Fracking in Virginia

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Part I: What is Fracking?

Hydraulic fracturing (a.k.a. fracking or fracing) is a method to release natural gas and oil trapped inside bedrock that cannot be economically retrieved with traditional methods. Fracking is a fiercely debated political and environmental issue. Advocates believe it is a safe and economical source of clean energy that provides jobs, assures energy independence, and boosts the economy. Critics claim it pollutes the air and drinking water, affects health, promotes seismic activity, contributes to the greenhouse gases, and will delay the development of renewable energy sources.

What is Natural Gas?

Natural gas is a mixture consisting primarily of methane (87-97%), ethane, propane, butane, and other gases. The exact composition varies by source. When processed, "**dry gas**" (gas) contains almost 100% methane; it is used for home heating and power generation. Ethane, propane, butane, etc., are separated from natural gas and sold as individual compounds. These are called LNG (liquefied natural gases), NLG (natural gas liquids), or "wet gases."

Why Frack? Conventional vs. Unconventional Resources

Oil or natural gas located in rock with connected pore spaces is called conventional. When wells are drilled for conventional resources, oil or natural gas will flow or can be pumped to the surface (Figure 1[1]). Unconventional refers to resources in low permeability rock like shale (shale gas), or sandstone and limestone (**tight** gas or oil), with poorly connected pores that make it difficult for oil and natural gas to move through the rock to the well (Figure 2[2]). Advances in fracking technology now enable oil and natural gas producers to economically tap into unconventional resources that were previously impossible to obtain.

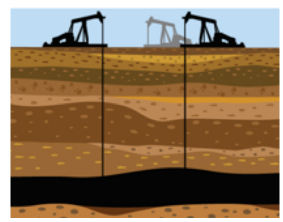

Figure 1- Conventional Resources

Fracking History

Fracking is not new. It was first done during the Civil War by putting torpedoes down wells. The idea of non-explosive fracking took off in the 1930s and in 1949 Halliburton patented a "Hydrafrac" process. But it was not until 2000 that Mitchell Energy developed a method to produce commercial volumes of shale gas. Modern fracking relies on two technologies, horizontal drilling and hydraulic fracturing. Horizontal drilling enables a well to make a 90° turn; it also enables one vertical well to reach resources that it otherwise would take 32 wells to tap (Figure 3[3]).

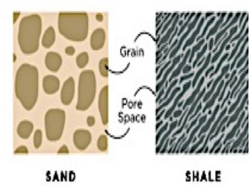

Figure 2- Sand has 1 billion times more pore space than shale

Fracking Vocabulary

- ***Fracking fluids:*** fluid injected into the well at high pressure, typically composed of 90% water, 9.5% proppants, and 0.5% chemicals.
- ***Proppants:*** granular particles like sand used to keep the cracks open.
- ***Flowback****:* fracking fluid that returns to the earth's surface along with extracted resources.
- ***Produced water****:* salty water/brine that has been under the earth for millions of years and comes to the surface; contains substances trapped in the rock, including naturally occurring radioactive material (NORM), such radium.
- ***Wastewater****:* produced water + flowback.

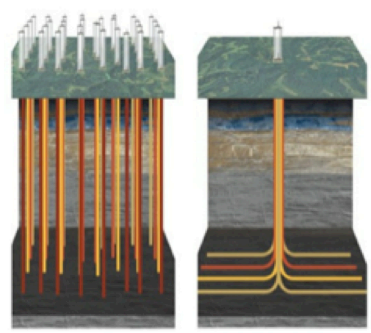

Figure 3- Traditional Vertical Well Spacing: 32 Padsites Needed for 32 Wells vs. Idealized Horizontal Spacing: 1 Padsite Yields up to 32 Wells

The Fracking Process

1. Drilling: After a well pad has been prepared, a well is drilled vertically to a depth of 1–2 miles. Once the vertical well reaches the layer of rock where the natural gas exists, the well is turned 90° and drilled horizontally along that rock layer. Horizontal drilling can extend more than a mile. At various stages during the drilling process, the well is encased in steel and cement to prevent leaking into groundwater (Figures 4[13] and 5[4]).

Figure 4- Cross section of a well casing

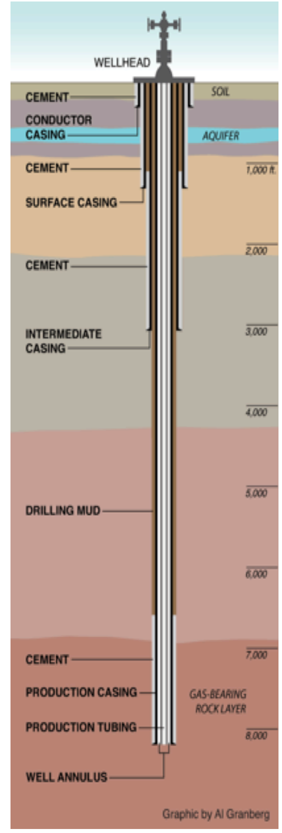

Figure 5- Anatomy of a Gas Well

2. Fracking: When drilling is complete, a perforation gun is lowered into the horizontal well section and shoots holes through the casing and cement. Water delivered to the well site is mixed with proppant and chemicals to make the fracking fluid that is injected into the well at extremely high pressure, fracturing the rock. When the pressure is released, some of the fracking fluid (now called flowback), produced water, and released gas flow up the well. The proppant remains behind, holding the fractures open. At the surface, gas production units (GPUs) separate out the gas. Wastewater is stored in open pits at the site, and can be disposed of in injection wells, treatment plants, or recycled (with or without treatment) for use in future fracking operations[5,6,7] (Figure 6[8]). Chesapeake Energy has two brief animations that explain the process: Chesapeake Energy Horizontal Drilling Method (https://www.youtube.com/watch?v=vvRCYLnVWG8) and Chesapeake Energy Hydraulic Fracturing Method (https://www.youtube.com/watch?v=qjP-K1VaI1k).

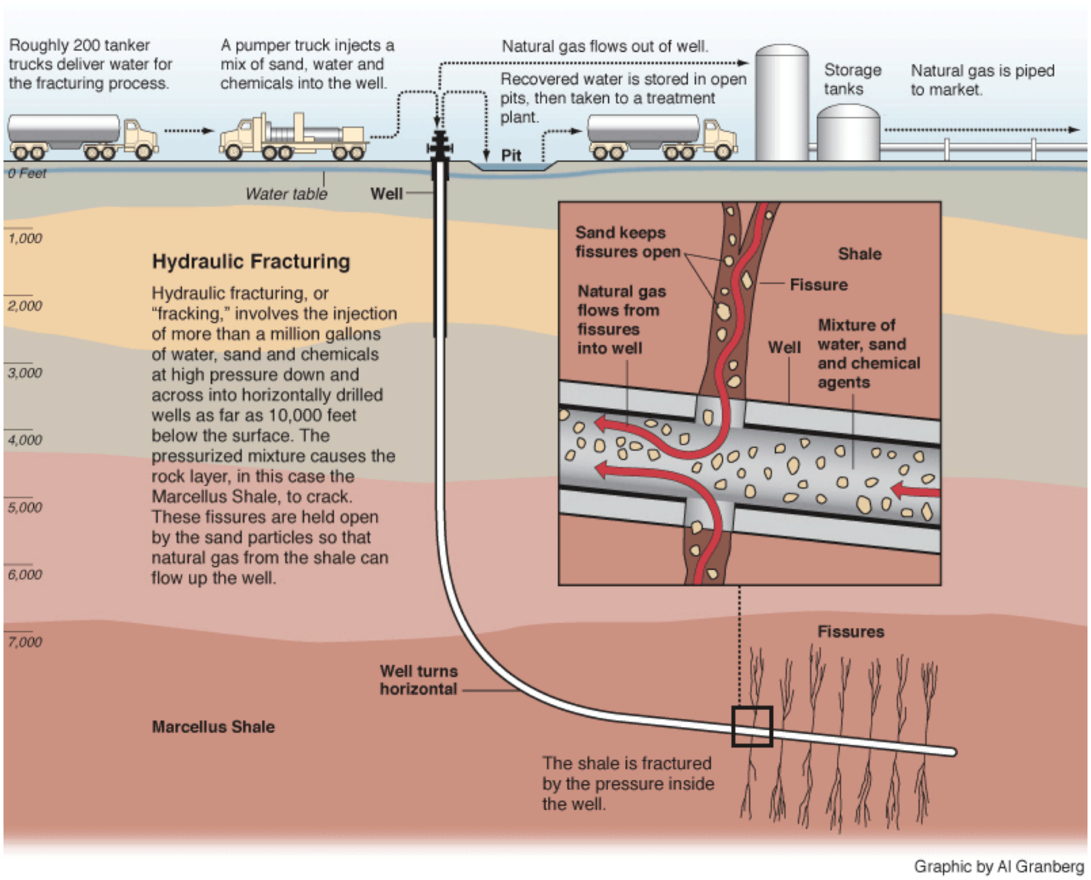

Figure 6- What is Hydraulic Fracturing?

3. ***Post-Fracking:*** A gathering pipeline brings the gas from the production well to large transmission pipelines. Compressor stations are located every 40-100 miles along the pipelines to compress the gas to a specified pressure, allowing it to continue traveling along the pipeline.

Wells are estimated to last 20–40 years. When a well is no longer in use, it is plugged. This is followed by reclamation (restoration) of the site.

How Much Shale Gas Is There?

