Hydraulic Fracturing and its Impact on Renewable Energy Development

Derek Brown
Advisor: Michael Oristaglio
Second Reader: Cary Krosinsky
May 5, 2017

A Senior Essay presented to the faculty of the Department of Geology and Geophysics, Yale University, in partial fulfillment of the Bachelor's Degree.

Abstract

The rise of hydraulic fracturing, or fracking, and the expansion of renewable energy have transformed energy consumption in the United States during the last decade. Easily accessible oil and gas deposits have largely been depleted in the U.S. after more than 150 years of exploration and exploitation. However, fracking, along with new technologies such as horizontal drilling, has emerged as a way to increase extraction efficiency and sustain the country's current oil and gas consumption rates without expanding its imports of these fuels. Widespread use of fracking in the U.S. has allowed access to reserves of natural gas once considered unavailable and led to an excess supply and lower prices. The boom in natural gas for power generation has been viewed as a deterrent to renewable energy sources, though, because of its low cost. It has alternatively been viewed as a necessary transitional energy "bridge" to clean renewable energy sources because of its relatively low carbon-dioxide emissions, especially compared to coal, and its potential to balance the intermittency problems in feeding renewable power onto the grid. This paper evaluates these two perspectives and determines that, when taking cost and environmental detriment into account, the ideal near-term energy distribution in the United States should include a mixture of natural gas and renewable energy sources. A carbon tax will probably need to be implemented to achieve this optimal energy distribution, but is projected to have a significant burden on the populace. This could lead to a drawn out political fight. There should also be government policies or tax incentives to encourage companies to use profits from fossil fuels for renewable energy research and development.

Introduction to Fracking

Hydraulic fracturing, first tested in the 1940s and researched more heavily by the Department of Energy in the 1970s, proved to be a key breakthrough for the natural gas industry (epa.gov, 2015). Previously, oil and gas companies would produce resources above and below shale layers, while the hydrocarbons within the shale remained trapped and untapped. Before the work undertaken by George Mitchell and Mitchell Energy in the 1980s in North Texas, fracking had been used mainly to enhance the production from conventional oil and gas reservoirs, in which the fluids flow naturally under pressure once a well provides a conduit to the surface (Gertner, 2013). Through a process of trial and error that spanned several decades, Mitchell discovered a fracking technique using a mixture of water, sand, and a few chemicals injected under high pressure which proved to be financially viable (Gertner, 2013). Following Mitchell's work, the main enabling technologies of "unconventional" natural gas production—hydraulic fracturing and horizontal drilling—have opened new areas for oil and gas development, with particular focus on reservoirs such as shale source rock and tight (low permeability) sandstones and limestones.

How it works

Hydraulic fracturing produces artificial fractures in rock formations that stimulate the flow of natural gas or oil, increasing the volumes that can be recovered compared to conventional (unstimulated) production. The artificial fractures are created by pumping large quantities of water, mixed with sand and chemicals, down a wellbore and into the target rock formation. Fracking of a typical well along a two-kilometer horizontal leg can use up to 20 million liters of water, and 200,000 liters of acids, biocides, friction reducers, and other chemical additives (epa.gov, 2015). Many of the known additives are toxic, and can cause serious problems if leaked into the drinking water supply (Murrill and Vann, 2012). Some additives are kept secret, to protect proprietary know-how developed by the companies that provide fracking services to their clients. This uncertainty surrounding the chemicals added to the fracking fluid creates an uneasiness that surrounds public perception of fracking and no such law or regulation exists at the federal level (Murrill and Vann, 2012).

After the drilling and fracking processes are completed, anywhere from twenty to eighty percent of the fracking fluid flows back up the well to the surface within a few weeks, with more continuing to flow back throughout the lifetime of the well (usgs.gov, 2014). The liquid that returns to the surface during the first few weeks, known as flowback, as well as the water that comes to the surface later, called produced water, can contain heavy metals and radioactive materials previously trapped in the shale (usgs.gov, 2014). The flowback and produced water is typically stored on site in pits before treatment and disposal, or recycling. In many cases, it is injected underground for disposal in a Class II well, which is used only to inject fluids associated with oil and natural gas production (epa,gov, 2016). Approximately 180,000 Class II wells are in operation in the United States in Texas, California, Oklahoma, and Kansas. These wells fall into three categories: disposal wells, enhanced recovery wells, and hydrocarbon storage wells. It is estimated that over 2 billion gallons of salt water fluid (brine) is injected in the United States every day (epa,gov, 2016). In areas where the use of Class II wells is not an option, fluids associated with oil and natural gas production may be treated and reused or processed by a wastewater treatment facility. The waste water storage wells and potential for drinking water contamination are the biggest environmental concerns of hydraulic fracturing to date, as this mix of water and chemicals can pose risks to ecosystems and public health near drill sites (eia.gov, 2016).

<u>Hydraulic fracturing by the numbers</u>

The number of hydraulically fractured wells drilled nationwide has jumped from 24,000 in 2000 to 300,000 in 2015, according to the U.S. Energy Information Administration (Grape, 2016). Hydraulically fractured wells provided two-thirds of U.S. natural gas production in 2015 — nearly 10 times the amount produced in 2000 (Grape, 2016). In addition to making the U.S. less dependent on foreign sources of oil and natural gas, fracking has delivered an economic boost to many parts of the country.

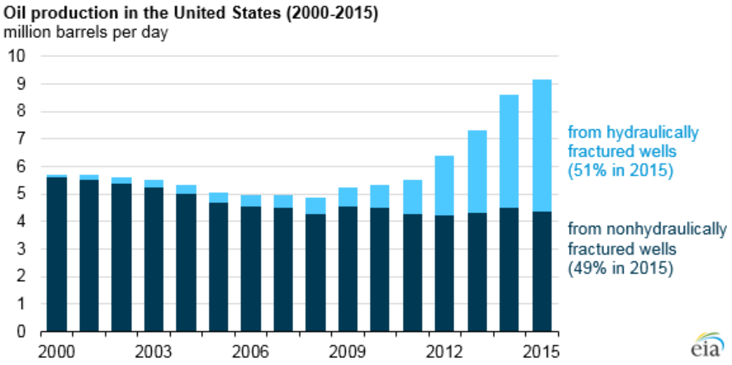


Figure 1. Even though hydraulic fracturing has been used for more than six decades, it has only recently been used to produce a significant portion of crude oil in the United States. Hydraulic fracturing accounts for about half of current U.S. crude oil production (eia.gov, 2015).

