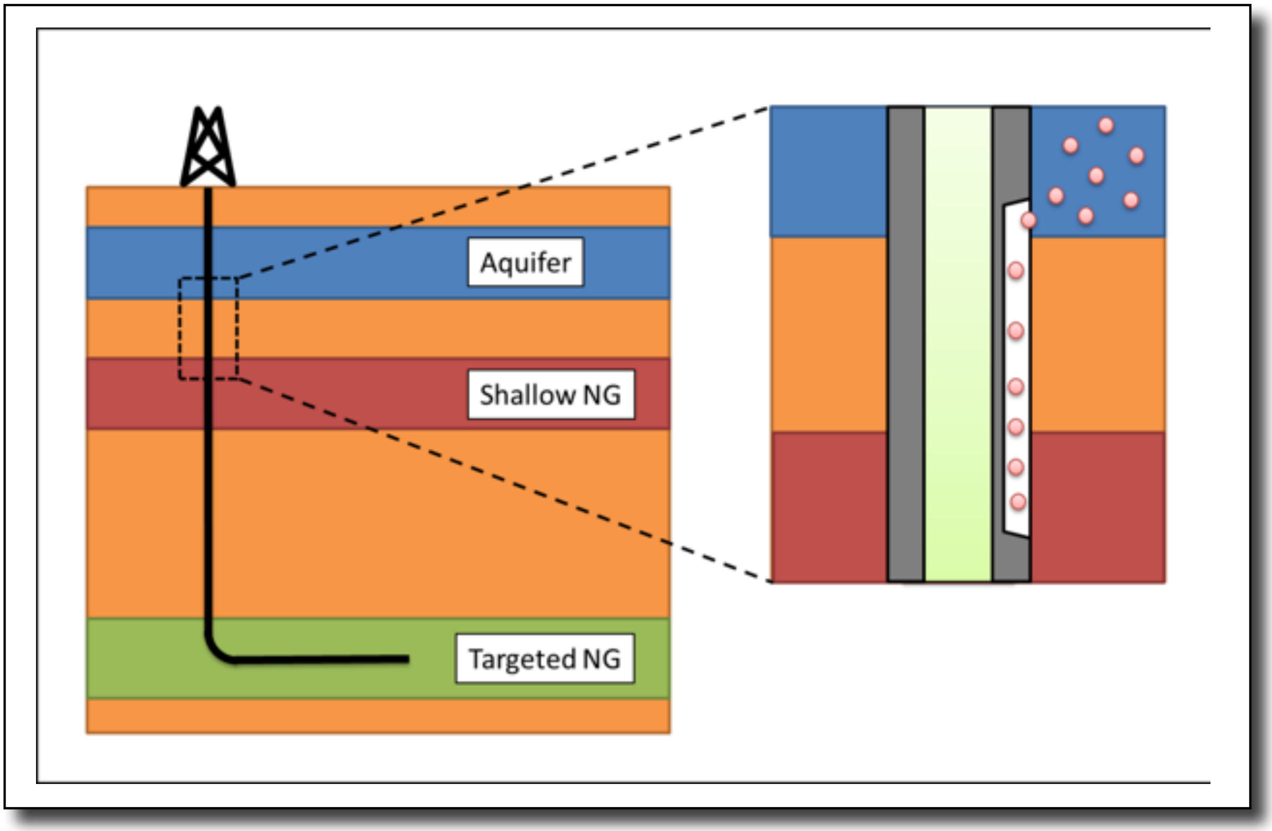
But the casing also works in the opposite direction: it protects the formations holding invasive fluids (including freshwater aquifers) from being contaminated with drilling fluids, fracking fluids, and hydrocarbons. Consequently, states have assumed the role of establishing minimum casing requirements, even though casing was used to seal-off freshwater formations long before it was ever required by regulations.

In Colorado, the first length of casing (the "surface casing") has to go at least 50 feet below the deepest freshwater zone. And the cement must form "a continuous column from the bottom of the casing to the surface." The second length of casing (the "intermediate casing") has to have at least 200 feet of cement above the shallowest formation capable of contaminating freshwater (i.e. brine, oil, and natural gas formations).[22] Combined, these regulations require at least 250 feet of watertight cement between freshwater formations and those that can cause contamination.

State regulators do not stop at the quantity of cement: they also regulate the quality. One rule sets a minimum compressive strength requirement for the cement. Another specifies the time companies must wait to allow the cement to set before they can continue operations.[23]

Companies are also required to verify the quality of the casing when a well is finished. They have to conduct pressure-tests that show the well will not leak during fracking. They also have use a special device, called a "cement-bond log," to measure the quality of the cement in the annulus.[24] The device is lowered into the well on a cable and uses acoustic waves to measure the cement bond from

Figure 14. *Natural gas from a shallow formation can bubble up through the cement and create a channel before the cement hardens. The channel, however, only connects the shallow natural gas formation to the aquifer: The aquifer is sealed off from the fracking fluids because the steel pipe remains intact. Source: Donovan D. Schafer (author).*



top to bottom. The output from the device then is submitted to the state for review.

Every E&P company is legally required to comply with these regulations for every well drilled in Colorado. Other states have similar requirements.

Despite the regulations, a tiny fraction of wells still end up with bad casing. The most common problem is a phenomenon known as channeling. Channeling occurs when a shallow, uneconomic natural gas formation (not the deeper, targeted formation) leaks bubbles into the annulus. The bubbles then can "cut" a channel in the cement before it hardens. These channels *do not* connect the *inside* of the well to the aquifer—the steel pipe is still in place. But they do connect formations on the outside that would normally be separated by the rock layers in between (figure 14).

For instance, a shallow natural gas formation at a depth of 1,500 feet could create a channel that connects it to an aquifer above it. Natural gas then could leak into the channel, and up into the aquifer. Meanwhile, the fracking fluids and/or fluids coming from the fractured formation 5,000 feet deeper would still be sealed inside the casing.[25] This fact explains why contamination from oil and gas activity is almost always in the form of natural gas (rather than fracking chemicals). It also explains why laboratory test results usually reveal that the contaminating gas comes from shallower formations and not from the deeper fractured formations.

Natural Gas: Health Effects

Since natural gas contamination is the most common, though still rare, form of contamination from oil and gas development, let us pause to consider the threat, if any, natural gas poses to human health.

Natural gas (methane) is not toxic, does not cause cancer, and has no negative effects from long-term exposure. The only way methane, through mere exposure, can harm a human body is when the concentration is so high that it effectively blocks out oxygen. The result is essentially the same as drowning. Water is not toxic (it is essential to human life), but immersion in water (or methane) simply cuts off the oxygen supply.

As such, methane is called an "asphyxiant gas." But so, too, is nitrogen, which makes up 79 percent of the air we breathe. When natural gas takes up a full 14 percent of the air mixture, people begin to feel nauseous and lightheaded, the same way they would feel at high altitude. Because methane concentrations build up gradually, people notice before it reaches concentrations that could actually cause suffocation.

... there never has been a case of methane suffocation due to methane in a water well.

For this reason there never has been a case of methane suffocation due to methane in a water well. Rather, death from methane suffocation occurs in bizarre circumstances—such as when five Mennonites died after climbing into an enclosed manure pit back in 2007.

A genuine risk is that methane can cause an explosion. Every year in the United States, roughly 2,000 fires and explosions result from methane ignition.[26] But in the last decade, only one of these incidents was caused by natural gas leaking into a water well due to oil and gas drilling.[27]

When natural gas contamination is identified, there are many ways to eliminate the risk of explosion altogether. The simplest solution is to install a vent that would allow natural gas to escape before entering the house, as suggested in Colorado's Water Well Construction Rules:

> Vents shall be constructed to vent all gases to the atmosphere outside of a building and to prevent gas accumulation that could produce a health or explosion hazard.[28]

Aerating systems offer another option. They actively remove methane from water. Lastly, special detectors can be installed to alert residents when methane levels reach 10 percent of the level required for ignition, allowing time to ventilate the house and thus keep the amount of gas far below the ignition level.

Pit Leaks and Surface Spills

The strongest and most defensible arguments against fracking are those that focus on the large amount of fluids oil and gas companies have to manage when fracking. These arguments are more defensible because contamination from surface spills actually can be in the form of chemicals and not just relatively benign methane.

The strongest and most defensible arguments against fracking are those that focus on the large amount of fluids oil and gas companies have to manage when fracking.

Even before fracking was introduced in the 1940s, oil and gas development involved the use of pits, tanks, and other forms of fluid containment. Fracking has significantly increased the total amount of fluids that need to be handled. So, other things being equal, the more fluids needed for the job, the more potential for leaks and spills.

There are three distinct fluid management considerations unique to fracking:

The first is handling the large amount of freshwater needed for the fracking fluid. Typically, the water is stored in a large earthen pit, lined with a thick sheet of plastic to keep it from seeping into the ground (figure 15).

The second consideration is the flowback water that returns to the surface after fracking. This water, too, is collected and stored in a large earthen pit lined with plastic.

The third and last consideration is the storage and management of the chemical additives prior to fracking. (After fracking, they become part of the flowback mixture.) This relatively small amount of fluid is easily stored in several containers on the back of one or two trucks.

