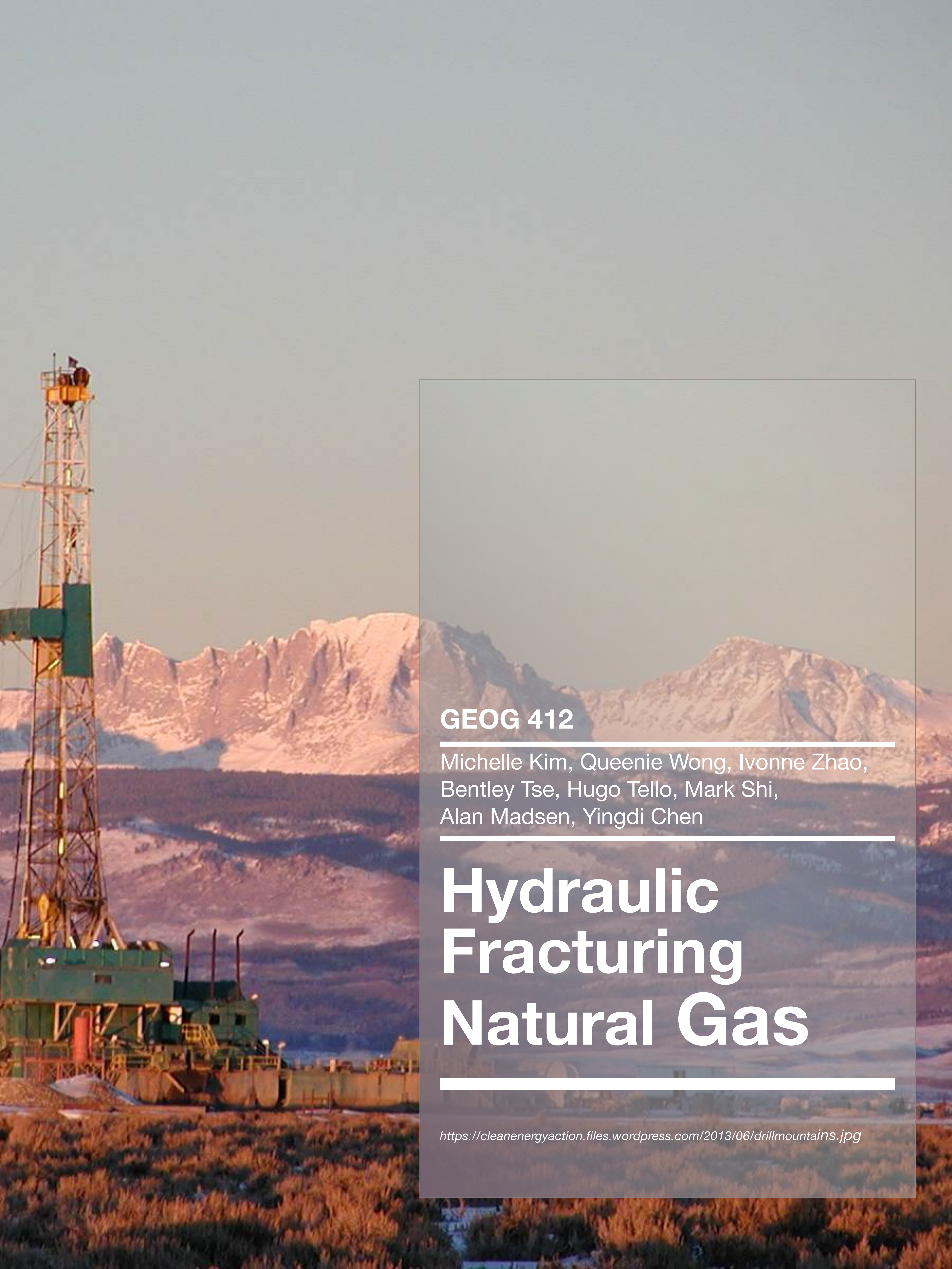

GEOG 412

Michelle Kim, Queenie Wong, Ivonne Zhao,
Bentley Tse, Hugo Tello, Mark Shi,
Alan Madsen, Yingdi Chen