But the boost also comes with a cost: in this case, environmental concerns about air and water contamination. If done properly, shale gas development can enhance energy security and the availability of energy fuels, lower natural gas prices, offer a cleaner environmental footprint than some other fossil fuels, and enable local economic development. If executed poorly, however, shale gas development can be prone to accidents and methane leakage, contribute to environmental degradation, and induce earthquakes. This paper will look at the technical, economic, environmental, and social costs and benefits of hydraulic fracturing in assessing its role as a transition fuel to renewable energy.

Here is an outline of the rest of this essay. The next section reviews the conclusions of the major EPA study on the potential impacts of hydraulic fracturing on U.S. drinking water supplies and I discuss other environmental concerns such as induced seismicity. I then discuss the state of renewable energy development in the U.S. and the potential to have near-term energy distribution in the United States with a mixture of natural gas and renewable energy sources. I will conclude with a discussion including the future energy outlook in the near and long term.

Fracking and the Environment

In 2009, concern over the environmental implications of fracking led Congress to urge the EPA to study the impact of fracking on drinking water supplies. An earlier EPA study in 2004 had concluded that fracking was safe and did not contaminate water sources in any stages of the water cycle, but the volumes of water used in fracking operations had risen enormously with the development of shale-gas resources after the 2004 study. On June 4, 2015, the U.S. Environmental Protection Agency (EPA) published the preliminary results of a five-year scientific study of hydraulic fracturing's effect on the nation's drinking water (epa.gov, 2015). The early conclusions of the study evaluated the risk of widespread groundwater pollution from fracking as low, with the resulting headline of "…no evidence of widespread systemic impacts" (epa.gov, 2015). The exact text from the 2015 executive summary is:

> "From our assessment, we conclude 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. We did not find evidence that these mechanisms have led to widespread, systemic impacts on drinking water resources in the United States." (EPA, 2015, retrieved from epa,gov, 2017)

The report identifies "potential vulnerabilities", but the emphasis on the lack of systemic impacts was strongly challenged as premature by many scientists because the study had found more than two dozen instances in which hydraulic fracturing had an impact on water resources. A five-year study was not considered sufficiently long to see long-term effects (Scheck and Tong, 2016)

On December 13, 2016, the EPA issued its final report on the $29 million study of hydraulic fracturing and drinking water (epa,gov, 2017). The conclusions in the final report were changed: it emphasized that fracking “can impact drinking water resources under some circumstances” and identified factors that influence these impacts (epa.gov, 2017). The study cited evidence of impacts to drinking water resources at each stage of the hydraulic fracturing water cycle. The uncertainties and gaps in the data were mentioned as reasons that prevented the study from making a definitive national conclusion on fracking’s impact of drinking water resources. Examples of problems that had occurred in local communities included accidents from poor well construction, spills of wastewater containing fracking fluid, and water withdrawals from areas that have low water resources (Scheck and Tong, 2016). Industry spokespeople and lobbyists insisted that no evidence of widespread contamination had been uncovered between the preliminary and final reports and that the EPA had simply slanted the conclusions based on available data in a different way. Environmental groups, meanwhile, praised the changes as confirming their stance that fracking has indeed caused pollution.

Thomas Young, a University of California Davis professor who served on the EPA’s Science Advisory Board, wisely stated, “the problem is everyone wants to decide that this is a horrendous problem and shut it down or they want to decide that it’s no problem at all and we’re done looking. I think neither of those is the right response” (Scheck and Tong, 2016). Professor Young’s perspective is one with some truth, which lobbyists and environmental groups should learn from.

While there has not been a clear conclusion on the relationship between fracking and drinking water contamination, scientists are urging oil and gas companies to test the drinking water before and after fracking processes in what is called “baseline testing” (Scheck and Tong, 2016). This would allow a better assessment of whether the process resulted in any contamination of groundwater during the period of fracking. Biogenic hydrocarbon gases, or those produced as a direct consequence of bacterial activity in the soil, would be easily identified versus thermogenic hydrocarbon, or gases at sub bottom depths exceeding 1,000m and produced under conditions of high pressure and temperature. Before and after data would definitely help with assessments; unfortunately, there are incentives on the sides of both the operators and the residents to not do testing beforehand. Residents may fear that the results of these initial tests will show that their drinking water is already contaminated and will force them to implement expensive mitigation. Operators may prefer not having baseline data that would help prove that their activities were the cause of future contamination. This makes it very difficult to determine the immediate effects of hydraulic fracturing because simply taking water samples randomly, performing lab analysis, interviewing residents, and modeling potential contamination is not enough (epa.gov, 2016).

The main conclusions from the December 2016 report, which is the latest findings of the EPA are as follow:

- Hydraulic fracturing can impact drinking water resources under some circumstances
- Examples of impacts were identified for all stages of the hydraulic fracturing water cycle
- Impacts can range in frequency and severity, depending on the combination of hydraulic fracturing activities and local or regional scale factors
- Significant data gaps and uncertainties prevent quantifying the number or frequency of impacts across the country

Methane Leakage

While it is true that methane has the lowest carbon footprint upon combustion, as measured by the weight of carbon dioxide emitted per unit of energy released, methane leakage during the production, delivery, and use of natural gas has the potential to undo much of the greenhouse gas benefits when natural gas is substituted for other fuels. The reason is that methane itself is a powerful greenhouse gas.

In a paper published in 2011 (Howarth et al., 2011), three Cornell University scientists show that substituting shale gas for these other fossil fuels may not have the desired effect of mitigating climate warming, which undercuts the logic of its use as a bridging fuel. Although there is no single way to measure or quantify the potency of different greenhouse gases in warming the atmosphere, a metric called the Global Warming Potential (GWP) is calculated by comparing the effects of methane in warming the atmosphere to the effects of carbon dioxide over a given period of time. According to the Fifth Assessment Report of the IPCC (climatechange2013.org), methane (CH_4) has a GWP of 20 over a 100-year time period. This means that, evaluated over the next 100 years, a kilogram of methane released into the atmosphere today will warm Earth’s atmosphere by about 20 times more than a kilogram of CO_2. Therefore, over a 20-year period, the GWP of methane is much higher.