Since the freshwater pits are filled with water that comes from streams and other legally permitted sources, leaks and spills do not pose a health or environmental risk other than the potential for erosion if a pit overflows: The water at this point has no chemicals added. Likewise, the chemical additives, prior to fracking, pose little or no risk. The additives are kept in fully enclosed containers, and the amount of fluid is small enough to easily manage, contain, and clean up in the unlikely event of a spill.

The flowback water is therefore the only fluid that deserves special consideration. It contains chemicals (though diluted) and represents a large amount of fluid. In addition to the chemical additives, it also has minerals picked up from underground that can make it even more harmful for the environment. This is precisely why the COGCC had detailed regulations in place that set standards for every aspect of flowback pit construction and use.

First, the COGCC requires oil and gas companies to submit a specific "Earthen Pit Report/Permit" for prior approval of each new pit planned for construction. After approval, pits must be built to satisfy soil compaction and permeability requirements. (Companies are required to conduct tests and keep records for proof of compliance.) The pit then must be lined with a uniform sheet of thick plastic. The COGCC has set a minimum thickness to prevent rips and tears that could cause a leak.

Companies are required to monitor and operate the pits while in use to ensure the fluid level never comes within two feet of the rim. Two feet represents a large margin because the pits are much wider than they are deep. Thus, it would take a large amount of fluid and a lot of time to raise the level by two feet. Where wildlife is a concern, companies also are required to install and maintain a fence around the perimeter to keep animals from falling into the pit.

When companies are done with a pit, it is emptied and soil samples are taken from the base of the pit. Any wastes are handled and treated in accordance with regulations. The samples are compared with soil samples from before pit construction

Figure 15: *Typical lined freshwater pit for water storage before fracking operation. Photo courtesy of ALL Consulting,* *http://www.netl.doe.gov/technologies/oil-gas/publications/epreports/shale_gas_primer_2009.pdf*

to ensure that no chemicals have leaked into the underlying ground. In the rare event contamination is detected, companies are required to excavate the contaminated soils and treat them at the company's expense.

These regulations ensure that flowback pits do not present a significant risk to public health or the environment. Nonetheless, in response to public concerns (or perhaps in response to cost increases from satisfying pit regulations) Colorado oil and gas companies have been moving to closed-loop fluid management systems. These systems keep all fluids—freshwater, chemicals, and flowback water—in fully enclosed containers (no pits at all) in order to further minimize the potential for spills and thus safeguard the companies against fines and lawsuits.[29]

Chemical Risks

While fracking chemicals have not been found in drinking water wells, it is at least conceivable that chemical contamination could result from pit leaks and/or surface spills. Let us, therefore, consider the health risks posed by this kind of contamination. For starters, many of the chemical additives are not harmful at all. Sodium chloride, a common additive, is simply table salt. Chemicals that can be toxic are not automatically harmful. Concentrations are just as important. As Paracelsus, the father of toxicology, once noted:

> Everything is poison, there is poison in everything. Only the dose makes a thing not a poison.

... methanol concentrations are so low that even if fracking did contaminate freshwater, the exposure would be 40 times lower than the average daily exposure from naturally occurring methanol in fruit and wine.

The most widely feared chemical in fracking is benzene: a biodegradable, naturally occurring substance. People are subjected to low concentrations of benzene every day—filling up at gas stations, smoking cigarettes, even enjoying campfires.[30] Likewise, methanol is extremely toxic and sometimes used as a chemical additive in fracking fluids. However, methanol concentrations are so low that even if fracking did contaminate freshwater, the exposure would be 40 times lower than the average daily exposure from naturally occurring methanol in fruit and wine.[31] Methanol, after all, is just a type of sugar, similar to ethanol, the alcohol enjoyed in beer, wine, and liquor.

The unsung benefit of chemical additives is that they actually reduce the overall environmental and health impacts from fracking. The chemicals are used precisely because they increase the efficiency of the operation. The reduced equipment requirements in turn reduce the land area that needs to be cleared and the amount of diesel fuel that needs to be burned. As a result, more trees are left standing and fewer benzene particles are released into the air.

If, for instance, a friction-reducing chemical could not be used, companies would need more horsepower. Therefore, more pump trucks would be needed to reach the pressure required to fracture a formation. Or if a gelling chemical could not be used to raise the fluid's viscosity, companies would have to use even more water to move the sand into the fractures. Companies would have to pump it at higher rates (even more horsepower) to keep the sand suspended in the fluid. The beauty of chemicals is that very small amounts (less than 1 percent) can yield huge performance gains, which allows companies to cut back on more brute force methods.

We already have discussed the huge reductions in environmental impact that have resulted from innovations in horizontal drilling and pad-drilling. The optimization of fracking fluids has had the same effect, meaning fewer emissions, cleaner air, and less land bulldozed to make room for heavy equipment.

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Broader Concerns

Air Pollution

In the debate over hydraulic fracturing, attention has recently turned to air pollution. The Colorado School of Public Health ("CSPH") recently released a study in which it found an increased risk of cancer for people living close to oil and gas development.[32] But when the CSPH findings are considered in the context of cancer risks more generally, they lose much of their significance.

The *increased risk* found by the CSPH study amounted to an increase of 10 additional cancer cases per million persons exposed. This is equivalent to an increase in cancer risk for each individual of 0.001 percent over their lifetime. However, the cancer risk for the general population is 200,000 per million or 20 percent.[33] Therefore, if a person lives within 500 feet of 40 natural gas wells (the assumption in the CSPH study, however unlikely it may be), that person's risk of developing cancer at some point in their life will increase from 20.000 to 20.001 percent.[34]

We also can compare the increased risks from air pollution from natural gas development to the increased risks from other activities, such as living in a city. According to the EPA's most recent National Air-Toxics Assessment (NATA), the increased risk from living in New York County is an extra 150 cancer cases per million. Figure 16 shows the results for several other areas. Garfield County, where the CSPH conducted its study, is near the bottom of the list, with 20 extra cancer cases per million (the lowest in the nation was 7.4 per million). In other words, from an air pollution perspective, someone living in Garfield County, within 500 feet of 40 different wells still would be better off than someone living in New York, Los Angeles, Denver, or even *Boulder*.[35]

Figure 16. *Tabulated results from the EPA's most recent National Air-Toxics Assessment. http://www.epa.gov/ttn/atw/nata2005/tables.html*

County	Total Cancer Risk (cases per million)
New York, NY	150
Los Angeles, CA	110
Denver, CO	79
Harris County, TX (Houston)	60
Nationwide Average	**50**
Boulder, CO	42
Garfield, CO	20
Park County, WY (Yellowstone National Park)	16
St. John, VI	7.4

Add all these risks together, a living, breathing human being starts out with a 20 percent lifetime cancer risk. For someone who lives in Garfield County, that risk increases to 20.002 percent (adding on the ambient air quality risk from the NATA results). If that person also lives within 500 feet of 40 natural gas wells, that increases further to 20.003 percent (adding on the results from the CSPH study). By comparison, if this same person decided to move to New York City instead of Garfield County, the risk would have a much greater increase: from 20 to 20.150 percent.

It is also worth noting that because of the way the EPA does its calculations, these air pollution risks are most likely overestimated. A wide range of statistical uncertainty results from the EPA's calculations. To play it safe, the agency always uses the most cautious estimates within the uncertainty ranges. In other words, there is an equal scientific plausibility that the risks could be much lower. This caveat also applies to the results from the CSPH study, because the study used the same EPA-specified procedures.

Water Depletion

Anti-fracking advocates also have made the claim that, because fracking uses large amounts of water, it will deplete freshwater supplies. This claim falls short when put into perspective.

A typical frack-job on a horizontal well (including all stages) uses 5 million gallons of water—roughly the same amount used by a golf course in 25 days.[36] How does this amount compare to Colorado's annual water use? According to the Colorado Division of Water Resources, Coloradans use 5.3 trillion gallons of freshwater every year—*one million times more than what is used in a fracking operation.* It should not be surprising, then, that fracking consumes a meager *eight-hundredths of a percent* (0.08%) of the state's annual water usage (figure 18).[37]

Anti-fracking advocates also have made the claim that, because fracking uses large amounts of water, it will deplete freshwater supplies. This claim falls short when put into perspective.

Contrary to popular belief, freshwater is not a fixed supply. If every drop of freshwater disappeared today, clouds still would rain tomorrow, thanks to the earth's hydrologic cycle. The inexhaustible oceans still would absorb the sun's rays, creating rainclouds to move inland with their precious load of evaporation-purified freshwater. Consequently, the fact that much of the fracking fluid is left underground does not imply there would be any permanent reduction in freshwater supplies.

The real question, therefore, is not a question of absolute or fixed amounts of freshwater, but of the rate of freshwater consumption versus the rate of freshwater replacement (rainfall). The question is: "Will fracking cause more freshwater to be used in a given period than what will be provided by rainfall over the same period?" In most regions, the answer is "no." In especially arid regions, where the answer could be "yes," authorities already regulate water use. In these areas, E&P companies are required by law to get permits that determine how much water they are allowed to use.