Shale plays, which are located within **basins**, contain significant accumulations of natural gas. (Figure 7[9]) Shale gas and tight oil plays make up half of US dry gas production. By 2018, the US will become a net exporter for the first time since the 1950s. By 2040, shale gas and tight oil plays are expected to be 69% of production, and net exports will be 18% of production[10] (Figure 8[10]).

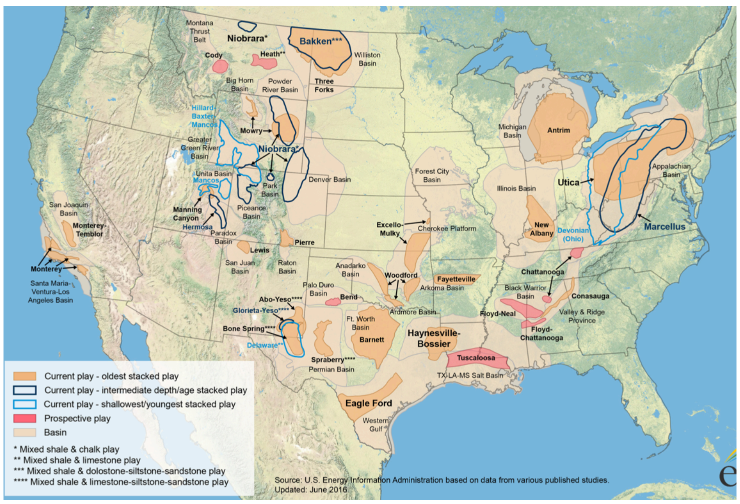

Figure 7- Shale Plays in the Lower 48 States

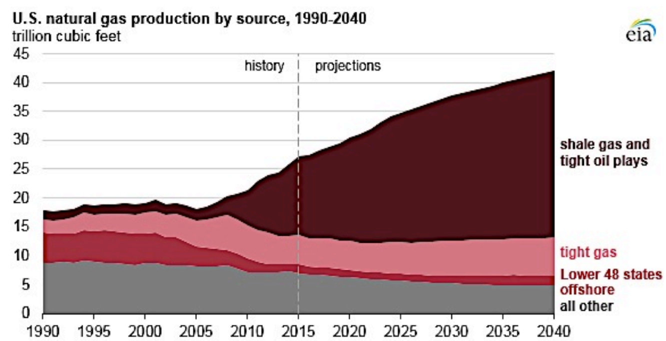

Figure 8- U.S. Energy Information Administration, Annual Energy Outlook 2016 ***Note:*** *All other includes natural gas production from coalbed methane, Alaska, and all Lower 48 onshore sources not specified above.*

Part II: What Gas Resources Are In Virginia?

Figure 9[11] shows the three areas where natural gas may be found in Virginia: the Marcellus Shale formation; the southwest Virginia coalbed methane and non-coal gas fields; and the Tidewater Mesozoic basins.

Marcellus Shale

The Marcellus Shale (Figure 9 inset) is the largest shale play in the US and in July 2016 accounted for 38% of US shale gas production.[12] It covers the western edge of the commonwealth, but a recent study by the US Geological Survey (USGS) indicates that the Marcellus in Virginia is thermally overmature, meaning that the shale was most likely heated to too high a temperature in the past to preserve economic quantities of gas or oil.[13] In 2014, the US Forest Service limited the amount of land available for oil and gas leases in the George Washington National Forest to 177,000 acres, down from 995,000 acres.[14]

Southwest Virginia

There are 8,062 producing wells in Virginia,[15] all located in the Southwest counties of Buchanan, Dickenson, Lee, Russell, Scott, Tazewell, and Wise. Approximately 2,100 gas wells have been fracked in shale, sandstone and limestone since the 1950s, and about 6,000 coalbed methane wells, which are unconventional, have been fracked using a “foam frack” of nitrogen, water, and chemicals. Nitrogen is used because water may cause the soil to swell and hinder or block the flow of gas. As little as 35,000 gallons of water may be required to fracture a coalbed methane well; in comparison, 6,000,000 gallons may be used to frack a well in the Marcellus. Development of southwest Virginia’s natural gas resources continues, with new wells being drilled and hydraulically fractured every year.[13]

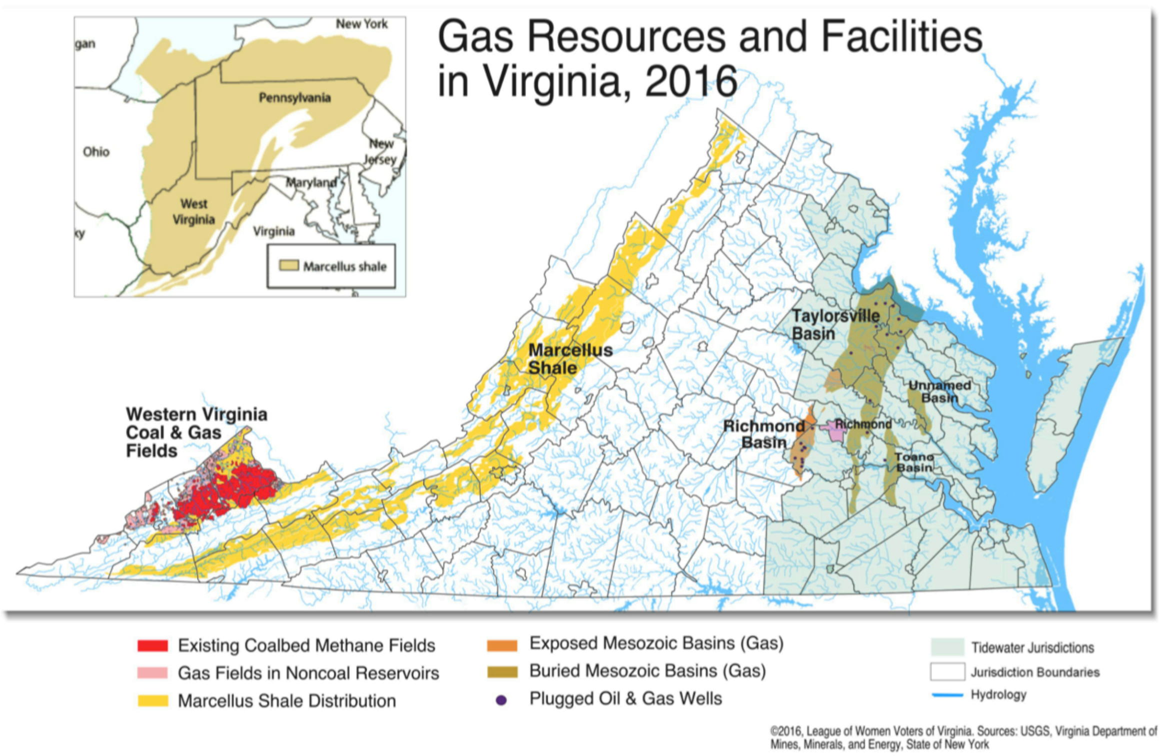

Figure 9- Gas Resources in Virginia

Tidewater Virginia Mesozoic Basins

The Chesapeake Bay Preservation Act § 62.1-44.15:68, defines **Tidewater Virginia** as the darker area shown in Figure 9. Within that area, there are four explored Mesozoic Basins: Taylorsville, Richmond, Toano, and an unnamed basin.

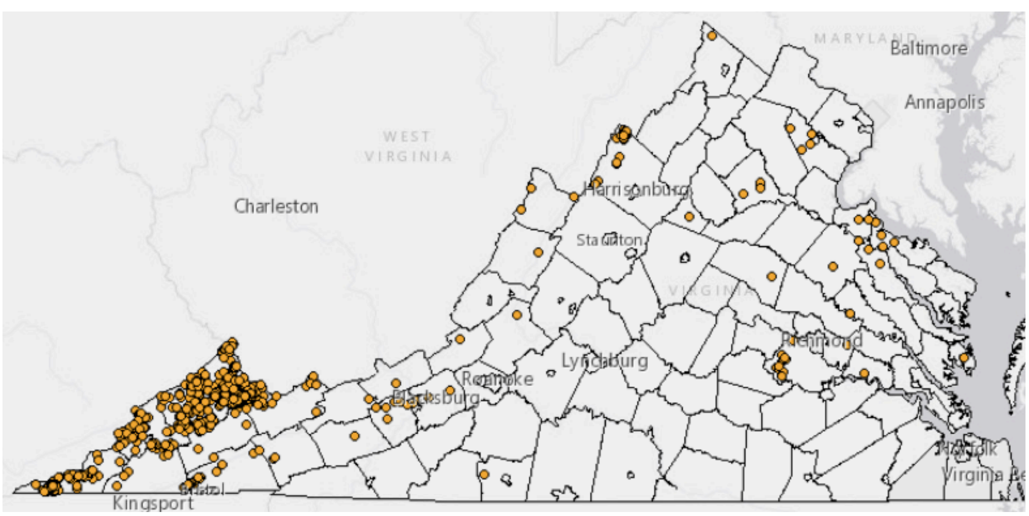

Figure 10- Plugged Wells in Virginia

Taylorsville and Richmond Basins

The Taylorsville Basin runs approximately 108 miles from Richmond to Annapolis, MD. Figure 9 only shows the Virginia portion. The Richmond Basin is located in Chesterfield, Henrico, Powhatan, Goochland, and Amelia counties (the latter three not in Tidewater Virginia). All wells drilled in these two basins from 1917-1992 were abandoned since they did not indicate viable flows of gas.[13] Figure 10[16] shows the known plugged wells in Virginia.