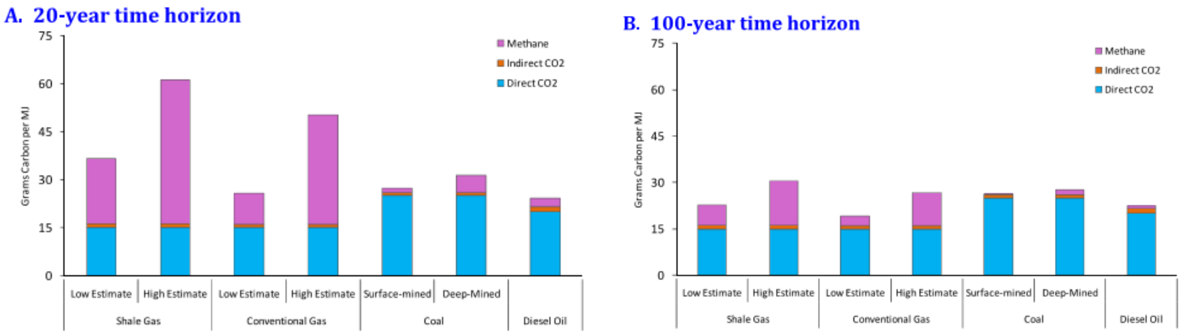


Figure 2. Compared to coal, the greenhouse gas footprint of shale gas is at least 20% greater and possibly twice as large on the 20-year horizon and is comparable when compared over 100 years. (worldclimatereport.com)

The reason for large differences in GWP values over 20-year and 100-year horizons is that methane has a short lifetime in the atmosphere: all methane released to the atmosphere is oxidized to CO_2 within about 12 years (Stocker et al., 2013). By contrast, CO_2 remains in the atmosphere naturally for about 10,000 years (Stocker et al., 2013). Although GWP is not generally used as a metric for comparing greenhouse gases for periods longer than 100 years, the long-term GWP of methane, on a mass for mass basis, would tend to a value of 2.75, because 1kg of CH_4 released to the atmosphere eventually turns into 2.75 kg of CO_2 (Howarth et al, 2011).

Oil and gas companies focus on a 100-year time horizon and often use out-of-date global warming potentials for methane, which results in inaccurate predictions for the future. This should be corrected, and the full GHG footprint of unconventional gas should be used in planning for alternative energy futures that adequately consider global climate change (Howarth et al, 2011). Assuming the Environmental Protection Agency's 2009 leakage rate of 2.4% from well to city, new natural gas combined cycle power plants reduces climate impacts compared to new coal plants. This remains the case as long as leakage remains under 3.2% (Allen et al., 2013).

Recent studies indicate that current inventories from the US EPA and the Emissions Database for Global Atmospheric Research underestimate methane emissions nationally by a factor of ~1.5 and ~1.7, respectively. A study from Miller et al (2013) estimated that emissions due to ruminants and manure are up to twice the magnitude of existing inventories. In addition, the discrepancy in methane source estimates is particularly pronounced in the south-central United States, where total emissions are ~2.7 times greater than in most inventories and account for 24 ± 3% of national emissions. Overall, methane emissions associated with both the animal husbandry and fossil fuel industries have larger greenhouse gas impacts than indicated by existing inventories (Miller et al, 2013).

Questions have been raised as to how greenhouse gas (GHG) emissions from the life cycle of shale gas production and use compares with that of conventionally produced natural gas or other fuel sources such as coal. Recent literature (Heath et al, 2014) has come to different conclusions on this point, largely due to differing assumptions, comparison baselines, and system boundaries. Through a meta-analytical procedure called harmonization, robust, analytically consistent, and updated comparisons of estimates of life cycle GHG emissions for electricity produced from shale gas, conventionally produced natural gas, and coal have been developed. On a per unit electrical output basis, harmonization reveals that median estimates of GHG emissions from shale gas-generated electricity are similar to those for conventional natural gas, with both approximately half that of the central tendency of coal (Heath et al, 2014). Sensitivity analysis on the harmonized estimates indicates that assumptions regarding liquids unloading and estimated ultimate recovery of wells have the greatest influence on life cycle GHG emissions, whereby shale gas life cycle GHG emissions could approach the range of best performing coal-fired generation under certain scenarios (Heath et al, 2014).

Induced Seismicity

In the United States, particularly the central and eastern United States, the number of M3+ earthquakes have increased greatly over the past few years. According to the USGS (usgs.gov, 2015), between 1973 and 2008, there was an average of 21 earthquakes of magnitude three and larger per year in the central and eastern U.S. This rate spiked to an average of 99 M3+ earthquakes per year from 2009-2013. Furthermore, in 2014, there were 659 M3 and larger earthquakes, which prompts two important questions: what is causing the earthquakes and what can be done in the future to reduce the risks associated with these earthquakes.

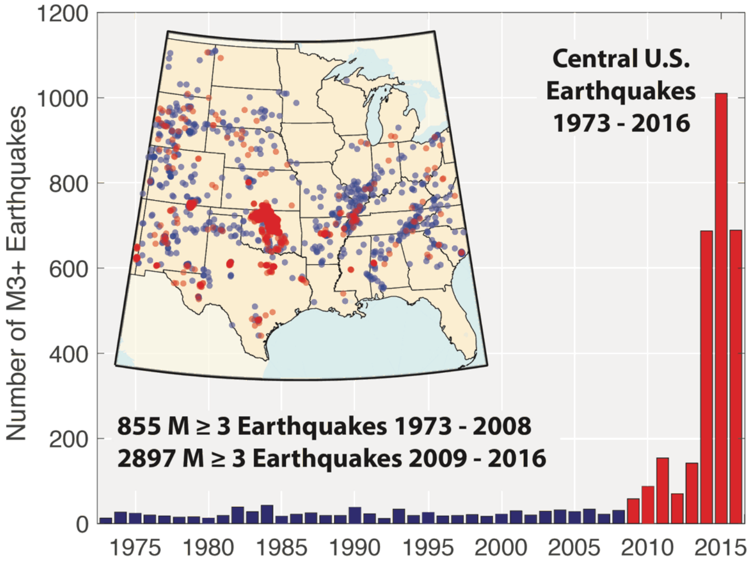


Figure 3. The cumulative number of earthquakes of magnitude 3 or greater in the central and eastern United States has increased drastically since 2009 (usgs.gov, 2015).