Furthermore, when considering the whole life-cycle of energy generation, natural gas uses less water than other sources. Coal, nuclear, and even concentrated solar power (CSP) use more water, overall, because of their boilers and cooling systems.[38] Currently, U.S. power plants use 143 billion gallons of freshwater every day—an amount that dwarfs the potential water use by fracking.[39]

Water Disposal

After a well is fracked, approximately 10 to 30 percent of the fracking fluid returns to the surface. Since the flowback water contains the chemical additives and is contaminated with naturally occurring minerals, it is unsafe for discharge back into the environment.

The most obvious solution is to reuse the flowback water on the next frack-job. But, for a long time, companies considered flowback water unfit for such use. The concern was that some of the minerals picked up by the fluid during the first frack-job would react with chemical additives on the second frack-job and clog up fractures. Problems of this kind can take years to materialize, so companies are hesitant to take on the risk. They might use recycled flowback water on a wide scale, only to find out 10 years later that all the wells fracked with recycled water are gradually clogging up and shutting off because of their costly miscalculation.
Nonetheless, the costs to procure freshwater,

Figure 17. *Source: "Water Sources and Demand for the Hydraulic Fracturing of Oil and Gas Wells in Colorado from 2010 through 2015." Jointly prepared by the Colorado Division of Water Resources, the Colorado Water Conservation Board, and the Colorado Oil and Gas Conservation Commission. http://cogcc.state.co.us/Library/Oil_and_Gas_Water_Sources_Fact_Sheet.pdf*

Sector	2010 Use (Acre-Feet/Yr)[4]	Percent of State Total
Total	**16,359,700**	
Agriculture	13,981,100	85.5%
Municipal and Industrial	1,218,600	7.4%
Total All Others	1,160,000	7.1%
Breakdown of "All Others"		
Total All Others	**1,160,000**	
Recreation	923,100	5.64%
Large Industry	136,000	0.83%
Thermoelectric Power Generation	76,600	0.47%
Hydraulic Fracturing	13,900	0.08%
Snowmaking	5,300	0.03%
Coal, Natural Gas, Uranium, and Solar Development	5,100	0.03%
Oil Shale Development	0	0.00%

dispose of flowback water, and haul both (which can total $200,000 or more per well) have driven E&P companies to experiment with recycling.

In Colorado, more than half of flowback water is recycled. The percentage keeps rising as new technologies are being developed for better onsite treatment. Since less than half of the fracking fluid returns to the surface, that means less than one-quarter of the fracking fluid (50 percent of 50 percent) has to be treated or disposed.

Earthquakes

Hydroelectric dams, coal mines, and nuclear explosions have been causing earthquakes for nearly a century.[40] Coal mines and dams cause earthquakes indirectly. They redistribute just enough mass to push nearby faults over the edge, triggering a release of the tension and energy that is already stored in the fault. Nuclear explosions, on the other hand, cause earthquakes directly: They release enough energy to cause seismic activity as a direct response, regardless of whether or not there is a fault nearby.

It seems intuitive that fracking, like a nuclear explosion, would cause earthquakes directly. The whole point is to create fractures! However, a fracture is not the same as a fault, and, in reality, there simply is not enough horsepower in one, two, or even 20 frack-pumps to unleash that kind of energy.

It seems intuitive that fracking, like a nuclear explosion, would cause earthquakes directly. The whole point is to create fractures! However, a fracture is not the same as a fault, and, in reality, there simply is not enough horsepower in one, two, or even 20 frack-pumps to unleash that kind of energy.

True, frack-jobs can create 1,000-foot-long fractures, but the fractures are not created in an instant. Each fracture is really the accumulation of many small fractures, each representing only a tiny release of energy at a given moment. The typical amount of energy released by one of these events, according to Stanford geophysicist Mark Zoback, "is the equivalent to a gallon of milk falling off the kitchen counter."[41] And the energy, of course, is released thousands of feet underground, making it impossible for humans or animals to feel it at the surface.

Fracking, therefore, cannot cause significant earthquakes directly. But what about indirectly? Can fracking cause earthquakes similar to the way coal mines and dams cause earthquakes? Yes, it can. However, the cause is not a change in stresses due to the shifting of large amounts of mass. Rather, on rare occasions, the fracking fluid can infiltrate a nearby fault and act as a lubricant, making it easier for the sides of the fault to slip past each other.[42] A few considerations nonetheless make such indirect earthquakes an insignificant concern.

First, these earthquakes are very small. Austin Holland, a geologist with the Oklahoma Geological Society, did a study of an increase in seismic activity in Garvin County, Oklahoma, that correlated with an increase in fracking in that area. The largest earthquake he studied was a 2.8 M_d (duration magnitude) earthquake, which translates to roughly 2.46 on the Richter scale.[43] This level is rarely felt by human beings. As Holland put it, the earthquakes that correlated with fracking activities were "really quite inconsequential," and comparable to mosquito bites. In fact, a naturally occurring earthquake that struck Oklahoma in November (magnitude 5.6) released more than 16,000 times the energy of the earthquakes Holland studied.[44]

As Holland put it, the earthquakes that correlated with fracking activities were "really quite inconsequential," and comparable to mosquito bites.

A second reason these mosquito bites do not warrant much concern is that they are exceedingly rare. In order for a fracking operation to cause such an earthquake there needs to be a significant fault very near. Also, a massive amount of fracking fluid has to be injected into the fault without the frack operators noticing. As discussed in the section "Economic Incentives," frack operators avoid injecting fracking fluids in ways that would allow them to escape the targeted formation. That includes injecting into faults, a waste of valuable fracking fluids. Operators often are aware of these faults ahead of time, because of large-scale seismic mapping, or from drilling through the faults during the horizontal portion of the well. Even if they are not aware of the faults ahead of time, they will see a pressure drop during the fracking operation when the fluid first makes contact with a fault. In short, it takes a strange (and rare) course of events for an operator to unwittingly inject large amounts of fracking fluids into a fault.

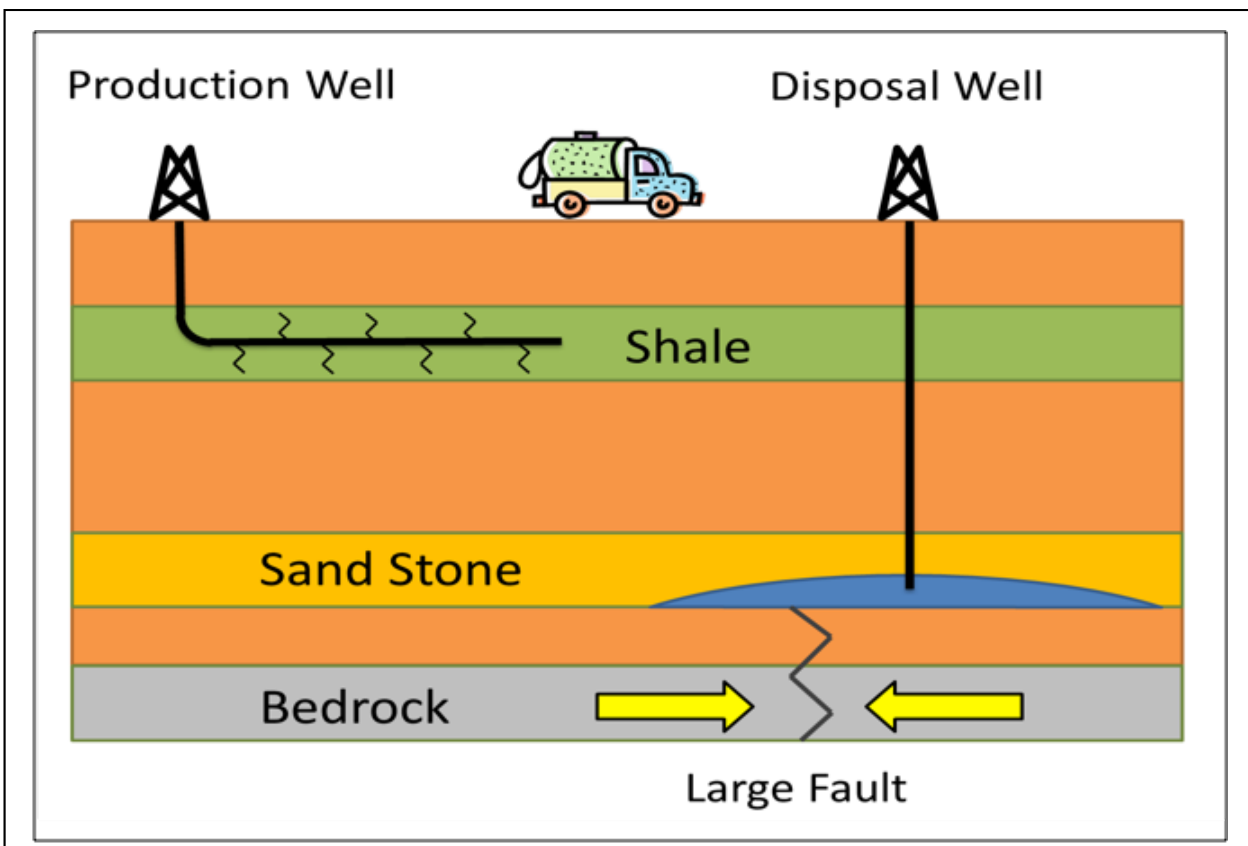
The real potential for significant earthquakes from oil and gas development does not come from the fracking process itself, but rather from the use of disposal wells. Disposal wells are better able to lubricate existing faults, because they receive much more water than hydraulically fractured wells. The 1962 Colorado earthquake, for example, a 5.0 magnitude quake, was caused after the Rocky Mountain Arsenal injected 165 million gallons of water into a single disposal well.[45] The largest frack-jobs, by comparison, use only 5 million gallons—just 3 percent of the amount that triggered the 1962 earthquake.