Hydraulic Fracturing Natural Gas

https://cleanenergyaction.files.wordpress.com/2013/06/drillmountains.jpg

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How it Works - Alan

Today's Energy Situation

- In today's society, as much as we like to promote renewable energy sources it still remains a fact that over 80% of our energy generation comes from fossil fuels (Sovacool, 2014)
- These fossil fuels consist of 3 major energy sources: Coal, Oil, and Natural Gas
    - Of these three, oil is utilized most often contributing to about 1/3 of the worlds total energy consumption, with Coal being next at 30% and Natural Gas coming third of the three with about 24% (~86% of the worlds energy consumption) (Sovacool, 2014)
- The burning of fossil fuels to generate energy comes at a huge cost however, producing greenhouse gases which is the leading cause of climate change
- As much as we are pushing renewable energy sources it remains clear that fossil fuels will continue to be a substantial contributor to energy generation in the foreseeable future
- Technological advances in the combustion of natural gas mean that burning natural gas can emit 50% to 60% less CO2 than typical coal burning power plants (BBC News, 2018)
    - Because of this, it is estimated that Natural Gas may become the primary energy producer in the next few decades, rendering coal and oil obsolete in favour of a more environmentally conscious process

Where's the Natural Gas?

- Natural Gas, like the rest of the fossil fuels is produced in the decomposition of organic plant and animal matter when subject to intense pressures and heats in the Earth
- It accumulates above oil fields in pockets where the gas cannot escape allowing for wells to be drilled to extract the gas (Lehr, Keeley and Kingery, 2014)
    - The typical way that Natural Gas is extracted however these types of reserves have mostly been depleted worldwide meaning new ways of finding the gas must take place
- Gas does not always accumulate together in one place, it is also found spread through large rock bodies known as **shale** (Sovacool, 2014)
    - Shale rock is the most commonly found sedimentary rock, it has a very high porosity meaning it has lots of space between the grains of the rock in which natural gas and oil can be trapped
- As the typical reservoirs of Natural gas dried up, the price for the commodity rose to a point where hydraulic fracturing became an economically viable option to extract the gas

Hydraulic Fracturing: How Does it Work?

- The process begins with identifying a large shale rock body deep below the surface which contains high levels of gas and oil within the rock's pores (NETL, 2010)
- A well is first drilled down vertically into the rock formation with protective steel casings and concrete reinforcing the sides and protecting any ground water sources

- Next, the well is drilled out horizontally, across the rock body and parallel to the surface
    - This process means that one well can access an entire shale formation with minimal surface disturbance
- Once the horizontal well is completed, and specialized tool runs the length perforating the shale rock around the horizontal shaft
- Now the entire drill well is pumped with a fracking fluid which consists primarily of water with sand, but also some chemicals which aid in the fracturing process
    - This fluid is pumped in at extremely high pressures, causing the already formed fractures to open farther
    - The sand in the fracking fluid ensures that these fractures stay open even when the fracking fluid is removed from the well
- Because of these fine fractures through the shale rock, it is then possible to access the oil and natural gas trapped within the shale
- The process takes about 3-5 months to complete, and once done the well can produce oil and gas for 20-40 years (NETL, 2010)

Past, Present, and Future of Fracking - Michelle

The need for technological change:

There has been a fundamental shift to extracting natural gas from deeper, previously inaccessible, unconventional deposits (Lane, 2013). This was a reactionary shift due to falling conventional oil and gas supplies while demand for fossil fuels and energy were ever increasing (Beckwith, 2010).

- Natural gas trapped in Shale rock formations is considered an unconventional form of fossil fuels due to the extreme impermeability of the Shale rock it is within (Lane, 2013; Sovacool, 2014)
  - Impermeable surfaces do not allow the flow of liquids or gas
  - This means that fossil fuels trapped within the pores of Shale rock are not easily accessible

The shift towards extracting unconventional natural gas has been facilitated by new technologies of horizontal and directional drilling, as well as, hydraulic fracturing (Sovacool, 2014).