Research by the USGS (usgs.gov) suggests that fracking is not responsible for most of the induced earthquakes, rather water disposal is the primary cause of the recent increase in earthquakes in the central United States. Wastewater disposal wells typically operate for longer durations and inject much more fluid than hydraulic fracturing. Not the mention wastewater injection can raise pressure levels more than enhanced oil recovery. That being said, the USGS (usgs.gov) believes that not all wastewater injection wells induce earthquakes either. A combination of factors includes: the injection rate and total volume injected to the well; the presence of faults that are large enough to produce felt earthquakes; stresses that are large enough to produce earthquakes; and the presence of pathways for the fluid pressure to travel from the injection point to faults (usgs.gov). Seismicity can be induced at a distance of 10 miles or greater away from the injection point and at much greater depths than the injection point. Seismometers are being used to accurately pinpoint the location of the seismicity of earthquakes.

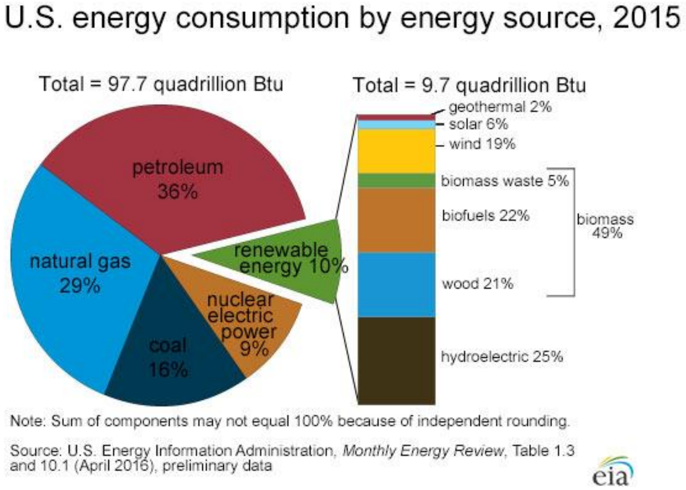
Summary

Opponents of fracking hoped to use the findings in the final EPA report on hydraulic fracturing and drinking water in addition to the increase of induced seismicity to mobilize opposition against the practice. But the reports themselves did not recommend a ban on fracking, and their conclusions regarding the potential of large-scale contamination of drinking water by fracking operations or physical harm were not dramatic enough to capture widespread attention. Even the recommendations of the EPA report regarding further study and careful regulation may not make a difference. President Trump has promised to further deregulate fracking during his administration, and appointed former Oklahoma Attorney General Scott Pruitt as EPA Administrator. In his role as attorney general for Oklahoma, Pruitt, who has ties to the oil and gas industry as a lobbyist, sued the EPA over implementation of its Clean Power Plan. Although promoted by the Obama administration, it is the EPA Clean Power Plan and remains so under the new administration. Prior to taking office, Pruitt said the EPA under a Trump Administration would be less aggressive when it comes to enforcing federal regulations on the industry and push for a regulatory rollback. During the Obama administration, the EPA's budget was reduced $2.1 billion, or 20 percent, between 2010 and 2016. The Trump administration has a stated goal of cutting more (Scheck and Tong, 2016)

Introduction to Renewables

Renewable energy is energy collected from resources that are naturally replenished on a human timescale. Examples of renewable resources include sunlight, wind, rain, tides, waves, and geothermal heat. Renewable sources now provide energy in electricity generation, air and water heating/cooling, transportation, and rural energy services and are currently responsible for 9.7 quadrillion BTU's of energy consumption in the United States (U.S. Energy Information Administration Annual Energy Outlook, 2015, retrieved from eia.gov, 2017). From 2001-2015, the share of renewable energy consumption relative to total US energy consumption increased 85% from 5.4% to 9.9% according to the U.S. Energy Information Administration Annual Energy Outlook (U.S. Energy Information Administration Annual Energy Outlook, 2015, retrieved from eia.gov, 2017). Additionally, renewable energy sources account for approximately 13% of the United States' electricity generation. Renewable energy sources do not directly emit greenhouse gases, and are considered to be the most attractive solution to the rising concerns about the contribution of the world's energy systems to man-made climate change.

Figure 4. In 2015, about 10% of total U.S. energy consumption was from renewable energy sources. More than half of U.S. renewable energy is used for producing electricity, and about 13% of U.S. electricity generation was from renewable energy sources in 2015 (eia.gov, 2016).



Note: Sum of components may not equal 100% because of independent rounding.

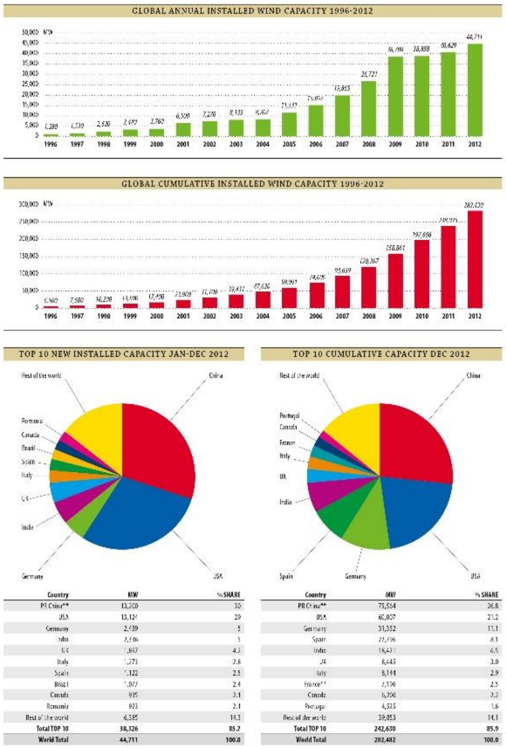
Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.3 and 10.1 (April 2016), preliminary data

The consumption of renewable energy for primary usage in the United States has increased at a steady rate over the last ten years. The United States renewable energy supply grew, on absolute terms, by 39% from 2006-2015, with a compound annual growth rate of 3.4% (U.S. Energy Information Administration Annual Energy Outlook, 2015, retrieved from eia.gov, 2017). While this is relatively smooth growth, there was a volatile trend of individual renewable energy sources. Within the last decade, energy supply from solar, wind, and liquid biofuels grew by 678%, 588%, and 197%, respectively. Geothermal and other biomass energy supplies increased by 23% and 30%, respectively, and hydropower decreased by 17%. The wide distribution of growth rates for individual renewable energy sources shifted the composition of the renewable energy supply over the past ten years. Although hydropower has remained the largest supplier of renewable energy, its supply share decreased from 46% to 27% from 2006-2015, while the supply from wind increased the most from 4% to 21% over that same time. The share of renewable energy derived from solar increased from 1% to 6%. These trends are correlated to technological advances and a decreasing cost that is becoming increasingly competitive in the overall energy marketplace.