Disposal wells take on much more water than fractured oil and gas production wells because the goals of both are inherently different. Fracking companies want to use the minimum amount of water that will yield good oil and gas production, so they can keep their costs low. Disposal operators, on the other hand, want to cram the maximum amount of water into disposal wells. They want to be able to cut costs by not having to drill new disposal wells. Figure 18 illustrates the differences between the wells that are hydraulically fractured and the disposal wells used to get rid of flowback water.

But just because fracking generates wastewater that is sometimes injected into disposal wells, it does not mean fracking inevitably leads to earthquakes. Disposal wells are only one of many ways to deal with wastewater. As discussed in the previous section, recycling makes wastewater disposal irrelevant in many areas. Even without recycling, wastewater treatment facilities are a viable alternative. Lastly, if disposal wells can be located away from significant faults, they are a perfectly safe solution.

As a final note on the subject of earthquakes,

Figure 18. *Disposal wells are typically much deeper than fractured wells, and much larger amounts of liquid are injected into disposal wells. For these two reasons they are more capable of lubricating significant faults and triggering small earthquakes. Source: Donovan D. Schafer (author)*



anyone who advocates for federal regulations on fracking, on the basis of the potential for disposal wells to cause earthquakes, should know that the only major man-made earthquakes, in the state of Colorado, were perpetrated by the federal government. The first was the 1962 earthquake caused by operations at the Rocky Mountain Arsenal. The other two were underground nuclear detonations conducted by the United States Department of Nuclear Energy in 1969 ("Project Rulison," directly causing a 5.5 magnitude quake!) and 1973 ("Project Rio Blanco"). Given the federal government's track record, it seems odd one would think the federal government is more concerned about mitigating man-made earthquakes than state regulators.[46]

Coal Bed Methane

The technology for coal bed methane (CBM) was conceived not as a way to produce useful gas, but as a way to get rid of nuisance gas that had been endangering coal miners for more than a century.[47]

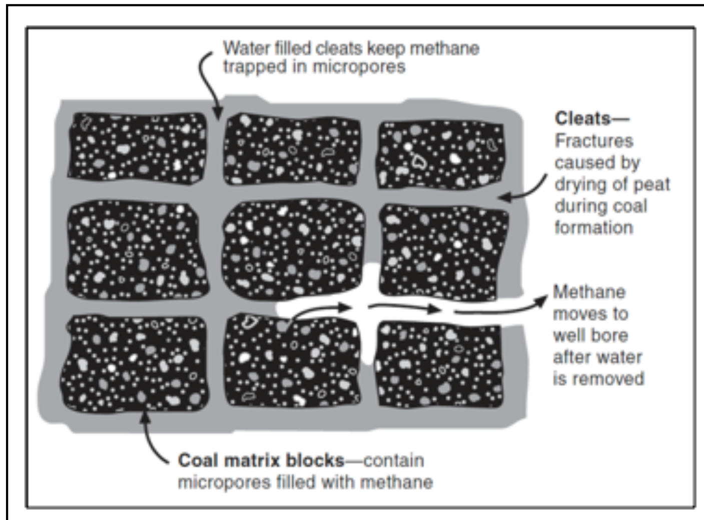
After CBM technology was developed in the 1960s, it gradually grew from a safety measure into a significant source of natural gas production. Today, it accounts for 8 percent of the natural gas produced in the nation.[48]

CBM operations are similar to other oil and gas operations. Horizontal drilling and fracking are sometimes used to access coal seams and recover the methane. But the operations are also distinct in several ways: First, CBM gas comes from coal seams and not shale formations. Second, the coal seams are generally—though not always—much shallower than productive shale formations. Finally, many CBM wells can produce without fracking, and when fracking is required, the frack-jobs are much smaller.

Unlike shale formations, coal seams have almost no *primary* porosity (void space between the actual rock grains). Instead, they have *secondary* porosity in the form of pre-existing fractures, called "cleats." These cleats form a dense, interconnected network and provide the space for storing the methane. Moreover, the methane is not trapped by the tightness of the cleats—as is the case with hydrocarbons trapped by the tightness of shale pores. Instead, the methane is adsorbed (not absorbed), meaning the molecules are smooshed up against the walls (bonded to the coal surface) due to the presence of water filling the middle of the cleats (figure 19). Think of the gas molecules as freshman in a crowded high school hallway. They are too timid to push through the crowd, so they stay pressed up against the walls until the bigger juniors and seniors (the water molecules) get out of the way.

Figure 19. *The cleats (natural fractures) in coal seams hold large amounts of methane and water. Source: Colorado Geological Survey, http://geosurvey.state.co.us/pubs/Documents/rtv3n3.pdf*

Producing from CBM wells is, therefore, less about



creating a network of fractures (the network is already there) and more about removing water from the cleats. A small frack-job might be necessary to tap into the existing network, but the driver behind CBM production is simply the process of draining water.

These unique aspects of CBM production raise additional concerns and considerations when evaluating potential impacts. For one, water depletion becomes a more relevant concern. Large amounts of water are being withdrawn from the wells, and these wells are potentially shallow enough to affect groundwater levels. For this reason, the Colorado Division of Water Resources (CDWR), the Colorado Geologic Survey (CGS), and the COGCC teamed up to study the potential impacts from CBM operations in the San Juan and Raton basins. These basins reflect CBM operations in the most active counties: Archuleta, La Plata, and Las Animas.

In the San Juan Basin (representing Archuleta County and La Plata County), the study found no significant water reductions resulting from CBM operations. The study's estimates show a miniscule 0.05 percent reduction in the area's annual freshwater supplies due to CBM operations.[49,50] In the Raton Basin (representing Las Animas County), the study expressed more concern, but the concern was directed toward legal issues regarding senior water rights and not toward a general fear of severe impacts. This makes sense in light of the study's results: an estimated 3.6 percent reduction in annual freshwater supplies.[51,52] This amount is enough to impact the irrigation needs of large farms, but not enough to cause a panic.

Nonetheless, as a result of these concerns (culminating in a 2009 Colorado Supreme Court decision) CBM operators are now required by law to get approval from the CDWR before they can drill CBM wells.[53] This mandate is in addition to meeting COGCC requirements The added scrutiny from the CDWR is designed to provide even greater assurances that CBM operations will not result in significant water reductions.

At this point, it should be re-emphasized that all reductions in water supplies due to CBM operations are temporary and not permanent. (Please revisit the explanation provided in the "Water Depletion" section if this is still unclear.)

While the de-watering phase of CBM operations presents a unique water depletion concern, it also provides an added protection against contamination. In the event that a hydrologic connection exists between a coal seam and the drinking water above it, the concern is not that contamination will leak up into drinking water. Rather, the concern is that drinking water will leak down into the coal seam. During the months of de-watering that follow a frack-job (assuming one is necessary), water sweeps back through the fractures and takes with it any potential contaminants.[54]

The largest CBM frack-jobs average 150,000 gallons (97 percent smaller than 5-million-gallon frack-jobs).[55,56] More typically, CBM frack-jobs use only 57,000 gallons (one one-hundredth of a 5-million-gallon frack-job).[57] This disparity, again, is because CBM frack-jobs do not have to create a network of fractures from scratch. They only need to tap into a network that's already there.

The final consideration unique to CBM operations is the highly brittle and cleated nature of coal seams. Such characteristics cause fracking fluids to be even more biased toward staying within the seams. The formations above and below are comparably tougher, making coal seams the path of least resistance.[58] Fracking fluids would rather spread through coal seams, like a knife through butter, than try to hammer through the formations above and below. This is in addition to the other factors (covered in "The Physics of Fracking") that also keep fracking fluids in the targeted formations.

For all the reasons above (and more), in a 2004 study on the use of fracking in CBM wells the EPA concluded:

> The injection of hydraulic fracturing fluids into CBM wells poses little or no threat to USDWs ["Underground Sources of Drinking Water"] ….[59]

Indeed, with all the factors inhibiting and minimizing contamination, it's hard to see how a different conclusion would be possible.

The Root of Public Fears

Natural, Natural Gas

The documentary *Gasland* became famous after showing footage of landowners lighting tap water on fire. The powerful image has been engraved in the minds of many, and has transformed disinterested citizens into anti-fracking crusaders. Few, however, realize that many of the landowners in *Gasland* already could light their taps on fire before drilling and fracking had begun

> ***Few, however, realize that many of the landowners in* Gasland *already could light their taps on fire before drilling and fracking had begun in their areas.***

in their areas. Methane-generating bacteria live naturally in their aquifers.