Leading up to Hydraulic Fracturing Today:

- Fracturing can be traced back to the 1860s when liquid nitrogen was used to create controlled explosions for shallow, hard rock wells in several states across the US (Sovacool, 2014; Apel, et al., 2015)
  - Originally, dynamite or nitroglycerin detonations were used to increase oil and natural gas production
  - ex) The “Torpedo” was an explosive device used to fracture the surrounding rock at the base of an oil well to stimulate the flow of oil and to remove built up paraffin wax that would restrict the flow
- In the 1930’s the idea of injecting a non explosive fluid into the ground to stimulate non-permeable surfaces was tested Liquids used would include acids which aided in allowing more oil and gas to escape from the fracture (Apel, et al., 2015)
- Began as an experiment in 1947 and first successful commercial application started in 1949 (Montgomery and Smith, 2010; Apel, et al., 2015).
- The department of Energy starts the Eastern Gas Shales Project in 1976 leading to advance hydraulic fracturing techniques in shale formations and to the development of extraction for unconventional natural gas reserves (Apel, et al., 2015)
- By 1997 hydraulic fracturing technologies have improved treatments and have various fracking methods depending on shale formations (Apel, et al., 2015)

Today:

- Fracking is the most preferred method of natural gas extraction and is used in 9/10 natural gas wells in the US (Sovacool, 2014)
- Drilling methods used in fracking have advanced significantly over the past few years
- Horizontal drilling methods which places wells horizontally within shale layers have greatly made the recovery of shale gas and natural gas highly economical (Sovacool, 2014)

- Since the introduction of hydraulic fracking in 1949, close to 2.5 million fracture treatments have been performed worldwide
    - Have added to reserves of oil and natural gas: approx 9 billion barrels of oil and more than 700 tsef of gas added since 1949 to US reserves alone (Montgomery and Smith, 2010)
- Approximately 60% of all wells drilled today are fractured (Montgomery and Smith, 2010)
- The development of Hydraulic Fracturing technology has been so effective that the innovation has been called disruptive to the continued development and use of other green energy sources (King, 2012)
- Increased attention towards the environmental and social impacts of hydraulic fracturing (Montgomery and Smith, 2010)

What does the future hold for hydraulic fracking?

- The US energy information administration reports that shale gas will account for almost 50% of natural domestic gas production by 2030 (Beckwith, 2010)
- The international energy agency expects the production of unconventional gas to more than triple from today to 2035 (Beckwith, 2010)
    - They also expect $6.9 trillion will be invested in shale gas infrastructure
- As there is more focus on the environmental and social impacts of hydraulic fracking, governments are increasingly turning to future innovations for improved environmental performance of the fracking technology (Canadian Association of Petroleum Producers)
    - Reducing methane leaks
    - Using solar power to power pumps
    - Improving monitoring and maintenance of fracking wells

Environmental Impacts 1 - Queenie

What are the ecosystem services?

1) Supporting Services: maintains the conditions of life in earth.
2) Provisioning services: the product obtains from ecosystem, like water and food
3) Cultural services: education and leisure opportunities
4) Regulating services: refers to the benefits obtains from regulation of ecosystem process

Pathway Group for the fluid flow (refer to appendix)

- In pathway group 0, the pollutant discharges that occurs directly at the ground, then the fluids flowback and pollutant discharges (Federal Ministry for the Environment,2012), this contains hazardous material from hydrocarbon like benzene (Benjamin, 2014)
- In pathway group 1, the potential pollutant discharges and spreading along wells, if wells leakage (Federal Ministry for the Environment,2012), there will be undesired entry of fracking fluids into the neighboring rocks, this catalyze the erosion and weathering activity, thus mosses on rock cannot survive, then lower the biodiversity
- Under pathway group 1 and 0, the spills at the shale gas well site of toxic chemicals and challenges with flowback water storage and handling that may contain radioactive materials

Environment Concerns

1. Migration of Fluid: Water Contamination

- Fluids flowback & pollutants discharges
- Contains hazardous materials from hydrocarbon
- Water contaminated by chemicals -> fish habitat, water plant and marine organism's life adversely affected
- In order to catalyze the fracking process, biocides added, constituting 2 or 3 percent of the total volume of fracking fluid (Benjamin, 2014), which changes and decrease the water quality