The potential for solar and wind power growth

Solar photovoltaic modules have significant growth potential and are a feasible large-scale renewable energy source. From 2008 to 2013, the costs of photovoltaic modules fell 68%, which led to large increases in installation. Installed capacity increased 30% from 2013 to 2014 with a sizable jump of 6,201 MW. Additionally, the cost and efficiencies are continuing to improve at fast rates. The United States Department of Energy has implemented the SunShot initiative to decrease the price of solar energy by 75% by the end of 2020. This emphasis on decreasing prices will lead to a sustained growth in installed capacity of solar energy (umich.edu, 2015).

Wind power also has the potential to grow rapidly given its capacity and regulatory environment. A 1 MW wind turbine displaces approximately 1,800 tons of carbon dioxide emissions annually, making wind energy a promising renewable investment. Although United States onshore wind capacity has increased drastically to roughly 70 GW, total capacity has to potential to produce approximately 10,500 GW of electricity. The federal government extended the wind energy federal production tax credit through 2019, facilitating an environment to take advantage of the surplus of unused wind resources. When the federal production tax credit initially expired in 2013, wind capacity installation decreased by 92%. Federal regulatory support, therefore, will remain essential for future growth in wind energy installation. Other reservations to wind energy installation is the loud noise associated with the large turbines, visual disturbance and likely harm to birds flying by (umich.edu, 2015).



Country	MW	% SHARE
PR China**	13,200	30
USA	13,124	29
Germany	2,439	5
India	2,336	5
UK	1,897	4.3
Italy	1,273	2.8
Spain	1,122	2.5
Brazil	1,077	2.4
Canada	935	2.1
Romania	923	2.1
Rest of the world	6,385	14.3
Total TOP 10	**38,326**	**85.7**
World Total	**44,711**	**100.0**

Country	MW	% SHARE
PR China**	75,564	26.8
USA	60,007	21.2
Germany	31,332	11.1
Spain	22,796	8.1
India	18,421	6.5
UK	8,445	3.0
Italy	8,144	2.9
France**	7,196	2.5
Canada	6,200	2.2
Portugal	4,525	1.6
Rest of the world	39,853	14.1
Total TOP 10	**242,630**	**85.9**
World Total	**282,482**	**100.0**

Figure 5. Global annual installed wind capacity and global cumulative installed wind capacity have seen drastic increases from 1996 to 2012. Wind turbines do not produce carbon emissions and have a large potential for electricity generation. The technology continues to improve and become less expensive (umich.edu, 2015).

On a geographically accessible and technically extractable domestic scale, the United States possesses about seven Terawatts (TW) of potential concentrated solar power capacity and another eight TW of potential land-based wind capacity. This potential capacity more than dwarfs the current U.S. energy demand of about four TW per year. However, two main barriers exist: economic competitiveness and grid integration difficulties (eia.gov, 2017).

The amount of sunlight that strikes the Earth every hour contains more energy than the amount the entire world consumes in a whole year (Harrington, 2015). In domestic terms, it would theoretically take just 2% of U.S. land area, or about 30 times the available roof space, to harvest enough of this solar energy to power the entire country (Tsao, 2006). The problem of intermittency and economic feasibility are the most significant barriers posed to renewable energy integration. More breakthroughs are needed to expand energy storage system capabilities while reducing their costs on a local, metropolitan, and grid-wide level.

The viability of large-scale renewable energy sources

Notwithstanding the growth of renewables over the past decade, renewable energy remains a small contributor to the overall energy supply. The modest implementation of renewable energy technology largely occurs due to the high relative expense of renewable energy compared to fossil fuel energy. This greatly limits the viability of large-scale renewable energy sources. Moreover, wind and solar energy produce maximum output during off-peak hours, with wind producing maximum energy at night and solar producing maximum energy during the middle of the day. Since large-scale storage systems for renewable energy sources does not exist at this time, the misalignment poses a problem with balancing the grid and supplying energy to numerous consumers on demand. Not to mention that overall energy demand in the United States is projected to grow through 2040 with a growing population, standard of living, and economy (Dumaine, 2012).

Natural Gas and Renewables: Is Bridge the Right Metaphor?

This section considers the pros and cons of natural gas as a transitional energy to a renewable energy future. It takes into account the alternatives to natural gas, increasing demand of electricity, and the levelized cost of electricity. While it is important to not become reliant on fossil fuels, natural gas can be complimentary to renewable energy sources and serve as a near ideal transitional energy if extraction, transportation, and disposal is performed properly.

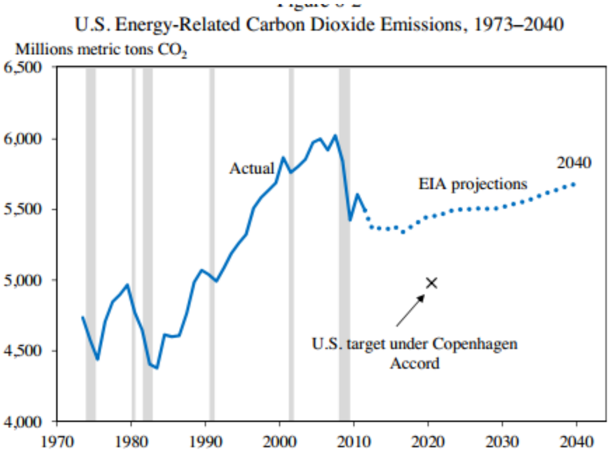
Natural gas is a valuable domestic resource given its abundance in the U.S. It is a much cleaner burning fuel than coal, the main fuel that it competes with in U.S. electricity production, when leakage is minimized. This is because while coal is composed primarily of carbon, it always has significant impurities due to its process of formation. Coal combustion releases more than twice as much CO_2 than combustion of natural gas, per unit of energy released, and also emits much larger quantities of pollutants such as sulfur and nitrogen oxides.