Two types of natural gas are found beneath the surface: *biogenic* natural gas and *thermogenic* natural gas. Biogenic natural gas is created through the process of fermentation. When yeast and bacteria digest organic matter in the form of sugar, they excrete ethanol,the alcohol found in beer. When they digest organic matter in the form of plant debris they excrete methane, the major component of natural gas. These bacteria can live in wetlands, landfills, coal seams, aquifers, cow stomachs, and yes, human stomachs. E&P companies rarely drill for biogenic deposits because they are usually too small to justify the costs of drilling.

Thermogenic natural gas, on the other hand, results from the same process that forms oil. The organic matter is broken down by temperature and pressure, not bacterial digestion. In contrast to fermentation, this process allows for the full variety of natural gas components—not just methane and ethane, but also propane, butane, pentane, and hexane. E&P companies predominantly target thermogenic deposits, because they are more often large enough to repay drilling costs and generate a profit.

Even though biogenic deposits are too small to justify drilling, they often exist inside aquifers at high enough concentrations to make tap water flammable. Since methane is a non-toxic, odorless gas, landowners often do not notice the methane already in their water.

Even though biogenic deposits are too small to justify drilling, they often exist inside aquifers at high enough concentrations to make tap water flammable. Since methane is a non-toxic, odorless gas, landowners often do not notice the methane already in their water. Nor do they think to check their water quality (or to try lighting their taps on fire) until drilling begins near their residence. This oversight creates a potential for mistaken associations between drilling activity and contamination.

Fortunately, scientists have developed ways to uniquely identify natural gas. By taking samples from both the water well and the suspected natural gas well, they can determine whether or not drilling activity has caused the contamination. They often find that the water well has biogenic natural gas that does not match gas from the suspected natural gas well. Sometimes they do find thermogenic natural gas, or a mixture of both. But even in these cases, the gas is matched to a shallow source and not the one targeted for fracking. In other words, the E&P company is at fault, but the contamination has resulted from drilling operations and not from fracking, as previously explained.

In Colorado, the COGCC investigates all contamination claims. Of the three Colorado residents interviewed in *Gasland*, two had naturally occurring biogenic contamination that could not be linked to drilling or fracking. The third resident had a mixture of both biogenic and thermogenic natural gas, and as a result was able to collect a settlement from the responsible company.

The COGCC was so upset when *Gasland* ignored these findings that it issued a document to correct many of the statements in the film.[60] The document cites many sources, reaching back to the 1970s, to show that Colorado has had naturally occurring biogenic methane in its aquifers for as far back as records have been kept on the matter.

Selective Emphasis

Consider two politicians who have just read the same report on a jobs-creation bill. This first politician says, "This bill will create 10 million jobs!" The second politician says, "This bill will add a trillion dollars to our deficit!" Even if both statements are true, the way in which these politicians emphasize one aspect while ignoring the other will have a profound impact on how the bill is perceived by their audience. This tactic, selective emphasis, often goes unnoticed. But it can be influential when used to shape public opinion.

The EPA employed selective emphasis when it chose to highlight one set of data while ignoring another in its recent report on contamination in Pavillion, Wyoming.

The EPA employed selective emphasis when it chose to highlight one set of data while ignoring another in its recent report on contamination in Pavillion, Wyoming.

The Wyoming report found contamination in two deep monitoring wells that had been drilled specifically to detect contamination. However, in addition to these wells, the EPA tested 51 domestic wells (wells people actually use). Not a single one showed any signs of contamination linked to fracking. Strangely, results for the domestic wells were given almost no attention. Instead, they were buried in the supplemental lab data where no one would be expected to find them.

If the EPA had wanted to offer a complete and thorough analysis, it would have presented the following two conclusions: groundwater had been contaminated (as shown by the monitoring wells) but no drinking water had been contaminated (as shown by the domestic wells).

If the EPA had wanted to offer a complete and thorough analysis, it would have presented the following two conclusions: groundwater had been contaminated (as shown by the monitoring wells) *but* no drinking water had been contaminated (as shown by the domestic wells). The EPA's decision to emphasize the first conclusion, while ignoring the second, is a clear example of selective emphasis.

This example shows not only how subtle the tactic can be, but also how effective. After the report was released, newspapers and bloggers ran articles with headlines such as "Bad Water Found At Fracking Site," and "New EPA Report Ties Hydraulic Fracturing to Groundwater Contamination." However, if the EPA had emphasized data from the domestic wells instead of that from the monitoring wells, there would have been headlines such as "Water Wells Untouched by Fracking" or "EPA Says No Fracking Chemical in Drinking Water." Both sets of headlines are accurate, but have profoundly different effects on public opinion. The fact that the first set of headlines dominated articles covering the report is proof that the EPA was able to use selective emphasis effectively.

The EPA report is just one example of this technique. Another can be found in a recent Duke study. The five-page report overwhelming dedicated its discussion to the finding that methane contamination was more common near drilling activity. (As already noted, this finding is neither new nor surprising, given that methane can migrate through the outside of bad well casings.) Yet only one sentence was reserved to state another finding with equally significant, or perhaps more profound, implications:

> We found no evidence for contamination of drinking-water samples with deep saline brines or fracturing fluids.[61]

As in the case of the EPA report, this selective emphasis had the same effect on public opinion—as evidenced by the headlines that followed. Beyond these examples, many other reports have enjoyed the subtle influence of selective emphasis, and, no doubt, there will be many more to come. Thus, it is always essential for those who want to fully understand the issues to read reports carefully and to review the supporting data.

Honest Mistakes

The Environmental Working Group (EWG), a non-profit environmental advocacy organization, recently discovered a 1987 EPA report in which a 1982 contamination incident was blamed on fracking.[62] This is the only recorded incident to date in which it is alleged that fracking fluids (and not merely natural gas) were found in a domestic water well.

The EPA report drew its conclusion after a superficial analysis, without considering some key considerations that would contradict their conclusion. Nonetheless, the EWG used the 1982 incident as a way to present a unique hypothesis—one that it claimed would make direct contamination by fracking possible. The hypothesis argues that old abandoned oil and gas wells can serve as shortcuts whereby fracking fluids could infiltrate freshwater aquifers. The EWG report suggests that fractures spreading outward from a well might intersect an old well that was drilled to the same depth or deeper. The fracking fluids could then travel vertically through the old well, and bypass all the rock layers that would otherwise stop them. Because many of these old wells were drilled before adequate regulations were in place, they have poor well casings or almost none at all. Therefore, EWG argues, if fracking fluids get into an old well, there will not be adequate casing and cement to prevent them from getting into freshwater aquifers.

The EWG hypothesis is more plausible than others, and therefore deserves serious consideration. However, in the case of the 1982 incident, the hypothesis fails to deliver.

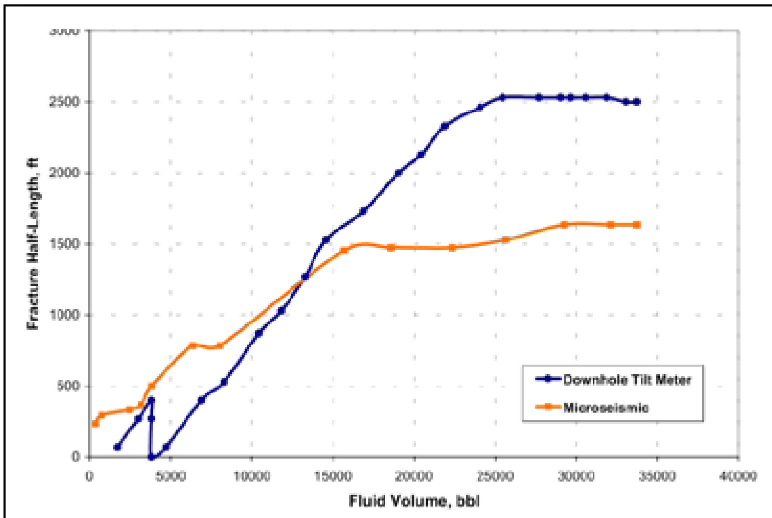
The EWG report bases its conclusion on the premise that the fractures created during the 1982 incident could have been at least 1,000 feet long in order to make contact with the nearest abandoned well. To prove the possibility, the EWG report cites a research paper in which a 2,500-foot-long fracture was recorded.[63] However, the frack-jobs in the cited research paper are massive when compared to the 1982 frack-job.

The EWG failed to consider the differences between the fracking fluids used in the 1982 incident and those used in the cited research paper. The research paper specifically analyzes frack-jobs where the base fluid is water, an incompressible fluid. The volume does not shrink when the fluid is subjected to the high pressures of fracking. The 1982 frack-job, on the other hand, used a nitrogen foam as the base fluid. Unlike water, nitrogen foam is highly compressible.