Research Study (Lehr, 2016)

- 1) Conducted by Duke University
- Analyzing 68 water wells in the Marcellus Shale -> found 85% of wells contained methane
- Methane in these wells was thermogenic
- 2) Conducted by Howarth and Ingraffea -> calculate 200000 of acids, biocides, scale inhibitors and surfactants are pumped under high pressure into each typical well

2. Migration of Gas: Air Pollution

- shale gas development includes pollutant emissions from diesel engines, the shale gas leakage during extraction and transport and the volatile compounds from the surface storage ponds (Benjamin, 2014)
- HOWEVER, shale gas has fewer emissions of Sulphur oxides, nitrogen, and mercury than coal and oil -> can reduce the greenhouse gases (Jackson, 2014)

Research Study (lehr, 2016)

- Environmental groups argue more methane releases to the atmosphere by hydraulic fracturing
- Air quality standards require the use of green well completion -> a technology to capture 95% of methane emissions
- Study conducted by the Massachusetts Institute of Technology -> the implementation of this technology helps companies to avoid losing money
- Cost effective and reducing greenhouse gases in a significant way

3. **Seismicity: Faulting and Earthquakes**
   - national research council has found some statistic to prove the injection and withdrawal of fracking fluid can cause increased seismicity (Benjamin, 2014)
   - When fracking water injected into an aquifer 3km down, it actually increases the pressure of groundwater in the rock and triggers the fault formation (Jackson,2014)
   - Earthquake induced by hydraulic fracturing are non destructive and it usually below 2 in magnitude (Zhang & Yang, 2015)
   - In United States, the active shale play areas, the depth of hypocenters and epicenters of these quake were close to the deep injection disposal wells (Zhang & Yang, 2015)

   Research Study (Lehr, 2016)
   - Conducted by Dr Richard
   - Investigate 198 examples of induced seismic activity from around the world registering at a magnitude greater than or equal to 1
   - Results: found hydraulic fracturing was responsible for ONLY THREE earthquakes large enough for people to feel

Environmental Impacts 2 - Yingdi

Water Scarcity:

- Hydraulic fracturing process involves the high-pressure injection of large amount of water and chemicals into wellbores → *water scarcity* and *water contamination*
- Quantity of water used in hydraulic fracturing depends on a few factors, including geology of the formation, amount of recoverable oil or gas, number of fracture "stages", and local regulation. So the degree of water stress water consumption vary from one place to another (Kuwayama, 2015).
- Fracking process involves withdrawing groundwater at higher rates than it is replenished by hydrologic process, the aquifer is undergoing unsustainable →*Groundwater Depletion*.
- The amount of water consumed is in a range between 2 million to 10 million gallons per well annually. Nearly 39% of global fracking sites lie within surface water-stressed regions (Tinker, 2012).
- Example: Tarrant County in Texas used 2.8 billion gallons of water in 2011 for hydraulic fracturing, which is equivalent to about 10% of the water used for hydraulic fracturing in Texas. Other Texan counties like Wise and Johnson also experienced high water consumption from hydraulic fracturing representing 19% and 29% of their overall county water consumption respectively. → Intensify the competition for water (Nicot, 2012)
- Water is mixed with proppant, methane, and many other chemical additives to create *fracking fluid*. These chemicals compounds can leak out and contaminate the groundwater. Preferential flow through fractures can transport contaminants from the fractured shale to aquifers and drive contaminants towards the surface. Also, 75% of the 353 chemicals used in fracking fluids can negatively impact an individual's immune system and cause cancer. → Scarcity of clean groundwater reservoir (Robert, 2013)
- Example: In 2013, methane was detected in 82% of 141 underground drinking samples found within one kilometer of fracking zones in shale gas wells in Northeastern Pennsylvania. Studies show the concentration of methane and propane in underground water near fracking sites are significantly higher than sites not near the zones (Robert, 2013).