The substitution of natural gas for coal in U.S. power generation during the last decade has had a large effect on U.S. CO_2 emissions. Energy related carbon dioxide emissions peaked in 2007 at just over 6000 million metric tons (Tour, 2010). The downward trend from this point marks a significant decrease in carbon after a long pattern of increasing yearly emissions (eia.gov, 2017).

Natural gas power plants complement renewable energies on the grid very well for many reasons. Because there is no large-scale economical way to store renewable energy and reconcile the misaligned supply and demand, most energy companies must still rely on non-renewable fuel sources during peak demand. Natural gas-fired plants can quickly meet those hourly variations by quickly ramping up or down at a moment's notice to meet minute-to-minute fluctuations. This contrasts coal-fired power plants, which are slow and inefficient to ramp up and have contractual minimum run times that can last several days.

Many environmentalists disregard the potential for a balanced energy system and still push for renewable energy instead of fossil fuels. However, economists believe that natural gas compliments renewable energy because they are price dependent. One example is peanut butter and jelly. Peanut butter and jelly are compliments because they're usually eaten together. If the cost of peanut butter goes down, people will eat both more peanut butter as well as more jelly, assuming that the cost of jelly hasn't changed (Reynolds, 2015). Likewise, when the price of

Figure 6. U.S. energy related carbon dioxide emissions have increased linearly from 1990 until 2010. The EIA projects that metric tons of CO_2 will level off from 2010 to 2040. Renewable energy sources will have to play a large role if emissions do not continue on a business as usual schedule (eia.gov, 2012).



Note: Shading denotes recession.
Source: EIA (2012b).

natural gas goes down, so does the effective cost of renewables, which are made ever more plausible by gas-fired generation. Improved public perception of fracking methods that will come with more research, paired with strict regulations and advanced technologies, can make fracking a less daunting and more environmentally practical strategy to serve as a transitional energy to renewables.

Sustainable Energy Innovation

In 2011, GE announced the first power plant to integrate wind and solar power with natural gas. It was designed to combine a traditional gas-fired steam turbine with solar thermal power and wind power. The 530 megawatt plant began operation in Turkey in 2015 and is made practical by a flexible, high-efficiency natural gas system along with a solar thermal power system and mirrors. The solar component is a field of sun-tracking mirrors that focuses sunlight on a tower to produce steam, which is fed into the steam turbine to increase the plant's output. The small wind farm connected to the plant provides another 22 megawatts of power and the natural gas component smooths out the variability problems inherent in wind energy. When the wind is not blowing, natural gas generates steam to spin the turbines. In 2015, Western Energy Partners announced they will build a $1 billion, 750 MW hybrid natural gas and photovoltaic (PV) solar power plant in New Mexico. This trend creates jobs and paves the way for more innovation, such as a battery-gas hybrid power plant or solar roof shingles to reduce pollution

Is natural gas a bridge to nowhere?

Many researchers argue that the most dangerous aspect of natural gas usage is the perpetuation of fossil fuel dependence. There are currently large, but not insurmountable barriers to harnessing natural gas and renewable energy to meaningfully reduce our national reliance on imported oil for transportation. However, much of the current conversation is narrowly focused on either natural gas or renewable energy as distinctly separate components or concentrates on the competitive impacts of one over the other.

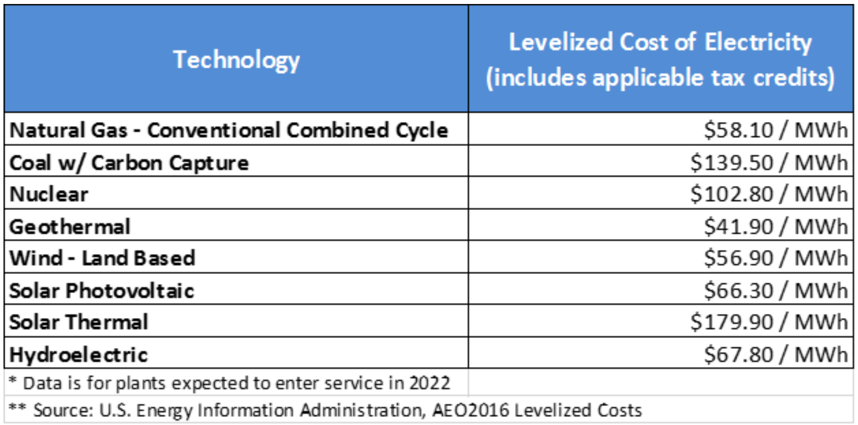
The two forms of energy, natural gas and renewable energy, are complementary in many respects: natural gas electricity generation enjoys low capital costs and variable fuel costs, while renewable energy generators have higher capital costs but generally zero fuel costs. Yet, despite the complementarities and potential for greater coordinated use, the natural gas and renewable energy industries have at times viewed each other as direct competitors, especially in the power sector. As of mid-2012, the primary competitive impact of inexpensive natural gas has been over

300 terawatt-hours (TWh) of fuel switching from coal- to natural gas-fired electricity since 2008 (Dumaine, 2012). If natural gas prices remain below roughly $5 million British thermal units (MMBtu), many developers of renewable electricity projects might be hard pressed to offer competitive power purchase prices, thus limiting the number of projects deployed (Howarth et al., 2011) Similarly, natural gas producers and biofuel producers might compete over water, especially in areas with limited water supply. The joint efforts of the natural gas and renewable energy industries to engage on these and other platforms of dialogue and collaboration in good faith can bring new insights to existing bodies of knowledge that will help define and frame current and future policy questions, but this may not happen while they see each other as competitors. Policymakers and regulators could use this foundation to craft well-designed and complementary energy policies and regulations to successfully guide the evolution of the U.S. energy industry along desired long-term pathways, but studies show that abundant natural gas decreases use of both coal and renewable energy technologies in the future. Researchers project that only climate policies bring about a significant reduction in future CO_2 emissions within the US electricity sector. Without strong limits on GHG emissions or policies that explicitly encourage renewable electricity, abundant natural gas may actually slow the process of decarbonization, primarily by delaying deployment of renewable energy technologies.