In 2011, a USGS Assessment[17] estimated that the Taylorsville and Richmond basins contained:

Basin	Natural Gas (Trillion cubic feet)	Liquid Natural Gas (ethane, butane, etc.)
Taylorsville	1 Tcf	37 million barrels
Richmond	0.2 Tcf	11 million barrels

In comparison, US Energy Information Administration (USEIA) estimates the Marcellus has 410 Tcf of gas.[18] The advances in fracking technology and USGS's assessment have revived interest in the area.

Shore Exploration & Production Corp. opened a field office in Caroline County and paid over $1.26 million to secure more than 84,000 acres of land in leases (Figure 11[19]). The approximate acreage per county is:

- Caroline (40,000 acres)
- Essex (13,000 acres)
- King and Queen (6,000 acres)
- King George (10,000 acres)
- Westmoreland (14,000 acres).

Landowners are only getting $15 an acre, but if a well becomes productive, they could receive $400,000 a year in royalties.[20] The leases are for 7 years; many were signed in 2011.

Shore Exploration officials have stated that they will sell the leases to a larger company. That company will apply for permits and determine the drilling methods to be used.[21]

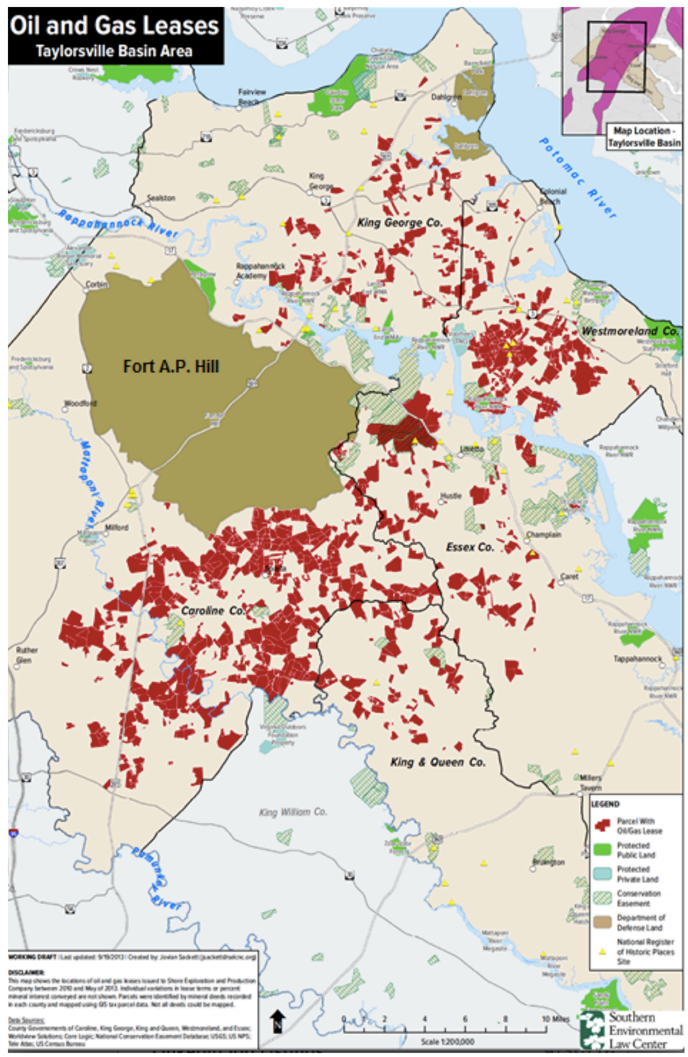

Figure 11- Taylorsville Basin Oil and Gas Leases (in red) as of 9/19/2013

Part III: What Laws and Regulations Govern Fracking?

1. Federal

Fracking is largely exempt from most federal environmental legislation, leaving the job of regulating to the states.

Fracking Exemptions to Federal Policies[22]

Act	Purpose	Fracking Exemption
Clean Air Act of 1963	Control air pollution at the federal level.	Treats each individual well as a source of pollutants and does not require well operators to consider the aggregate impact of many wells in a specific area.
National Environmental Policy Act of 1969	Requires federal agencies to conduct environmental assessments of federal actions.	Energy Policy Act of 2005 excludes oil and gas drilling from NEPA.
Clean Water Act of 1972	Ensure that surface waters meet minimum pollution standards.	Fracking fluids are exempt from classification as pollutants even though more common pollutants such as storm run-off are included.
Safe Water Drinking Act of 1974	Protect the quality of the country's groundwater and drinking water supply.	Amended in 2005 to exclude injection wells.
Resource Conservation and Recovery Act of 1976	To regulate waste for the protection of human health and the environment.	Waste from oil fields was exempted in 1982.
The Energy Policy Act of 2005	Regulates many aspects of federal energy policy.	Only regulates fracking when diesel fuels are used in the fracking fluids.

Recent Changes to Federal Fracking-Related Regulations

March 2015: The first major federal regulations on hydraulic fracturing were put in place by the Department of the Interior's Bureau of Land Management "to ensure that wells are properly constructed to protect water supplies, to make certain that the fluids that flow back to the surface as a result of hydraulic fracturing operations are managed in an environmentally responsible way, and to provide public disclosure of the chemicals used in hydraulic fracturing fluids."[23]

June 2016: A federal judge struck down the regulations, ruling that, in accordance with the 2005 Energy Policy Act, the Bureau of Land Management doesn't have the authority to establish rules over fracking.[24]

May 2016: The Environmental Protection Agency (EPA) issued three rules to curb fracking emissions.[25]
August 2016: 15 states sue to block those standards.[26]

June 2016: The EPA banned unconventional oil and gas extraction wastewater from municipal sewage plants, citing the inability of these plants to handle toxic and radioactive pollutants.[27]

2. The States

- Massachusetts and Vermont (states without shale resources), and New York have banned fracking.[28]
- Maryland has a moratorium in place until October 2017. On September 26, 2016 Maryland unveiled the country's "most stringent" fracking regulations; environmentalists and fracking opponents in the state legislature say they will try to prohibit fracking altogether, while the moratorium is still in place.[29]
- North Carolina, Oklahoma, and Texas have passed restrictions on local communities' ability to limit fracking.[28]
- The Delaware Basin River Commission (Delaware, New Jersey, New York, Pennsylvania) has had a de facto moratorium on gas drilling there since 2010, but in May 2016 a complaint was filed in federal district court.[30]

3. Virginia

In Virginia, all oil and gas operators must comply with:[31]

The Virginia Gas and Oil Act of 1990
Virginia Gas and Oil Regulation
Virginia Gas and Oil Board Regulations
State Water Control Law
Virginia Pollution Discharge Elimination System Regulations
Additional requirements for the Tidewater Region (see Figure 9 for boundaries)

A Southern Environmental Law Center attorney said a 2013 survey found that Virginia had, and will continue to have, the least stringent regulations of states with shale gas production, at least until its rules are updated.[32]

Who has regulatory authority over natural gas and oil wells in Virginia?

- **Virginia Department of Mines Minerals and Energy (DMME)** is the regulatory authority for statewide gas and oil permitting and operations. DMME's mission is to enhance the development and conservation of mineral resources in a safe and environmentally sound manner to support a more productive economy.
- **Division of Gas and Oil,** a division of DMME, is responsible for regulating the effects of gas and oil operations both on and below the surface, issuing permits, client assistance programs, inspection of well sites and gathering pipelines, reclamation of abandoned well sites, protection of correlative rights [receiving an equitable share of a resource pool such as water or gas], and promotion of resource conservation practices.
- **Virginia Gas and Oil Board**, the Division's governing body is composed of a Director, one representative from the gas or oil industry; one from the coal industry; and four who cannot represent those industries.
- **State Corporation Commission** has jurisdiction over interstate pipelines and gas storage.
- **Virginia Department of Environmental Quality** (DEQ) administers state and federal laws and regulations for air quality, water quality, water supply and land protection.

Recent Changes to Virginia's Fracking-Related Regulations	
2013	DMME initiated a regulatory action to review its existing Gas and Oil Regulation.
Feb 2014	The General Assembly killed: SB48, "Eastern Virginia Groundwater Management Area; prohibition on oil and gas drilling" which allowed for drilling for oil and gas only if DEQ standards were met.
Aug 2014	DMME and DEQ signed a Memorandum of Agreement[33] outlining special requirements for wells drilled in the Tidewater region.
Oct 2015	New Gas and Oil Regulations were published. In summary, DMME "proposes to (i) amend permit application requirements to include disclosure of all ingredients anticipated to be used in hydraulic fracturing operations, certification that the proposed operation complies with local land use ordinances, inclusion of a groundwater sampling and monitoring plan, and submission of an emergency response plan; (ii) require a pre-application meeting jointly conducted by the DMME and the Department of Environmental Quality before an operator drills for gas or oil in Tidewater Virginia; (iii) require well operators to use FracFocus, the national hydraulic fracturing chemical registry website, to disclose the chemicals used in hydraulic fracturing operations; (iv) establish a groundwater sampling, analysis, and monitoring program before and after well construction; (v) add language related to the use of centralizers in the water protection string of the casing; (vi) strengthen casing and pressure testing requirements for well casings used in conventional and coalbed methane gas wells; and (vii) provide protection for trade secrets from public dissemination while allowing this information to be made available to first responders and local officials in the event of an emergency."[34]

2016	DMME asked STRONGER (State Review of Oil and Natural Gas Environmental Regulations) for a Follow-Up Review of Virginia regulations. STRONGER also held public hearings. STRONGER anticipates publishing the review in December 2016. (An Initial Review was done in 2004. STRONGER is a 501(c)3 nonprofit whose Board is comprised of equal representation from the oil and gas industry, state oil and gas environmental regulatory agencies, and the environmental public advocacy community.)
Aug 2016	The new Gas and Oil Regulations were submitted for final executive branch approval; there is no timeline, but approval is expected this year.
Sept 2016	Gas industry pushes for delay in Virginia's regulations so the General Assembly can pass a Freedom of Information Act exemption for fracking chemicals.[35] HB1389 continued from 2016 Legislative Session.