In the research paper, all the frack-jobs that spread to 2,500 feet used more than one million gallons of water. The nitrogen foam used in the 1982 frack-job consisted of 760,000 standard cubic feet of nitrogen (equivalent to 5.7 million gallons) and 13,000 gallons of water. But the nitrogen volumes were reported at standard conditions (very low pressure, 14.7 psi). When the foam was injected under high pressure (2,500 psi), the nitrogen foam would have compressed to less than 50,000 gallons—20 times smaller than the frack-jobs in the cited research paper!

When the compressibility of nitrogen foam is properly accounted for, the cited research paper actually undermines the EWG report. In the same research paper, a graph plots the fracture lengths against the volumes of fracking fluids used for the various wells in the study (figure 20). The graph shows that roughly 500,000 gallons (12,000 bbl in the graph) would be required to make a 1,000-foot fracture—10 times more than what was used in the 1982 frack-job!

Figure 20. *Two technologies used to measure the length of fractures are plotted against the volume of fracture treatments. Source: Kevin Fisher. Research paper available for purchase at:* http://www.onepetro.org/mslib/servlet/onepetropreview?id=SPE-77441-PA



A second major oversight in the EWG paper stands out. The laboratory records referenced in the report describe the contaminant as a "gelatinous" material, but they also go on to say that it is "characteristic of a sealant." The EWG report neglected to mention this latter point, which was a crucial mistake. Fracking fluids do not use any sealants. Sealants would clog up the permeability that the fracking process is trying to create; it would be completely counterproductive. But if the EWG theory cannot explain the contamination, what did happen? Fortunately, the EWG report concedes that another explanation is possible—one that does not implicate fracking. The gelatinous material that contaminated the freshwater well may not have been fracking fluids. It may have been aquagel, a substance used during the drilling process. Aquagel, on the other hand, is designed to be a sealant, so it can prevent permeable formations from impacting the drilling process after those formations have been drilled through and exposed.

The EWG report essentially suggested that both explanations are possible, but went on to heavily endorse the old-wells-as-short-cut hypothesis. Given these new considerations (not present in the EWG report), the aquagel hypothesis becomes, by far, the most plausible explanation.

A Spurious Diagnosis

On September 16, 2011, ProPublica published an article that opened with the dramatic story of Susan Wallace-Babb.[64] The story was included as anecdotal evidence that fracking and drilling are destroying people's lives. However, a thorough examination of Susan's testimony reveals a different and more compelling story that could explain similar horror stories elsewhere.

Susan was living a happy life in Garfield County, Colorado. One day, after parking her truck near a natural gas well, she stepped out, took a deep breath and collapsed, unconscious.

Susan was living a happy life in Garfield County, Colorado. One day, after parking her truck near a natural gas well, she stepped out, took a deep breath and collapsed, unconscious. She regained consciousness and was able to drive away, but from that point on her life was permanently changed. She was diagnosed with a chemically sensitivity, meaning that the trauma from her collapse made her hyper-sensitive to chemicals similar to whatever caused her initial collapse. Even non-toxic substances, such as methane, can now induce skin rashes and send her into fits of vomiting.[65]

Susan's story is terrifying. In fact, it is so startling that her testimony was submitted to Congress on Halloween in 2007. But like all ghost stories, what we know of reality contradicts what the storyteller wants us to believe.

Susan's official diagnosis, multiple chemical sensitivity (MCS), is not recognized by the American Medical Association, the World Health Organization, nor the American Academy of Allergy, Asthma and Immunology. In fact, the entire field of specialization that diagnoses and treats MCS, clinical ecology, is not recognized as a valid medical specialty.[66] Why? Because double-blind, controlled studies have shown that people diagnosed with MCS show the exact same symptoms even when they are exposed to placebos, such as clean air or saline solutions. As long as they believe they are being exposed to toxic chemicals, they show the same symptoms. Dr. Stephen Barrett explains:

> Well-designed investigations suggest that many [sufferers of MCS] have a psychosomatic disorder in which they develop multiple symptoms in response to stress.[67]

Psychosomatic means that someone's belief (in this case, that she is exposed to toxic chemicals) is so strong that it causes real stress. In turn, the severe stress produces physical symptoms. Stress and anxiety have long been known to have serious physical side-effects, including rashes and vomiting.

In Susan's case, it seems likely that her reactions are psychosomatic. For one, she says her chemical sensitivity is triggered by hydrocarbons, even though she blames hydrogen sulfide ("H2S"), which is not a hydrocarbon, for her collapse. H2S is a toxic gas sometimes found with oil and natural gas—similar to many non-petroleum products, including brine and carbon dioxide. If Susan was chemically sensitized by exposure to H2S, her fits should be triggered by other sources of H2S, such as eggs and sewage. She should not be affected by the refined petroleum products, such as methane and propane, to which she reacts.

Susan logically attributed her collapse to hydrogen sulfide, because hydrocarbon gases are not strong enough to cause a collapse from just one breath. However, there is good reason to suspect that this part of her story is not true either. For instance, when the concentration of H2S is strong enough to cause unconsciousness from a single breath, it is also strong enough to be fatal. And because H2S is heavier than air, if Susan really did collapse, she would have been immersed in even higher concentrations. If Susan's story is correct, it is almost inconceivable that she would have survived.

If Susan's story is correct, it is almost inconceivable that she would have survived.

More likely, Susan suffered a fainting episode from standing up too quickly (known as a postural syncope). She says she collapsed immediately after stepping out of her truck, which would have involved shifting from a sitting position to a standing position. Such a change in posture lowers one's blood pressure and frequently causes a type of fainting that would better fit Susan's description. She says she experienced a "crushing headache" just before collapsing, which sounds like the head rush that precedes postural syncopes. She also only briefly lost consciousness, which also fits the description of a postural syncope. Once blood pressure normalizes, a person regains full consciousness.

Instead of drawing (or even considering) this conclusion, and because she was already wary of the gas well, Susan may have created a false association between the well and her collapse. She did some "intense research online," most likely to confirm her own suspicions. During her research she learned about H2S—the only chemical that both could explain her collapse AND be linked to a gas wells. Unfortunately, she failed to realize H2S is not a petroleum product. However, if her reaction is really psychosomatic, it would make no difference. She only would need to believe that H2S is a petroleum product in order for petroleum products to become her psychosomatic trigger.

Psychosomatic Contagion

Now take the story of Susan Wallace-Babb in the preceding section, as she believes it, and broadcast it around the world. If Susan's reaction is psychosomatic, what are the chances that the broadcast will result in more cases of psychosomatically induced MCS?

In the 21st century, doctors have begun to struggle with an increase in patient visits due to widespread horror stories and lists of symptoms available through the internet.

In the 21st century, doctors have begun to struggle with an increase in patient visits due to widespread horror stories and lists of symptoms available through the internet. The term "cyberchondria" was coined to describe this increasing internet-induced paranoia. Cyberchondria describes people who develop an increased awareness, and therefore paranoia, of all diseases and disorders. It also particularly applies to MCS. Dr. Ronald E. Gots noticed this back in 1995 when he said:

> The phenomenon of multiple chemical sensitivities is a peculiar manifestation of our technophobic and chemophobic society.[68]

If there is any doubt this phenomenon could explain more than a handful of the ambiguous symptoms blamed on oil and gas development, recall the 2001 anthrax attacks. More than 2,300 false alarms were reported in the first month following the initial attack. In a more recent example, 34 people were rushed to the hospital in Fort Worth, Texas, after some perfume set off a carbon monoxide scare. Even though it was a false alarm, all 34 people showed symptoms that were, no doubt, psychologically induced. If news reports and amateur YouTube videos cause people to believe they are being exposed to toxic chemicals, whether from fracking or drilling, why would they react any differently?

If news reports and amateur YouTube videos cause people to believe they are being exposed to toxic chemicals, whether from fracking or drilling, why would they react any differently?

Further, in the examples above, there is no incentive that would motivate people to fake their reactions. However, in the case of oil and gas drilling, the ranks of people who honestly believe they have symptoms from oil and gas development could be increased by those who see an opportunity to collect a big settlement check. This occurred to Dr. Berrett when he considered the people arguing for acceptance of MCS as a valid diagnosis:

> Many [MCS advocates] are also part of a network of questionable legal actions alleging injuries by environmental chemicals. [emphasis added][69]

The real danger, and the reason groups like the American Medical Association are fighting against the recognition of MCS, is that people are experiencing real pain, even if it is psychosomatically induced. If people are diagnosed with MCS, they will not get the psychiatric treatment they need. Instead, dubious clinical ecologists will continue to treat these patients with injections of enzymes and other treatments that have no proven efficacy. The treatments peddled by clinical ecologists also have come under criticism. MCS patients, again, respond just the same to placebo treatments, as long as they believe they are getting the proper treatment. Thus, MCS has become a racket for clinical ecologists to line their pockets by turning every form of industrial activity into a gold mine of their own. However, they can only profit by MCS as long as the root psychological cause of their patients' suffering is never addressed.

Hidden Agenda

The superficial arguments that attack fracking as a direct cause of contamination have been largely discredited. Consequently, anti-fracking groups have begun resorting to broad arguments against development in general. This tactic is mere sleight-of-hand. Direct arguments seamlessly are followed by arguments about air pollution, endangered species, and the like. However, these are not specifically fracking issues; they apply to every form of development.