If oil and gas companies involved in fracking claim to use natural gas from fracking to be a transitional energy, then they should find ways to facilitate and not delay the transition. This is done quite simply by investing more in renewables. Renewable generation costs have declined in many parts of the world due to sustained technology progress, improved financing conditions and expansion of deployment to newer markets with better resources. In order to stabilize the amount of carbon-dioxide in the atmosphere at about 450 parts per million — giving us a shot at limiting global warming below 2°C — fossil fuels must be strictly regulated and used only when a substitute cannot be found (Howarth et al, 2011). Energy Secretary, Ernest Moniz, told the Senate that natural gas use would need to get phased out by mid-century or so, and that "we must continue to invest in research in carbon-free sources— renewables, nuclear and carbon capture and storage for both coal and natural gas [to limit global warming below 2°C]” (Howarth et al, 2011).

The levelized cost of electricity

Levelized cost of electricity (LCOE) is a convenient indicator for the overall competitiveness of different generating technologies. It represents per-kilowatt hour cost of building and operating a generating plant over an assumed financial life and duty cycle. It attempts to compare different methods of electricity generation and offer an economic assessment of the average total cost to build and operate a power-generating asset over its lifetime divided by the total energy output of the asset over that lifetime. Important aspects to consider include capital costs, fuel costs, fixed and variable operations and maintenance costs, financing costs, and an assumed utilization rate of each plant type. The importance of the factors various among the technologies. Below is a table with the estimated LCOE for new generation resources in 2022. The levelized capital cost for wind, solar and hydroelectric are much greater than for conventional and advanced combined cycle and combustion turbine. This makes it easy to believe that fracking can function as a rather large barrier to a swift energy transition to renewable energy sources (eia.gov, 2016).



Technology	Levelized Cost of Electricity (includes applicable tax credits)
Natural Gas - Conventional Combined Cycle	$58.10 / MWh
Coal w/ Carbon Capture	$139.50 / MWh
Nuclear	$102.80 / MWh
Geothermal	$41.90 / MWh
Wind - Land Based	$56.90 / MWh
Solar Photovoltaic	$66.30 / MWh
Solar Thermal	$179.90 / MWh
Hydroelectric	$67.80 / MWh

* Data is for plants expected to enter service in 2022

** Source: U.S. Energy Information Administration, AEO2016 Levelized Costs

Figure 7. The LCOE depends on the location and local tax regulations, but in general is very competitive for renewable energy sources and fossil fuels. The numbers are a simple average of regional values for plants entering service in 2022 (eia.gov, 2016).

Energy policy

The use of renewable sources in energy generation currently grows 7.2% annually (eia.gov). Non-renewable sources only see 1.6% of growth annually (eia.gov) Taking into account the economic incentives to continue burning fossil fuels, this is substantial growth every year in renewable energy sources. However, most of the growth receives support from policy. Renewable Portfolio Standards (RPS) provides an effective regulatory avenue for promoting renewable energy growth. RPS are state-level regulations that require increased energy production from renewable energy sources. At the end of 2016, twenty-nine states had implemented Renewable Portfolio Standards while eight additional states had set renewable energy goals (Nordhaus, 2009). Projections indicate that state-level RPS will support approximately 103,000 MW of renewable electricity generation (Nordhaus, 2009). Net metering, which allows consumers who generate electricity to sell any excess supply back to the grid, incentivizes the growth of residential renewable energy devices. Forty-four states currently have net metering programs (Nordhaus, 2009). On a federal level, the Investment Tax Credit promotes the growth of renewable energy by offsetting initial installation costs by up to 30% (keystone-xl.com, 2017). Significant policy action on both the state and federal level has supported energy growth over the past decade, as there is a $36 billion market for renewable energy sources, but long-term renewable energy goals will require additional regulatory measures.

Aggressive goals regarding climate change control and renewable energy growth in the United States were set by the Obama administration. The Clean Power Plan, announced August 2015 by President Obama and the EPA aims to reduce power plant carbon dioxide emissions by 32% from 2005 levels by 2030 (Nordhaus, 2009). The plan also includes an intermediate goal to double wind and solar energy generation by 2020. It intends to accomplish this goal by developing fuel economy standards for heavy-duty vehicles, which currently stand as the second largest source of greenhouse gas emissions in the transportation sector. Projections indicate, that, if followed, this plan will lead to an increase in renewable energy generation by 30% in 2030, while continuing to drive the economic feasibility of renewable energy (Nordhaus, 2009). These policy goals reveal the desire to continue to accelerate the transition towards renewable energy generation, however, is widely expected to be eliminated or lightened under President Donald Trump.

Future

President Trump is pushing for an “America First” energy plan. The Trump Administration is committed to energy policies that lower costs for Americans and maximize the use of American resources, freeing us from dependence on foreign oil. President Trump is committed to achieving energy independence from the OPEC cartel and any nations hostile to our interests. However, our need for energy must go hand-in-hand with responsible stewardship of the environment. Protecting clean air and clean water, conserving our natural habitats, and preserving our natural reserves and resources will remain a high priority. President Trump will refocus the EPA on its essential mission of protecting our air and water. The Trump administration believes that fracking can and will stimulate the economy, ensure security, and protect American's health. This can be seen with the Keystone XL Pipeline, Dakota Access Pipeline, American Pipeline, reducing regulatory burdens for domestic manufacturing, appointing Scott Pruitt to head the Environmental Protection Agency (EPA), and appointing Rex Tillerson, the former chief executive of Exxon Mobil, to be the Secretary of State.

Further discussion and conclusion

The Howarth article (Howarth et al., 2011), determines that 3% methane leakage is necessary for coal and methane to have the same greenhouse-gas footprint per GJ of energy produced on a 20-year time scale (calculation in Appendix). Additionally, methane leakage has a larger global warming potential in the 20-year time scale. Therefore, because of this and other factors including drinking water contamination, well storage sites, induced seismicity, and a reliance on fossil fuels, I do not believe that natural gas is the lone solution to burning dirty coal as a primary energy source. A transition to renewable energy sources is necessary and the rapid improvements in technology and economic feasibility make it a strong possibility in the next forty or fifty years. However, policy will have an important role in this transition. The first, and most important implementation, in my opinion, to assist in the transition to more renewable energy sources is a carbon tax with the use of carbon capture and storage.