Recent Developments on Local Regulatory Authority	
Jan 2013	Virginia Attorney General Ken Cuccinelli issued an opinion that stated "a local governing body cannot ban altogether the exploration for, and the drilling of, oil and natural gas within the locality's boundaries."[36]
May 2015	Virginia Attorney General Mark Herring issued an opinion that stated "Localities may use their zoning authority to prohibit "unconventional gas and oil drilling," commonly known as fracking."[37]
Aug 2016	The King George Board of Supervisors voted to amend their zoning ordinance and Comprehensive Plan, prohibiting drilling within 750 feet from resource protected areas, such as rivers and creeks, as well as roads, buildings and schools, making only 9 percent of the county potentially eligible for drilling.[38]

Part IV: The Pros And Cons of Fracking?

In the *Yale Climate Connection*, John Wibhey wrote a brief guide to the pros and cons of fracking.[39] His summations of the issues are in italics in this section. Below each are the findings of the Fracking Study Committee.

1. Drinking water

"ISSUE: Fracking may threaten human health by contaminating drinking water supplies.

PRO FRACKING: It is highly unlikely that well-run drilling operations, which involve extracting oil and gas from thousands of feet down in the ground, are creating cracks that allow chemicals to reach relatively shallow aquifers and surface water supplies. Drinking water and oil and gas deposits are at very different levels in the ground. To the extent that there are problems, we must make sure companies pay more attention to the surface operations and the top 500 to 1,000 feet of piping. But that's not the fracking – that's just a matter of making sure that the steel tubing, the casing, is not leaking and that the cement around it doesn't have cracks. Certain geologies, such as those in Pennsylvania's Marcellus Shale region, do require more care; but research has found that between 2008 and 2011, only a handful of major incidents happened across more than 3,500 wells in the Marcellus. We are learning and getting better. So this is a technical, well-integrity issue, not a deal-breaker. As for the flammable water, it is a fact that flammable water was a reality 100 years ago in some of these areas. It can be made slightly worse in a minority of cases, but it's unlikely and it is often the result of leaks from activities other than fracking. In terms of disclosure, many of the chemicals are listed on data sheets available to first-responders. The information is disclosed to relevant authorities.

CON FRACKING: This April [2015], yet another major study, published in the Proceedings of the National Academy of Sciences, confirmed that high-volume hydraulic fracturing techniques can contaminate drinking water. There have been numerous reports by citizens across the country of fouled tap water; it is a fact *that some of the tap water has even turned bubbly and flammable, as a result of increased methane. Well blowouts have happened, and they are a complete hazard to the environment. The companies involved cannot be trusted, and roughly one in five chemicals involved in the fracking process are still classified as trade secrets. Even well-meaning disclosure efforts such as FracFocus.org do not provide sufficient information. And we know that there are many who cut corners out in the field, no matter the federal or state regulations we try to impose. They already receive dozens of violation notices at sites, with little effect. We've created a Gold Rush/Wild West situation by green-lighting all of this drilling, and in the face of these economic incentives, enforcement has little impact."*[39]

Fracking Study Committee's Findings on Water

Water-based fracking has several limitations. The most obvious is the need for large quantities of water, especially in areas where water is scarce. In addition, the wastewater that returns to the surface must be treated or disposed of.

Chemicals in Fracking Fluids

Chemicals are added to fracking fluids to control viscosity, and prevent build-up of particulates, fouling, and corrosion of pipes. Each well requires a unique blend of these components that depend upon the type of rock, the material being extracted, and the flowback viscosity desired, but a typical ratio would be ~90% water: ~9.5% proppant: ~0.5% chemicals. From 2005-2009, 29 known or possible human carcinogens regulated under the Safe Drinking Water Act, or listed as hazardous air pollutants were used in 650 out of 2500 fracking products.[40] Fracfocus.org is a website where fracking operators are required by some states to post their ingredients (though not their quantities). DMME has recommended that VA require posting on this website. (FracFocus.org has two informative tables, *Why Chemicals Are Used,* and *What Chemicals Are Used*; appended to this study.)

Wastewater disposal[41,42,43]

There are five basic options being used to manage fracking wastewater:

Minimization and recycling/reuse are becoming increasingly popular as the costs of obtaining input water and treating wastewater increase. However, at some point the now highly concentrated waste must be treated.

Wastewater treatment plants: In June 2016, EPA banned wastewater from municipal treatment plants. Treatment is done in centralized treatment plants dedicated to handling brines and industrial waste.

Injection wells: used to place fluids underground for storage or disposal or enhanced recovery. Difficult to treat industrial waste has been disposed of in this manner for many years and it is the method is preferred in the industry. There are six types of injection wells. Class I wells are highly regulated and the EPA has deemed them safe for the disposal of hazardous and non-hazardous waste materials. Class II wells are less tightly regulated are used to inject fluids associated with oil and natural gas production.

Beneficial uses: Brines have been applied to roads for deicing or dust control. This use is decreasing because their efficacy is inferior to commercial products and the contaminants left behind are detrimental to the environment.

Contamination of Drinking Water

In a June 2015 report[44], the EPA concluded that there are above and below ground mechanisms by which hydraulic fracturing activities have the potential to impact drinking water resources. These mechanisms include

- water withdrawals in times of, or in areas with, low water availability;
- spills of hydraulic fracturing fluids and produced water;
- fracturing directly into underground drinking water resources below ground migration of liquids and gases; and
- inadequate treatment and discharge of wastewater.

EPA did not find evidence that these mechanisms have led to widespread, systemic impacts on drinking water resources. In August 2016, the EPA's Scientific Advisory Board noted that while the EPA's analysis on a national level was appropriate, it failed to "recognize that many stresses to surface or groundwater resources… are often localized…These local-level impacts, when they occur, have the potential to be severe."[45]

There is no clear evidence that contamination of drinking water wells is occurring, at least in wells more than 0.6 miles from a fracked well.[46] There remains a concern that, over time, fracking materials from deep wells or faulty casings may find its way into aquifers and wells by travelling through underground channels. Methane gas has been reported in some drinking water wells. However, where carefully investigated, the cause seems to be old oil/gas wells that were abandoned many years ago and improperly sealed. "The number of abandoned wells nationwide is…unknown…abandoned wells are especially worrisome in areas where Marcellus shale drilling is now under way, because aquifers can be contaminated when new drilling and fracking forces toxic materials up old corroded abandoned wells and into underground drinking water supplies."[47] The issue of abandoned wells is discussed in a later section.

Surface water contamination: Accidents or spills from wastewater storage pits (Figure 12[48]) have been minimal and transient because the contaminants present in most produced water have low mobility, solubility, and volatility. These contaminants do not, in general, spread far from the spill site, allowing for feasible cleanup with minimal long-range effects. As has been observed where monitored, more volatile or soluble contaminants are present as such a low percentage of the total that they quickly disperse to non-harmful levels. Contaminants of concern include (1) salts, (2) hydrocarbons (oil and grease), (3) inorganic and organic additives, and (4) naturally occurring radioactive material (NORM). Because the chemicals used in any given well are a unique mixture, each spill must be treated for its specific contaminants. Careful monitoring and rapid cleanup when warranted are essential.

Figure 12- Fracking site with wastewater storage pit

Tidewater Virginia is part of the North Atlantic Coastal Plain Aquifer System. In addition, four of Virginia's major rivers: Potomac, Rappahannock, York and James, run through the region. Special consideration must be given to protecting this region's water resources.

Alternatives to Water-Based Fracking

Three main alternatives to water are being tried: Liquid Propane Gas (LPG), Carbon Dioxide (CO_2), and Nitrogen (N_2). The two that are being most seriously pursued are CO_2 and N_2. These are either being used to substitute for water in specialized circumstances, or more commonly to "energize" water-based fluids. Energized fluids contain one or more compressible gas phases. The use of energized fluids can increase recovery by as much as 1.5-2.1 times, while simultaneously decreasing the amounts of both water and additives required.[49]

CO_2 has been used as an energizer in some wells, particularly in areas where CO_2 pipelines already exist. It is highly soluble in water, has a similar density, and is miscible in hydrocarbons. These properties allow for enhanced mobility and recovery of product. Because the density of CO_2 is similar to that of water, the same equipment can be used to inject these two materials.

N_2 gas fracking has a number of advantages. Some or all of the fracking fluid is replaced by N_2. N_2, a gas at room temperature, can be converted to a liquid under increased pressure and decreased temperature. When the ultra-cold N_2 hits the rock, it causes fractures to form. When the pressure is released, N_2 converts back to its gaseous phase enhancing the fracking ability of the injected material and helping release trapped oil and/or gas. Additionally, N_2 does not cause the swelling that water-based technologies do, so the fracked fissures remain open.[50] The viscosity of the injection fluid can be varied by adjusting the amount of N_2 used. These properties significantly increase the amount of fracked material able to be recovered. As ~78% of the air we breathe is N_2, this gas is relatively non-toxic, and can be released directly into the atmosphere, minimizing the amount of produced waste to be treated and disposed. However, because it has a lower density that water, N_2 needs to be pumped at higher pressures, necessitating the use of specialized equipment.