We are told that fracking will pollute and deplete water (direct arguments), and furthermore, that fracking will cause air pollution, cut off animal migration routes, and render the land barren and unaesthetic (indirect arguments). The indirect arguments may or may not be valid, but they miss their target. If fracking were replaced altogether—by some unimagined technology, equally able to unlock oil and gas—the indirect arguments would remain exactly the same. Even if fracking no longer existed, the land still would be impacted and traffic still would drive to and from the oil and gas extraction sites.

A ban on fracking would not satisfy those who present general arguments against any kind of development. Acceptance of these arguments would require an outright ban on all oil and gas activities, new wind farm construction, electric transmission construction, residential housing developments, road construction, and the like. Before accepting any argument against fracking as sufficient grounds to restrict or ban its use, one should take that argument to its logical conclusion and consider the full set of repercussions. For if such arguments are granted valid status, they will be used again and again by whichever parties can benefit from shutting down any particular form of development.

Figure 21. *Protestor at Occupy Wall Street. Together, the sign and apparel decry fracking, natural gas, oil, coal, companies, work, and consumption. For many protestors the issues go far beyond fracking. Source: El Marco, http://www.lookingattheleft.com/2011/11/zuccotti-utopia-portraits-of-revolutionaries/*

Endnotes

[1] John Hickenlooper, Opening Remarks at 2011 Rocky Mountain Energy Epicenter conference, delivered August 2, 2011.

[2] COGA, *Fast Facts: Natural Gas Facts*, updated June 14, 2011, http://www.coga.org/pdfs_facts/Natural%20Gas%20Facts.pdf

[3] There has been much debate over whether to call the process "fracking" or "fracing." The first term has been used most widely by the public, while industry papers use the latter term. Since this paper is targeting a broader audience than the oil and gas production industry, the term "fracking" will be used throughout.

[4] Cathy Proctor, "'Fracking' Aids Oil and Gas Extraction, Raises Environmental Eyebrows," *Denver Business Journal*, September 2, 2011, http://www.bizjournals.com/denver/print-edition/2011/09/02/fracking-aids-oil-and-gas.html

[5] Even though they have tiny pores, unconventional formations are able to store a significant amount of hydrocarbons because they have more pores per cubic inch. The overall storage capacity does not change much even as grains get smaller and smaller. The permeability, however, is reduced, which leads to the need for fracking.

[6] Incidentally, fracking is just one of many ways to enhance production (known collectively as "stimulation" techniques). Before fracking became popular, companies used nitroglycerine (dynamite) to stimulate oil and gas wells. In the 1960s, the federal government experimented with underground nuclear detonations to unlock unconventional natural gas.

[7] For more on the fracking revolution, see Daniel Yergin, "Stepping on the Gas," *Wall Street Journal*, April 2, 2011, http://online.wsj.com/article/SB100014240527487037125045762325829900890 02.html

[8] Chesapeake Energy, "Horizontal Drilling Method," online video, uploaded November 12, 2010, quoted from 5:29 to 5:59, available at: http://www.youtube.com/watch?v=AYQcSz27Xp8&feature=relmfu

[9] COGA, supra note 2.

[10] Proctor, supra note 3.

[11] "Oil & Gas Operations at a Glance," COGCC, website, accessed November 22, 2011, http://cogcc.state.co.us/General/AtAGlance.html

[12] *Horizontal Wells in Colorado*, COGCC, staff presentation, November 29, 2010, http://cogcc.state.co.us/Library/Presentations/ColoradoHorizontalWells_Nov29_2010v1.pdf

[13] David Neslin (director of the COGCC), memorandum discussing oil and gas activity during Q1 2011, dated April 25, 2011, http://cogcc.state.co.us/announcements/CommissionLtr4_25_11.pdf

[14] Depths were determined from a survey of well permits issued in these counties as reported in the COGCC online database, accessed November 22, 2011, http://cogcc.state.co.us/

[15] Mark Jaffe, "An Inside Look at Fracking a Well," *Denver Post*, November 20, 2011, http://www.denverpost.com/business/ci_19371498

[16] The only exception this author is aware of is the fracking that took place in Pavillion, Wyoming. In this case, fracking was taking place at unusually shallow depths (as shallow as 1,200 feet deep). Synthetic chemicals (i.e. chemicals that could not have occurred naturally) were detected in two deep monitoring wells drilled by the EPA to roughly 800 and 1,000 feet depth. None of the 51 domestic water wells that were tested (those actually used by human beings and animals) showed any signs of contamination that could be linked to hydraulic fracturing.

[17] There are several different physical mechanisms that restrict vertical fracture growth. There is still a debate over which ones are the most influential. An overview of the different mechanisms can be found in the paper by A. Ali Daneshy "Factors Controlling the Vertical Growth of Hydraulic Fractures," Society of Petroleum Engineers, January 2009, available for purchase at: http://www.onepetro.org/mslib/servlet/onepetropreview?id=SPE-118789-MS&soc=SPE

[18] Michael J. Economides, "Natural Gas, 'Fracking,' Water, and $500 billion," *Energy Tribune*, September 1, 2011, http://www.energytribune.com/articles.cfm/8440/Natural-Gas-Fracking-Water-and-$500-Billion

[19] Kevin Fisher, "Data Confirm Safety of Well Fracturing," *The American Oil & Gas Reporter*, July 2010, http://www.halliburton.com/public/pe/contents/Papers_and_Articles/web/A_through_P/AOGR%20Article-%20Data%20Prove%20Safety%20of%20Frac.pdf

[20] It's also worth mentioning that microseismic monitoring overestimates the extent of fractures, so the fracture heights shown in Figure 11 and Figure 12 are likely greater than the heights of the actual fractures. This is because microseismic monitoring equipment detects what are called shear or slippage events, which are not the same as tensile fractures (the fractures that actually spread apart and allow fracking fluids to flow through them). Shear or slippage events can occur far away from the wellbore, beyond the actual extents of tensile fractures, but there is no separation in these events through which fluids can flow.

[21] Percentage calculated using numbers from the United States Geological Survey website: "How much water is there on, in, and above the Earth?", accessed November 22, 2011, http://ga.water.usgs.gov/edu/earthhowmuch.html

[22] Rules and Regulations, COGCC, Rule 317 (e)(f)(g)(h)(i), http://cogcc.state.co.us/RR_Docs_new/Rules/Completed%20Rules.pdf

[23] Ibid., (h)(i).

[23] Ibid., (j)(o).

[25] This is exactly what happened in Dimock, PA (featured in the documentary *Gasland*). The Pennsylvania DEP determined that the contamination was natural gas coming from a shallower formation than the one that had been fractured. Fred Baldassare, internal DEP email to Kelly Burch, Pennsylvania Department of Environmental Protection, dated February 4, 2009, http://www.damascuscitizens.org/Internal-DEP-Discussion.pdf

[26] National Fire Protection Association, *Natural Gas and LP-Gas Home Structure Fires* , accessed December 20, 2011, http://www.nfpa.org/assets/files/PDF/GasFactSheet.pdf

[27] The incident caused by drilling activity took place in Bainbridge, Ohio on December 15, 2007. No one was

hurt. The state investigation can be found at: http://www.dnr.state.oh.us/bainbridge/tabid/20484/Default.aspx

[28] Water Well Construction Rules (2 CCR 402-2), Office of the State Engineer, State of Colorado, page 34, section 11.5.1, http://water.state.co.us/dwripub/documents/constructionrules05.pdf

[29] The latest rules promulgated by the EPA will actually require all fracking operations to use these closed-loop systems (also known as "green completions") by 2015, thus removing concerns about flowback pits altogether.

[30] Burning wood releases significant quantities of benzene. U.S. Department of Health and Human Services, *Toxicological Profile For Benzene*, August 2007, p. 278, http://www.atsdr.cdc.gov/toxprofiles/tp3.pdf

[31] Tarek Saba et al., *Methanol Use in Hydraulic Fracturing Fluids*, August 29, 2011, p. 4-4, http://www.methanol.org/Environment/Resources/Environment/Methanol-Fracking-Fluid-White-Paper-Aug-2011.aspx

[32] McKenzie et al., "Human health risk assessment of air emissions from development of unconventional natural gas resources," *Science of the Total Environment*, February 2012, http://www.sciencedirect.com/science/article/pii/S0048969712001933

[33] The life-time cancer risk for the general population used in this paper (200,000 cases per million) comes from a variety of sources. Argonne National Laboratory used this figure for comparison purposes in the last sentence of its *Human Health Facts Sheet* for Potassium-40 (reported as 20,000 per 100,000 persons). http://www.ead.anl.gov/pub/doc/potassium.pdf The number is also supported by Table 6 in the "Summary Health Statistics for U.S. Adults: National Health Interview Survey, 2010" published by the National Center for Health Statistics. The table says that people who live to be between the ages of 65 and 74 have a 20.4% chance that they will have been diagnosed with cancer. http://www.cdc.gov/nchs/data/series/sr_10/sr10_252.pdf

[34] While the CSPH study says it assumed people were living within a ½ a mile of 40 natural gas wells (2 well-pads with 20 wells each), all of the data it used to represent exposures within ½ a mile were actually collected within 500 feet of well sites. Some were taken as close as 130 feet away. Thus, the results are really only representative of exposures assuming someone is living within 500 feet of 40 natural gas wells. This is extremely unlikely to happen in reality.