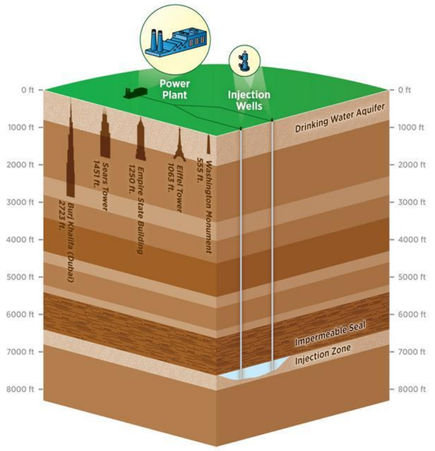


Figure 8. Schematic image of the carbon capture and storage process and typical depth at which carbon dioxide would be injected. Subsurface depth to scale, 5,280 feet equals one mile. Carbon dioxide capture and sequestration could play an important role in reducing greenhouse gas emissions (epa.gov, 2017).

Carbon dioxide emission reduction is sliding to the forefront of priorities in jurisdictions to maintain environmental stability and combat climate change. Carbon capture and storage (CCS) is a process that makes use of technology to reduce carbon dioxide emissions (epa.gov, 2017). CCS collects CO_2 from power plants or other industrial processes, transports the captured and compressed CO_2, usually in pipelines, and injects it underground to be stored deep in rock formations (epa.gov, 2017). These formations are usually a mile or more beneath the surface and consist of porous rock to hold the CO_2. Impermeable, non-porous rock layers overlie these formations, which trap the CO_2 and prevent it from migrating upward.

Carbon capture, use, and storage technologies can capture 90 perfect of carbon dioxide emissions from a power plant or industrial facility and store them in underground geologic formations (GCCSI, 2011). However, it is still a relatively expensive technology that is just reaching maturity. Seldom would oil and gas companies willingly opt to spend more money to capture and store CO_2 emissions unless a tax or incentives were in place. Policy options to help promote carbon capture and storage include: putting a price on carbon, offering funding for continued CCS research development, and demonstration, incentivizing CCS, setting GHG emissions rates, or defining a CO_2 storage regulatory framework. Policy that would place a price on emissions, such as cap and trade, would discourage investments in traditional fossil-fuel use and increase investments in a range of clean energy technologies. Funding, incentives, and setting emission rates would also encourage large companies to invest and research more into clean, renewable energy sources. BP, one of the world's leading integrated oil and gas companies is at the forefront of renewable energy research and development. I believe government policies and/or tax incentives are necessary to encourage companies to use their profits from fossil fuels for renewable energy research and development.

The natural gas and renewable energy industries have seen a lot of advancements over the past fifteen years that have significantly affected the energy distribution of the United States. The process of hydraulic fracturing and horizontal drilling has unlocked large reserves of previously unattainable natural gas, sending costs of the fuel to record lows and greatly increasing its share of power generation. Renewable energy technologies have undergone revolutions as well, making carbon free systems such as solar photovoltaic cells and offshore wind turbines viable options. However, in conclusion, the current cost of the renewable energy technology remains too expensive in comparison to natural gas. This makes balancing the relationship between the two forms of energy production a challenge moving forward. While natural gas has properties that make it an almost ideal complement to renewable energy sources as they continue to progress and expand, it is important to ensure that cheap gas prices do not deter the expansion of renewable energy. With the help of government incentives and a carbon tax, the fracking revolution and shale gas boom has the potential to bridge the gap from a carbon heavy industry to a green system that runs on renewable resources. By examining other countries with a similar platform, it is evident that near-term utilization of both energy sources can balance economic stability and ensure environmental protection.

Appendix

1.) This calculation uses a Global Warming Potential of 20 for methane to determine the amount of leakage of methane (in kilograms) that would be necessary for coal and methane to have the same greenhouse-gas footprint per GJ of energy produced. Leakage will be expressed as a percentage of the total amount of methane involved.

1 mol (carbon)/394 kJ * 10^6 kJ/GJ * 12 g/mol * 1kg/1000g = 30.5kg (carbon)/GJ
30.5 kg (carbon)/GJ * cm^3/2.7g * 1000g/kg * $1m^3/10^6cm^3$ = $0.0113m^3$ (carbon)/GJ
1 mol (carbon)/394kJ * 10^6kJ/GJ * 1 mol(CO_2)/1mol (carbon) * 44g/mol * 1kg/1000g = 111.7kg (CO_2)/GJ

Combustion of coal produces 111.7 kg of CO_2 per GJ of energy
Combustion of natural gas (methane) produces 49.4 kg of CO_2 per GJ of energy produced

111.7 kg (CO_2)/GJ – 49.4 kg (CO_2)/GJ = 62.3 kg (CO_2)/GJ

Global Warming Potential over a 100-year period: one kg of methane released to the atmosphere is equivalent to 20 kg of CO_2

Energy balance for 1 GJ of energy production:
111.7 kg CO_2 = 49.4 kg CO_2 + (20 kg CO_2 / 1 kg CH_4) * M
M represents the amount of methane leaked to balance the equation

(111.7-49.4)/20 = 3.1 kg CH_4

Generating a GJ of energy from methane requires combustion of 19 kg so the percentage of methane that must be leaked to create an equivalent GHG footprint with combustion of coal is: 3.1/(18+3.1) * 100% = 14.7%

- Howarth et al. (2011) estimates that methane leakage from shale-gas operations ranges from 3.6 to 7.9%
- GHG footprint of shale gas is comparable to coal on a 100-year horizon and up to twice as great on a 20-year horizon using a GWP of 33 for methane

Acknowledgements

First and foremost, I would like to thank my advisor, Michael Oristaglio. Without his assistance and involvement in the process, this geology senior essay would not have been accomplished. I would like to thank you very much for your support and commitment to this paper. Your dedication in the form of meetings, edits, and research did not go unnoticed or unappreciated.

I would also like to thank the entire Geology and Geophysics department at Yale. Thank you for peaking my interest in energy. I have thoroughly enjoyed all of my courses and that is in large part due to the great Professors I have had along the way. Thank you for a memorable four years.

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