There are three main ways in which N_2 is currently being used in fracking:

(1) Pure N_2 gas fracking: For wells < 5000 ft deep and of light sands, shales, or coalbed methane.
(2) N_2 foam fracking: N_2 is mixed with water and other additives, then cooled to form a dense foam-like fluid. N_2 makes up 53-95% of the fluid, depending upon the proppant used and the nature of the shale being fracked. This material can be used at greater depths than pure N_2.
(3) N_2 energized fracking: <53% N_2 is used to energize a more standard water-based fracking fluid to increase the flow-back and fracking efficiency of deep wells.

N_2 foam fracking is currently being used in Southwest Virginia and has been proposed for use in the Taylorsville basin by Shore Exploration. However, if Shore sells its leases, the new owner would determine the fracking methods to be used.

2. Earthquakes: Seismic worries

"ISSUE: Fracking wells, drilled thousands of feet down, may change geology in a potentially negative way, leading to earthquakes.

PRO FRACKING: Earthquakes are a naturally occurring phenomenon, and even in the few instances where fracking operations likely contributed to them, they were minor. We've had tens of thousands of wells drilled over many years now, and there are practically zero incidents in which operations-induced seismic effects impacted citizens. There's also research to suggest that the potential for earthquakes can be mitigated through safeguards.

CON FRACKING: We are only just beginning to understand what we are doing to our local geologies, and this is dangerous. The 2014 Annual Reviews of Environment and Resources paper notes that "between 1967 and 2000, geologists observed a steady background rate of 21 earthquakes of 3.0 Mw or greater in the central United States per year. Starting in 2001, when shale gas and other unconventional energy sources began to grow, the rate rose steadily to [approximately] 100 such earthquakes annually, with 188 in 2011 alone." New research on seismology in places such as Texas and Oklahoma suggests risky and unknown changes. It is just not smart policy to go headlong first – at massive scale – and only later discover the consequences."[39]

Fracking Study Committee's Findings on Seismic Activity

There have been several comprehensive studies[51, 52, 53] showing that earthquakes are not directly caused by fracking, but are caused by the rapid injection of fluids into wastewater injection wells, inducing high pressure that destabilizes fragile existing fault lines. Furthermore, this pressure differential can be exaggerated if large volume water withdrawals occur nearby. Injection into less fragile rock formations have not been associated with subsequent earthquakes. By regulating the location, depth, and rate of waste fluid injection and by establishing overall limits on pressure differences within a field, associated earthquakes may be minimized.

According to the EPA, in 2016 there were 14 Class II injection wells in Virginia, all in the southwestern counties of Dickenson and Buchanan.[54] Class II wells are used only to inject fluids associated with oil and natural gas production, primarily produced water. The EPA's Underground Injection Control Program governs injection well activity in Virginia.

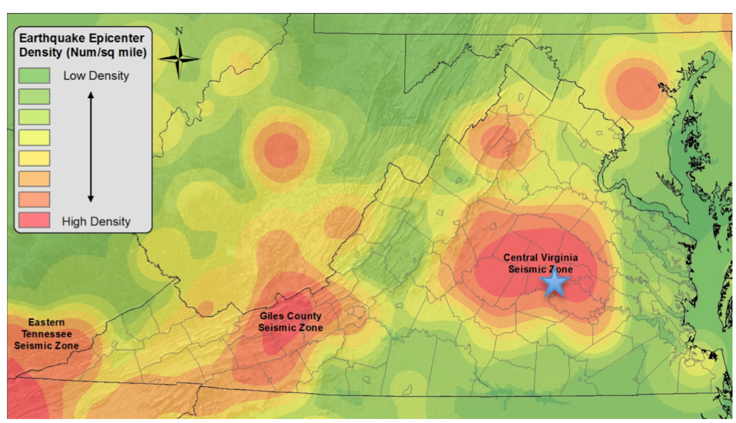

Figure 13- Virginia's Seismic Zones- approximate location of Richmond Basin indicated by star

The Richmond Basin is located within the Central Virginia Seismic Zone (Figure 13[55]). Before the 2011 earthquake centered in Louisa County, the active fault lines in Virginia had never been mapped. In 2014, Virginia received a grant from FEMA to map the fault lines; the work is expected to be completed this year. The implications of allowing fracking, injection wells and pipelines in an active seismic zone need to be considered.

3. Greenhouse gas leaks, methane and fugitive emissions

"ISSUE: The extraction process results in some greenhouse gas emissions leakage.

PRO FRACKING: We know that, at the power plant level, natural gas produces only somewhere between 44 and 50 percent of the greenhouse gas emissions compared with burning of coal. This is known for certain; it's basic chemistry. That is a gigantic benefit. Further some research that claims methane is so harmful uses a 20-year time horizon; but over a 100-year time horizon – the way we generally measure global warming potential – methane is not nearly so harmful as claimed. Thus, methane's impact is potent but relatively brief compared with impacts of increased carbon dioxide emissions. The number-one priority must be to reduce the reliance on coal, the biggest threat to the atmosphere right now. Fears about emissions leaks are overblown. Even if the true leakage rate were slightly more than EPA and some states estimate, it is not that dramatic. We are developing technology to reduce these leaks and further narrow the gap. Moreover, research-based modeling suggests that even if energy consumption increases overall, the United States still will reap greenhouse benefits as a result of fracking.

CON FRACKING: Research from Cornell has suggested that leaked methane – a powerful greenhouse gas – from wells essentially wipes out any greenhouse gas benefits of natural gas derived from fracking. And at other points in the life cycle, namely transmission and distribution, there are further ample leaks. Falling natural gas prices will only encourage more energy use, negating any "cleaner" benefits of gas. Finally, there is no question that the embrace of cheap natural gas will undercut incentives to invest in solar, wind, and other renewables. We are at a crucial juncture over the next few decades in terms of reducing the risk of "tipping points" and catastrophic melting of the glaciers. Natural gas is often seen as a "bridge," but it is likely a bridge too far, beyond the point where scientists believe we can go in terms of greenhouse gas levels in the atmosphere."[39]

<u>Fracking Study Committee's Findings on Greenhouse Gases</u>

"Methane, the key constituent of natural gas, is a potent greenhouse gas (GHG) with a global warming potential more than 25 times greater than that of carbon dioxide. Methane is the second most prevalent GHG (Figure 14[56]) emitted in the United States from human activities, and nearly one-third of those emissions comes from oil production and the production, transmission and distribution of natural gas."[57] Estimates of methane leakage vary from 1 - 12%; the EPA is seeking innovative strategies that can accurately and cost-effectively locate, measure and mitigate methane emissions. The gas industry points out that methane emissions have gone down, even as the amount of gas produced has increased (Figure 15[58]). Carbon dioxide is the most prevalent greenhouse gas; in comparison to other fossil fuels, natural gas's emissions are low (Figure 16[59]).

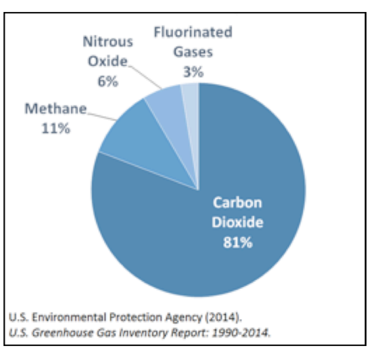

Figure 14- US Greenhouse Gas Emissions in 2014

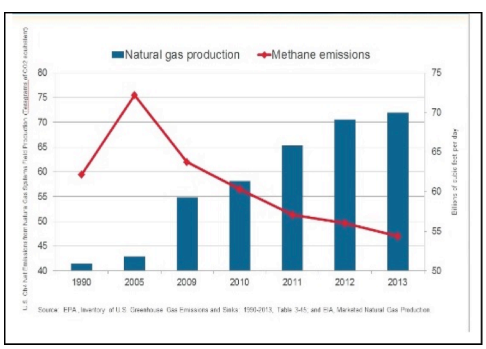

Figure 15- Methane emissions are falling even as natural gas production is increasing

Pounds of CO_2 emitted per million British thermal units (Btu) of energy for various fuels:	
Coal (all types)	210.2
Asphalt and Road Oil	166.7
Diesel fuel & heating oil	161.3
Gasoline	157.2
Jet Fuel	156.3
Propane	139.0
Natural gas	117.0
Municipal Solid Waste	91.9
Geothermal (average all)	17.0

Figure 16- Different fuels emit different amounts of carbon dioxide (CO2) in relation to the energy they produce when burned. To analyze emissions across fuels, compare the amount of CO2 emitted per unit of energy output or heat content.

In May 2016, the EPA issued three rules to curb emissions of methane, smog-forming volatile organic compounds (VOCs), and toxic air pollutants such as benzene.[25] These rules only apply to new, reconstructed and modified oil and gas sources. The EPA has also begun the process of regulating emissions from existing sources. In August 2016, 15 states sued the EPA over the new standards.[60]

In August 2016, the 7th Circuit US Court of Appeals affirmed a 2014 Department of Energy rule that , for the first time, set energy efficiency standards by using the social cost of carbon as part of its cost-benefit analysis--justifying the rule in part because of the amount of climate change regulators believe it would avoid.[61]

4. Infrastructure, resources, and communities

"ISSUE: Fracking operations are sometimes taking place near and around populated areas, with consequences for the local built and natural environments.