[35] United States Environmental Protection Agency, 2005 National-Scale Air Toxics Assessment, data taken from spreadsheets accessible through the following website: http://www.epa.gov/ttn/atw/nata2005/tables.html

[36] Chesapeake Energy Corporation, *Water Use in Deep Shale Exploration: Fact Sheet*, May 2011, http://www.chk.com/Media/Educational-Library/Fact-Sheets/Corporate/Water_Use_Fact_Sheet.pdf

[37] Joint report from Colorado Division of Water Resources, the Colorado Water Conservation Board, and the Colorado Oil and Gas Conservation Commission, *Water Sources and Demand for the Hydraulic Fracturing of Oil and Gas Wells in Colorado from 2010 through 2015*, accessed May 2012, http://cogcc.state.co.us/Library/Oil_and_Gas_Water_Sources_Fact_Sheet.pdf

[38] Matthew E. Mantell, *Deep Shale Natural Gas: Abundant, Affordable, and Surprisingly Water Efficient*, presented at the 2009 GWPC Water/Energy Sustainability Symposium held in Salt Lake City, Utah, September 13-16, 2009, Table 5, http://www.energyindepth.org/wp-content/uploads/2009/03/MMantell_GWPC_Water_Energy_Paper_Final.pdf

[39] Worldwatch Institute, *How Energy Choices Affect Fresh Water Supplies: A Comparison of U.S. Coal and Natural Gas*, http://cce.cornell.edu/EnergyClimateChange/NaturalGasDev/Documents/PDFs/Water%20Usage%20and%20Impacts%20(November%202010).pdf

[40] The area around the Hoover Dam felt hundreds of earthquakes during the 1930s while the reservoir was being filled. The largest quake was roughly a 5.0 magnitude. Alexis Madrigal, "Top 5 Ways to Cause a Man-Made Earthquake," *Wired*, June 4, 2008, http://www.wired.com/wiredscience/2008/06/top-5-ways-that/

[41] Jonathan Fahey, "Experts: Oklahoma Quakes Too Powerful to be Man-made," *Associated Press*, November 7, 2011, http://www.google.com/hostednews/ap/article/ALeqM5gnMAj02_yXaZ986T_c0NmzRLHzFA?docId=35f0abf919f542789520f9ed9e4b0820

[42] It is not technically accurate to say that the fracking fluid is acting as a lubricant; rather, it is providing the additional pressure and volume needed to cause a phenomenon known as hydrodynamic lubrication. So while the substance itself is not a lubricant, when it comes into contact with a fault it essentially has the same effect.

[43] The articles reporting on Holland's study failed to distinguish between duration magnitude and the Richter scale (the measurement scale most people are familiar with), and were thereby effectively reporting an inflated number. For the purposes of this paper, duration magnitude was converted to the Richter scale (also known as the "local magnitude") using an empirical formula developed by D. S. Brumbaugh in his paper "A Comparison of Duration Magnitude to Local Magnitude for Seismic Events Recorded in Northern Arizona," *Journal of the Arizona-Nevada Academy of Science*, 1989, Vol. 23, 29-31. http://www.jstor.org/pss/40026547

[44] Fahey, supra note 35.

[45] Madrigal, supra note 34.

[46] The underground nuclear detonations were part of the Plowshares Program, designed to see if nuclear bombs could unlock unconventional natural gas reserves. These projects were pursued for the purpose of bolstering the nation's energy security. But fortunately, fracking has advanced to a point where these schemes would be comparably inefficient, removing the temptation altogether.

[47] Colorado Geological Society, "Coalbed Methane—Colorado's World Class Commodity," *Rock Talk*, no. 3 (July 2000): 2, http://geosurvey.state.co.us/pubs/Documents/rtv3n3.pdf

[48] U.S. EPA, *Coalbed Methane Extraction: Detailed Study Report*, October 2011, page 3-6, http://water.epa.gov/lawsregs/lawsguidance/cwa/304m/upload/cbm_report_2011.pdf

[49] S.S. Papadopulos & Associates, Inc. in conjunction with Colorado Geological Society, *Coalbed Methane Stream*

Depletion Assessment Study – Northern San Juan Basin, Colorado, February 2006, http://geosurvey.state.co.us/water/CBM%20Water%20Depletion/Documents/San_Juan_CBMSDA_Study.pdf

[50] The percentage (0.05%) was calculated using the estimated CBM depletion rate (156 ac-ft/yr) and the combined yearly base flow rates for relevant rivers (227,000 ac-ft/yr) as provided in a memorandum dated April 4, 2006 from Assistant State Engineer, Dick Wolfe. The memorandum summarizes the report's findings and is included as the first three pages of the report PDF as provided at the following link: http://geosurvey.state.co.us/water/CBM%20Water%20Depletion/Documents/San_Juan_CBMSDA_Study.pdf

[51] S.S. Papadopulos & Associates, Inc. in conjunction with Colorado Geological Society, *Coalbed Methane Stream Depletion Assessment Study – Raton Basin, Colorado*, March 2008, http://geosurvey.state.co.us/water/CBM%20Water%20Depletion/Documents/RatonCBMdepletion_FINAL.pdf

[52] The percentage (3.6%) was calculated using the estimated CBM depletion rate (2,500 ac-ft/yr) and the mean flow rates for the Cucharas River (assuming the low end of the reported typical range, 20 cu-ft/sec) and the Purgatoire River (75 cu-ft/sec) as provided on report pages ES-2, 28, and 30 respectively. Mean flow rates were converted to units of acre-feet per year (54,298 ac-ft/yr and 12,479 ac-ft/yr respectively) and combined for a total yearly base flow rate (68,777 ac-ft/yr). The Apishapa River was not considered given the discussion on page 29 of the report.

[53] "Colorado Court: Coal Bed Methane Producers Need Water Permits," *Environmental News Service*, April 20, 2009, http://www.ens-newswire.com/ens/apr2009/2009-04-20-093.html

[54] U.S. EPA, *Evaluation of Impacts to Underground Sources of Drinking Water by Hydraulic Fracturing of Coalbed Methane Reservoirs*, June 2004, page ES-17, http://water.epa.gov/type/groundwater/uic/class2/hydraulicfracturing/wells_coalbedmethanestudy.cfm

[55] Ibid., page 11.

[56] Page 11 of the 2004 EPA report also mentions 350,000-gallon CBM frack-jobs, but this number is from outdated sources from the 1980s and early 1990s, when companies were first experimenting with CBM for productive purposes.

[57] U.S. EPA, supra note 47, page 11.

[58] Ibid., page 3-7.

[59] Ibid., page ES-1.

[60] "Gasland Correction Document," COGCC, http://cogcc.state.co.us/Announcements/Hot_Topics/Hydraulic_Fracturing/GASLAND%20DOC.pdf

[61] Stephen G. Osborne et al., "Methane Contamination of Drinking Water Accompanying Gas-Well Drilling and Hydraulic Fracturing," *PNAS* 108, no. 20 (May 17, 2011): 8175, http://www.pnas.org/content/108/20/8172.full.pdf

[62] U.S. EPA, *Report to Congress: Management of Wastes from the Exploration, Development, and Production of Crude Oil, Natural Gas, and Geothermal Energy*, December 1987, page IV-22, http://www.epa.gov/osw/nonhaz/industrial/special/oil/rtc1987.pdf

[63] Kevin Fisher et al., "Integrating Fracture-Mapping Technologies to Improve Stimulations in the Barnett Shale," Presented at the 2002 SPE Annual Technical Conference and Exhibition in San Antonio, Texas, Sept. 29-Oct. 2, 2002, available for purchase at: http://www.onepetro.org/mslib/servlet/onepetropreview?id=SPE-77441-PA

[64] Abrahm Lustgarten and Nicholas Kusnetz, "Science Lags and Health Problems Emerge Near Gas Fields," *ProPublica*, September 16, 2011, http://www.propublica.org/article/science-lags-as-health-problems-emerge-near-gas-fields/single

[65] Susan Wallace-Babb, *Is the Oil and Gas Industry Worth Your Life*, testimony submitted to the Congressional Committee on Government Oversight and Reform, October 31, 2007, http://oversight-archive.waxman.house.gov/documents/20071031105539.pdf

[66] Stephen Barrett, "Multiple Chemical Sensitivity: A Spurious Diagnosis," *Quackwatch*, revised March 18, 2011, http://www.quackwatch.org/01QuackeryRelatedTopics/mcs.html

[67] Ibid.

[68] Ronald E. Gots, "Editorial Commentary: Multiple Chemical Sensitivities–Public Policy," *Clinical Toxicology*, January 1995, Vol. 33, No. 2, 111–113, http://informahealthcare.com/doi/abs/10.3109/15563659509000459

[69] Barrett, supra note 60.

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