PRO FRACKING: Water intensity is lower for fracking than other fossil fuels and nuclear: Coal, nuclear and oil extraction use approximately two, three, and 10 times, respectively, as much water as fracking per energy unit, and corn ethanol may use 1,000 times more if the plants are irrigated. For communities, the optics, aesthetics, and quality of life issues are real, but it's worth remembering that drilling operations and rigs don't go on forever – it's not like putting up a permanent heavy manufacturing facility. The operations are targeted and finite, and the productivity of wells is steadily rising, getting more value during operations. Moreover, the overall societal benefits outweigh the downsides, which are largely subjective in this respect.

CON FRACKING: More than 15 million Americans have had a fracking operation within a mile of their home. Still, that means that a small proportion of people shoulder the burden and downsides, with no real compensation for this intrusive new industrial presence. Fracking is hugely water-intensive: A well can require anywhere from two- to 20-million gallons of water, with another 25 percent used for operations such as drilling and extraction. It can impact local water sources. The big, heavy trucks beat up our roads over hundreds of trips back-and-forth – with well-documented consequences for local budgets and infrastructure. In places such as Pennsylvania, Ohio, and Colorado, the drilling rigs have popped up near where people have their homes, diminishing the quality of life and creating an industrial feel to some of our communities. This is poor planning at best, and sheer greed at its worst. It seldom involves the preferences of the local residents.

Finally, it's also the case that relatively low impact fees are being charged and relatively little funding is being set aside to mitigate future problems as wells age and further clean-up is necessary. It is the opposite of a sustainable solution, as well production tends to drop sharply after initial fracking. Within just five years, wells may produce just 10 percent of what they did in the first month of operation. In short order, we're likely to have tens of thousands of sealed and abandoned wells all over the US landscape, many of which will need to be monitored, reinforced, and maintained. It is a giant unfunded scheme."[39]

Fracking Study Committee's Findings on Infrastructure, Resources and Communities

Communities

Most proposed gas drilling projects are located in rural areas where a ready supply of fresh water is essential to agriculture, tourism, sport fishing, hunting and manufacturing. "Drilling accidents…can have a profound impact on these industries, and the boom-bust cycle of energy extraction can irreparably change the way of life in rural communities."[62] Local governments should monitor: population growth & worker residency patterns; employment, personal income, and local business effects; cost of living and housing; service, infrastructure, capacity, and revenue; quality of life and other local concerns.[63] In Pennsylvania, fracking has brought a number of transient workers and a host of social problems including disorderly conduct arrests and public health issues like sexually transmitted diseases.[64] "Monitoring can help local governments better understand the socioeconomic impacts caused by energy development, and support requests to industry and state government for assistance to implement appropriate mitigation. Effective monitoring also is an essential part of adaptively managing drilling activity to minimize negative impacts while maximizing benefits."[65]

"Because of the immense value of these energy sources, the landowners who have property rights over them become tremendously wealthy, while the working class people who keep the oil rigs running do not."[66]

Eventually, the natural gas will run out and landowners may find that the value of the property, the ability to insure it, and to mortgage it, may all be negatively impacted. A 2008 study of western counties that have relied on fossil fuel extraction for growth shows that they are doing worse economically than their peers, with less-diversified economies, a less-educated workforce, and greater disparities in income.[67]

Short-Term Benefits and Costs

Benefits:	**Costs:**
Local government revenue: Property, sales and severance taxes Jobs creation: Goods and services suppliers-- healthcare, amusement, food, merchandise Construction Oil and gas extraction Environmental hydro-geologists Ecologists Drill site managers Pipeline engineers Metal fabrication Truck transport Financial, administrative, HR, IT, legal Real estate Sales managers	Local government costs: Increased demand for public services Police, emergency and medical personnel, and other government workers Road repair associated with truck traffic Sewer and water services associated with industry-driven population growth Raising compensation to compete with high-paying jobs in the oil and gas sector Other costs: Negative effect on other businesses, property values, current land uses Land remediation Water pollution treatment Noise Traffic and accidents Night-time lighting Demand on water supplies Demand on housing supply Air pollution

Transportation Infrastructure

For each well, trucks must haul in gravel, pipes, water, and chemicals, then haul out liquid fuels and waste — anywhere from 600 to 1,000 one-way trips for the fracking phase alone.[68] A 2014 study[69] analyzed the damage on local transportation infrastructure in the Marcellus in Pennsylvania and found that:

- Local roads are generally designed to support passenger vehicles, not heavy trucks. Heavier vehicles cause exponentially greater roadway damage: a 30,000-pound single-axle does 7,500 times more damage than a 3,000-pound single axle pass.
- The estimated road reconstruction costs associated with a single horizontal well range from $13,000 to $23,000.
- In 2011, the estimates of fracking-related road costs paid by state transportation authorities, and thus taxpayers, ranged up to $39 million.

The study suggested potential approaches including an additional fee or tax on top of current per-well impact fees, limiting truck size and weight, and encouraging the use of pipelines rather than trucks.

Other traffic-related issues that need to be considered include road congestion, vehicle noise, diesel air pollution, and accidents. Accidents can involve direct injury and damage to property, or accidental spillage of materials or chemicals. Heavy-truck crashes rose 7.2% in heavily fracked rural Pennsylvania counties (with at least one well for every 15 square miles) but fell 12.4% in unfracked rural counties after fracking began in 2005.[64] "An Associated Press analysis of traffic deaths…in six drilling states shows that in some places, fatalities have more than quadrupled since 2004 — a period when most American roads have become much safer…The industry acknowledges the problem, and traffic agencies and oil companies say they are taking steps to improve safety."[70]

Taxes, fees and revenue

Fracking can increase local government revenue through increases in taxes. The primary revenue streams from fracking—mineral leasing revenues and severance taxes—go to state and federal governments. Mineral leasing revenue is the income generated by those who lease their property to oil and gas developers. Severance taxes are intended to compensate present and future citizens of the state from which natural resources were extracted ("severed") for the loss of those natural resources. As of June 2013, Virginia employed the following city and county license taxes on severed resources:

- 1.5% gross severance tax on oil
- 1% on gross severance tax on coal or gas
- Counties and cities can levy an additional maximum 1% gross tax on gas
- Cities and counties may adopt a maximum 1% gross tax on every person engaged in the business of severing coal or gas.

The revenue collected from an additional gas tax is deposited in the general fund of the respective county or city. Revenue from an additional county or city coal or gas tax is deposited into the Coal and Gas Road Improvement Fund. Areas that comprise the Virginia Coalfield Economic Development Authority have 75 percent of their tax deposited into the Coal and Gas Road Improvement Fund and 25 percent deposited into the Virginia Coalfield Economic Development Fund. In FY 2014, Virginia collected almost $2.2 million in severance taxes, which accounted for 0.01 percent of Virginia's tax revenue."[14]

Financial Assurance

Most states, including Virginia, require financial assurance only for the costs of plugging a well and reclaiming the site. This leaves communities at risk of having to pay for any infrastructure, health, and environmental damages that might emerge.

There are several types of financial assurance:

- Surety bonds: a commitment by a third party (surety) to meet the financial obligations of the driller; provisions must be in place in the event that the surety company goes out of business.
- Personal or collateral bonds: backed by cash or cash equivalents.
- Trust funds: a dedicated pot of money, often paid into over time; effective only if fully funded when needed.
- Insurance: driller only pays a premium, shifting responsibility to insurer whose policy may have a maximum liability; provisions must be in place to assure the driller continues to pay the premium.
- Financial tests: do not guarantee that funds will be available when needed, only that driller financially capable at the time of the test.

Blanket bonding is a maximum bonding requirement that covers all drilling by a company within a particular jurisdiction.

The Code of Virginia § 45.1-361.31 Bonding and financial security required, has the following requirements for financial assurance:

- Surety or cash bond of no less than $10,000 per well plus $2,000 per acre of disturbed land.
- In lieu of separate bonds for each well, the Director of the Gas and Oil Board may require a blanket bond in the following amounts:
    1. For one to fifteen wells, $25,000.
    2. For sixteen to thirty wells, $50,000.
    3. For thirty-one to fifty wells, $75,000.
    4. For fifty-one or more wells, $100,000.
- Each gas or oil operator who elects to post a blanket bond shall pay into the Gas and Oil Plugging and Restoration Fund a fee of $50 per permit held annually, until the payments and interest accruing to the Fund totals $100,000.
- Disbursements from the Fund shall be used only to pay for the full cost of plugging and restoration in the event of a blanket bond forfeiture.
- When the Fund's balance has fallen below $25,000, the Director shall assess a fee of fifty dollars per permit per year on all permittees with blanket bonds until the Fund's balance once again reaches $100,000.
- Each operator who applies for a new permit shall pay a $50 surcharge per permit into the Orphaned Well Fund.

The Environment America Policy and Research Center [71] recommends a minimum level for a plugging and reclamation bond of $250,000 per well, noting that the average cost in Pennsylvania's Marcellus shale is $100,000 per well and that three well sites cost $700,000+ each. They also suggest that bond amounts be indexed to inflation and that blanket bonding be eliminated. In addition to plugging and reclamation, they recommend that financial assurances also cover:

- Full restoration of damage to the environment and natural resources
- Compensation for damage to property and health
- Provision of alternative sources of drinking water and other temporary measures to mitigate the impact of environmental, health and property damage
- Full restoration of damage to public infrastructure, such as roads [some states do require road bonds].

Abandoned, Orphaned and Inactive Wells

From the first well in 1859 to the 1960s, when a well stopped producing, it was usually abandoned by its owners. Wells were rarely plugged, and only sometimes were wellheads and piping taken out for scrap metal. These wells, called **orphaned wells**, are environmental dangers--they provide pathways for methane, oil, gas or brine to contaminate groundwater or to travel up to the surface. Fracking exacerbates this by increasing underground pressure and causing gas and fluids to leak from nearby abandoned wells, a phenomenon called communication.[72] Orphaned wells do not have any responsible party to plug them. States bear the burden of locating and decommissioning these wells. Virginia currently defines orphaned wells as those abandoned prior to July 1, 1950, or for which no records exist concerning drilling, plugging or abandonment. DMME has asked the citizens of Virginia to help locate them[73], and an Orphaned Well Fund (Code of Virginia § 45.1-361.40) administered by Division of Gas and Oil has been established. When sufficient funds are available, the orphaned wells deemed the greatest risk to public safety or the environment are plugging and restored.

Abandoned wells are those no longer in use, whether dry, inoperable or no longer productive. Upon the abandonment or cessation of the operation of any well, the Code of Virginia § 45.1-361.34 requires the operator to immediately fill and plug the well in the manner required by regulations in force at the time of abandonment. This is followed by reclamation (restoration) of the site, at which point the financial assurance provided by the operator is released.

Inactive wells have ceased production but have not been abandoned and plugged, possibly because the decommissioning cost is more than the cost of relinquishing the bond, or perhaps to wait for re-fracking at a later time, or until market prices or technology improves. Even if a well has a responsible operator, it may represent an environmental risk due to failure to comply with current standards, or communication from nearby fracking.

The issues associated with orphaned, abandoned and inactive wells apply to all well types, conventional and unconventional. Although the locations of modern abandoned and inactive wells are known, the costs to be borne by the communities and taxpayers are unclear. The life expectancy of the cement plugs used to decommission the wells is unknown, and this may put the state and communities in the position of caring for a new generation of orphaned wells.

5. Air quality, health, and the energy menu

"ISSUE: The new supply of natural gas reachable by fracking is now changing the overall picture for US electricity generation, with consequences for air quality.

PRO FRACKING: Increasing reliance on natural gas, rather than coal, is indisputably creating widespread public health benefits, as the burning of natural gas produces fewer harmful particles in the air. The major new supply of natural gas produced through fracking is displacing the burning of coal, which each year contributes to the early death of thousands of people. Coal made up about 50 percent of US electricity generation in 2008, 37 percent by 2012; meanwhile, natural gas went from about 20 percent to about 30 percent during that same period. In particular, nitrogen oxide and sulfur dioxide emissions have been reduced dramatically. Fracking saves lives, and it saves them right now and not at some indiscernible date well into the future.

CON FRACKING: First, it is not the case that a new natural gas facility coming online always replaces a legacy coal-fired power plant. It may displace coal in West Virginia or North Carolina, but less so in Texas and across the West. So fracking is no sure bet for improving regional air quality. Second, air quality dynamics around fracking operations are not fully understood, and cumulative health impacts of fracking for nearby residents and workers remain largely unknown. Some of the available research evidence from places such as Utah and Colorado suggests there may be under-appreciated problems with air quality, particularly relating to ozone. Further, natural gas is not a purely clean and renewable source of energy, and so its benefits are only relative. It is not the answer to truly cleaning up our air, and in fact could give pause to a much-needed and well thought-out transition to wind, solar, geothermal, and other sources that produce fewer or no harmful airborne fine particulates."[39]

Fracking Study Committee's Findings on Air Quality, Health and the Energy Menu

Air Quality

A study[74] in Pennsylvania in 2011 found that emissions are associated with four shale gas-related activities:

- Diesel and road dust emissions from trucks
- Emissions from well drilling and hydraulic fracturing
- Emissions from the production of natural gas
- Combustion emissions from natural gas powered compressor stations

More than half of emissions damages come from compressor stations, which may serve dozens of individual wells. The study's investigators concluded that regulatory agencies and the shale gas industry, in developing regulations and best practices, should account for air emissions from ongoing, long-term activities and not just emissions associated with development.

Health

The abstract from *The implications of unconventional drilling for natural gas: a global public health concern* states, "Unconventional drilling for natural gas by…(fracking) is an important global public health issue. Given that no sound epidemiologic study has been done to assess …health effects among populations living in areas where natural gas extraction is going on, it is imperative that research be conducted … not just in the short-term, but over a longer time period since many diseases (i.e., cancers) appear years after exposure. It should not be concluded that an absence of data implies that no harm is being done."[75]

From National Institute of Environmental Health Sciences (NIEHS): Does hydraulic fracturing pose health risks to the people living near drilling sites? The short answer is we don't know. Few studies to date have provided conclusive evidence about how unconventional natural gas development affects nearby communities. It may be possible for chemicals to travel into a drinking water source. Drilling sites can potentially affect local air quality in several ways. Most of what is known comes from studies of workers at these sites. Currently, three hydraulic fracturing-specific health risks have been identified:

- Silica sand inhalation can cause lung diseases
- Exposure to chemical spills
- Exposure to high levels of volatile hydrocarbons during flowback operations, which have resulted in the deaths of at least 4 workers since 2010.

NIEHS is investigating the potential health effects.[76]

Renewable Energy

According to US EIA, in 2015, renewable energy sources accounted for about 10% of total US energy consumption and about 13% of electricity generation.[77] In the US, 29 states, DC, and 3 territories have renewable portfolio standards (RPS)[78] that require utility companies to source a certain amount of the energy they generate or sell from renewable sources. These vary widely by state; for example, Vermont's RPS is 75% by 2032 and Arizona's RPS is 15% by 2025. Eight states, including Virginia, and one territory have renewable portfolio goals that set voluntary standards. Virginia gives electric utilities the option to meet a renewable energy target of 15% of electric energy sales by 2025. In the 2016 Legislative Session, SB 761, which would have converted the voluntary goal to a mandatory RPS, was passed by indefinitely. The Virginia Energy Plan (Title 67 of the Code of Virginia) states “it shall be the policy of the Commonwealth to…Support research and development of, and promote the use of, renewable energy sources.” On Sept 22, 2016, the Virginia Energy Efficiency Council released preliminary results of an industry census it says shows that the annual revenue for clean energy businesses in Virginia increased from $500,000 in 2013 to $2.1 billion in 2016.[79]

Part V. Concluding Thoughts

Hydraulic fracturing is a moving target. Every day, new legislation, lawsuits, and technologies are created. Every geology and well requires a different extraction method. Every piece of data has advocates and opponents. Industry, government, and citizens struggle to find a balance that will provide low-cost, environmentally clean energy in quantities that will support our current lifestyles and future energy requirements. The public's right to know, protection and management of natural resources, social and economic justice, and health and safety are all issues to be considered when examining hydraulic fracturing.

Appendix 1: Why Chemicals Are Used[80]

Given today's technology, chemicals must be used in hydraulic fracturing to ensure the producing formation is effectively treated. The chart shown below depicts generic hydraulic fracturing chemical usage including the types of chemicals, their uses in the process and the result of their use.

Additive	Purpose	Downhole Result
Acid	Helps dissolve minerals and initiate cracks in the rock	Reacts with minerals present in the formation to create salts, water, and carbon dioxide (neutralized)
Acid/Corrosion Inhibitor	Protects casing from corrosion	Bonds to metal surfaces (pipe) downhole. Any remaining product not bonded is broken down by micro-organisms and consumed or returned in produced water.
Biocide	Eliminates bacteria in the water that can cause corrosive by products	Reacts with micro-organisms that may be present in the treatment fluid and formation. These micro-organisms break down the product with a small amount of the product returning in produced water.
Base Carrier Fluid (water)	Create Fracture Geometry and Suspend Proppant	Some stays in formation while remainder returns with natural formation water as "produced water" (actual amounts returned vary from well to well)
Breaker	Allows a delayed break down of gels when required.	Reacts with the "crosslinker" and "gel" once in the formation making it easier for the fluid to flow to the borehole. Reaction produces ammonia and sulfate salts which are returned in produced water.
Clay and Shale Stabilization/control	Temporary or Permanent Clay Stabilizer to lock down clays in the shale structure	Reacts with clays in the formation through a sodium - potassium ion exchange. Reaction results in sodium chloride (table salt) which is returned in produced water. Also replaces binder salts like Calcium Chloride helping to keep the formation in tact as the Calcium Chloride dissolves.
Crosslinker	Maintains viscosity as temperature increases	Combines with the "breaker" in the formation to create salts that are returned in produced water
Friction Reducer	Reduces Friction effects over base water in pipe	Remains in the formation where temperature and exposure to the "breaker" allows it to be broken down and consumed by naturally occurring micro-organisms. A small amount returns with produced water.
Gel	Thickens the water in order to suspend the proppant	Combines with the "breaker" in the formation thus making it much easier for the fluid to flow to the borehole and return in produced water
Iron Control	Iron chelating agent that helps prevent precipitation of metal oxides	Reacts with minerals in the formation to create simple salts, carbon dioxide and water all of which are returned in produced water
Non-Emulsifier	Used to break or separate oil / water mixtures (emulsions)	Generally returned with produced water, but in some formations may enter the gas stream and return in the produced natural gas.
pH Adjusting Agent/Buffer	maintins the effectiveness of other additives such as crosslinkers	Reacts with acidic agents in the treatment fluid to maintain a neutral (non-acidic, non-alkaline) pH. Reaction results in mineral salts, water and carbon dioxide which is returned in produced water.
Propping Agent	Keeps Fractures Open allowing for hydrocarbon production	Stays in formation, embedded in fractures (used to "prop" fractures open)
Scale Inhibitor	Prevent Scale in Pipe and Formation	Product attaches to the formation downhole. The majority of product returns with produced water while remaining reacts with microorganisms that break down and consume the product.
Surfactant	Reduce Surface tension of the treatment fluid in the formation and helps improve fluid recovery from the well after the frac is completed	Some surfactants are made to react with the formation, some are designed to be returned with produced water, or, in some formations they may enter the gas stream and return in the produced natural gas.

Appendix 2: What Chemicals Are Used[81]

As previously noted, chemicals perform many functions in a hydraulic fracturing job. Although there are dozens to hundreds of chemicals that could be used as additives, there are a limited number which are routinely used in hydraulic fracturing. The following is a list of the chemicals used most often. This chart is sorted alphabetically by the Product Function to make it easier for you to compare to the fracturing records.

Chemical Name	CAS	Chemical Purpose	Product Function
Hydrochloric Acid	007647-01-0	Helps dissolve minerals and initiate cracks in the rock	Acid
Glutaraldehyde	000111-30-8	Eliminates bacteria in the water that produces corrosive by-products	Biocide
Quaternary Ammonium Chloride	012125-02-9	Eliminates bacteria in the water that produces corrosive by-products	Biocide
Quaternary Ammonium Chloride	061789-71-1	Eliminates bacteria in the water that produces corrosive by-products	Biocide
Tetrakis Hydroxymethyl-Phosphonium Sulfate	055566-30-8	Eliminates bacteria in the water that produces corrosive by-products	Biocide
Ammonium Persulfate	007727-54-0	Allows a delayed break down of the gel	Breaker
Sodium Chloride	007647-14-5	Product Stabilizer	Breaker
Magnesium Peroxide	014452-57-4	Allows a delayed break down the gel	Breaker

Magnesium Oxide	001309-48-4	Allows a delayed break down the gel	Breaker
Calcium Chloride	010043-52-4	Product Stabilizer	Breaker
Choline Chloride	000067-48-1	Prevents clays from swelling or shifting	Clay Stabilizer
Tetramethyl ammonium chloride	000075-57-0	Prevents clays from swelling or shifting	Clay Stabilizer
Sodium Chloride	007647-14-5	Prevents clays from swelling or shifting	Clay Stabilizer
Isopropanol	000067-63-0	Product stabilizer and / or winterizing agent	Corrosion Inhibitor
Methanol	000067-56-1	Product stabilizer and / or winterizing agent	Corrosion Inhibitor
Formic Acid	000064-18-6	Prevents the corrosion of the pipe	Corrosion Inhibitor
Acetaldehyde	000075-07-0	Prevents the corrosion of the pipe	Corrosion Inhibitor
Petroleum Distillate	064741-85-1	Carrier fluid for borate or zirconate crosslinker	Crosslinker
Hydrotreated Light Petroleum Distillate	064742-47-8	Carrier fluid for borate or zirconate crosslinker	Crosslinker
Potassium Metaborate	013709-94-9	Maintains fluid viscosity as temperature increases	Crosslinker
Triethanolamine Zirconate	101033-44-7	Maintains fluid viscosity as temperature increases	Crosslinker
Sodium Tetraborate	001303-96-4	Maintains fluid viscosity as temperature increases	Crosslinker
Boric Acid	001333-73-9	Maintains fluid viscosity as temperature increases	Crosslinker
Zirconium Complex	113184-20-6	Maintains fluid viscosity as temperature increases	Crosslinker
Borate Salts	N/A	Maintains fluid viscosity as temperature increases	Crosslinker
Ethylene Glycol	000107-21-1	Product stabilizer and / or winterizing agent.	Crosslinker
Methanol	000067-56-1	Product stabilizer and / or winterizing agent.	Crosslinker
Polyacrylamide	009003-05-8	"Slicks" the water to minimize friction	Friction Reducer
Petroleum Distillate	064741-85-1	Carrier fluid for polyacrylamide friction reducer	Friction Reducer
Hydrotreated Light Petroleum Distillate	064742-47-8	Carrier fluid for polyacrylamide friction reducer	Friction Reducer
Methanol	000067-56-1	Product stabilizer and / or winterizing agent.	Friction Reducer
Ethylene Glycol	000107-21-1	Product stabilizer and / or winterizing agent.	Friction Reducer
Guar Gum	009000-30-0	Thickens the water in order to suspend the sand	Gelling Agent
Petroleum Distillate	064741-85-1	Carrier fluid for guar gum in liquid gels	Gelling Agent
Hydrotreated Light Petroleum Distillate	064742-47-8	Carrier fluid for guar gum in liquid gels	Gelling Agent
Methanol	000067-56-1	Product stabilizer and / or winterizing agent.	Gelling Agent
Polysaccharide Blend	068130-15-4	Thickens the water in order to suspend the sand	Gelling Agent
Ethylene Glycol	000107-21-1	Product stabilizer and / or winterizing agent.	Gelling Agent
Citric Acid	000077-92-9	Prevents precipitation of metal oxides	Iron Control
Acetic Acid	000064-19-7	Prevents precipitation of metal oxides	Iron Control
Thioglycolic Acid	000068-11-1	Prevents precipitation of metal oxides	Iron Control

Sodium Erythorbate	006381-77-7	Prevents precipitation of metal oxides	Iron Control
Lauryl Sulfate	000151-21-3	Used to prevent the formation of emulsions in the fracture fluid	Non-Emulsifier
Isopropanol	000067-63-0	Product stabilizer and / or winterizing agent.	Non-Emulsifier
Ethylene Glycol	000107-21-1	Product stabilizer and / or winterizing agent.	Non-Emulsifier
Sodium Hydroxide	001310-73-2	Adjusts the pH of fluid to maintains the effectiveness of other components, such as crosslinkers	pH Adjusting Agent
Potassium Hydroxide	001310-58-3	Adjusts the pH of fluid to maintains the effectiveness of other components, such as crosslinkers	pH Adjusting Agent
Acetic Acid	000064-19-7	Adjusts the pH of fluid to maintains the effectiveness of other components, such as crosslinkers	pH Adjusting Agent
Sodium Carbonate	000497-19-8	Adjusts the pH of fluid to maintains the effectiveness of other components, such as crosslinkers	pH Adjusting Agent
Potassium Carbonate	000584-08-7	Adjusts the pH of fluid to maintains the effectiveness of other components, such as crosslinkers	pH Adjusting Agent
Copolymer of Acrylamide and Sodium Acrylate	025987-30-8	Prevents scale deposits in the pipe	Scale Inhibitor
Sodium Polycarboxylate	N/A	Prevents scale deposits in the pipe	Scale Inhibitor
Phosphonic Acid Salt	N/A	Prevents scale deposits in the pipe	Scale Inhibitor
Lauryl Sulfate	000151-21-3	Used to increase the viscosity of the fracture fluid	Surfactant
Ethanol	000064-17-5	Product stabilizer and / or winterizing agent.	Surfactant
Naphthalene	000091-20-3	Carrier fluid for the active surfactant ingredients	Surfactant
Methanol	000067-56-1	Product stabilizer and / or winterizing agent.	Surfactant
Isopropyl Alcohol	000067-63-0	Product stabilizer and / or winterizing agent.	Surfactant
2-Butoxyethanol	000111-76-2	Product stabilizer	Surfactant

One of the problems associated with identifying chemicals is that some chemicals have multiple names. For example ethylene glycol (antifreeze) is also known by the names Ethylene alcohol; Glycol; Glycol alcohol; Lutrol 9; Macrogol 400 BPC; Monoethylene glycol; Ramp; Tescol; 1,2-Dihydroxyethane; 2-Hydroxyethanol; HOCH2CH2OH; Dihydroxyethane; Ethanediol; Ethylene gycol; Glygen; Athylenglykol; Ethane-1,2-diol; Fridex; M.e.g.; 1,2-Ethandiol; Ucar 17; Dowtherm SR 1; Norkool; Zerex; Aliphatic diol; Ilexan E; Ethane-1,2-diol 1,2-Ethanedio.

This multiplicity of names can make a search for chemicals somewhat difficult and frustrating. However, if you search for a chemical by the CAS number it will return the correct chemical even if the name on the fracturing record does not match. For example if the fracturing record listed the chemical hydrogen chloride and you searched for it by name using a chemical search site you may not get a result. But if you search for CAS # 007647-01-0 it might return hydrochloric acid which is another name of hydrogen chloride. Therefore, by using the CAS number you can avoid the issue of multiple names for the same chemical.

Multiple names for the same chemical can also leave you with the impression that there are more chemicals than actually exist. If you search the National Institute of Standards and Technology (NIST) website [http://webbook.nist.gov/chemistry/name-ser.html], the alternate names of chemicals are listed. This may help you identify the precise chemical you are looking for. The NIST site also contains the CAS numbers for chemicals. NIST is only one of many websites you can use to locate additional information about chemicals.

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