Radioactivity:

- In hydraulic fracking process, radioactivity comes from two sources: *radioactive tracers* and *naturally occurring radioactive material* injected into wells.
- Radioactive tracers are injected with hydraulic fracturing fluids to trace and measure the location of created fractures. Tracer isotopes include: iodine-131 (8.02 days), silver-110m (8.28 days), argon-41(109.61 minutes), and so on. → have short *half-life period*.

*Half-life period is the time it takes for a radioactive substance to reduce to half its initial value. 1 gram of iodine-131 would have 0.5 gram remaining after 8 days. Shorter half-life → emitting more radioactive particles in a given time → lower dose needed to produce health and environmental impact

- Naturally occurring radioactive material (NORM) in fracking site is created when fracking fluids carry sulfates up to the ground. Radium-226 and Radium-228 (1600 years) are common sulfate compounds to discover in fracking site → *long Half-life period* (Hanlon, 2012).
- Example: Widespread accidental wastewater spills in North Dakota fracking site caused long-lasting contamination of soil and water. Soil samples collected downstream from spill sites have higher level of radioactivity than soil at spill sites. High level of radium was detected four years after spill occurred (Duke, 2016).
- Hazard: resistance to biodegradation, cell proliferation, bio-mutation, cancer, leukemia, biological diversity crisis, and so on (Duke, 2016).

Political - Ivonne

Fracking and Governments - General Observations

- Fracking is contentious and treated differently not only across countries, but also throughout different locations within the same country.
    - Examples: banned in New York, France, Netherlands. Permitted in Texas, UK (Choma, Hanoch, & Currie, 2016).
- States must balance resource development with environmental protection.
- Some governments enthusiastically adopt shale gas production, especially Canada and the US. Other countries are less enthusiastic because of environmental hazards, unfeasible geology, and stricter government regulations (McBride & Sergie, 2015).

Fracking and Geopolitical Influence

- Advantages: Full development of shale gas bolsters state's economy and overall political influence.
    - Example: Hydraulic fracturing has allowed the US to overtake Russia and Saudi Arabia as the world's largest producer of crude oil in 2013, strengthening their geopolitical influence in comparison (Sovacool, 2014).
- Disadvantages: Influx of "cheaper", "cleaner" oil from fracking upsets economic balance of those countries who do not participate in fracking. Puts investments in other sources of energy at stake, taking away from economy and amount of geopolitical influence state has.
    - Example: Great shale gas production by Europe could lessen their dependence on Russia for gas. Russia will drive down gas prices and lose geopolitical influence over region (Sovacool, 2014).
- However, either way, hydraulic fracturing is reshaping global energy affairs, especially considering that the three largest energy consumers (China, EU, and USA) have large shale gas deposits (Sovacool, 2014).
    - Influence is not insignificant - International Energy Agency expects $6.9 trillion to be invested in infrastructure from now until 2035, and 80% of natural gas wells in the next decade are predicted to use hydraulic fracturing. Whichever country utilizes hydraulic fracturing will yield significant economic wealth and thus, significant geopolitical influence (Sovacool, 2014).

Fracking and Government Regulations - USA & Canada

- Governments susceptible to both industry influence and anti-fracking groups when forming policies. Both "pro-drilling and anti-drilling groups…use courts and the political or administrative powers at their disposal to win their goals" (Rahm) (Sovacool, 2014, p. 260).
- USA:
    - Regulated on a state by state basis, with guidance from the Interstate Oil and Gas Compact Commission (IOGCC). Many parties influence regulations: defensive politics from the IOCGG, trade groups like the American Gas Association, and the public.

- Fracking treated very differently from other forms of oil and gas extraction. Federal governance generally limited (Davis, 2017).
    - Congress exempts if from certain provisions of the Environmental Protection Agency's Clean Water Act.
    - Lack of federal laws mandating hydraulic companies to be transparent about the types of chemicals used in the hydraulic fracturing process leads to lack of research and hinders knowledge
- Within states: conflict between natural gas policy actors and environmental policy actors (Davis & Hoffer, 2012).

- Canada:
    - Provincially regulated because water and drilling permits vary from province to province.
        - Example: No requirement in Saskatchewan or Manitoba to disclose chemicals in fracking fluids, unlike BC and Alberta (Rivard et al., 2014).
    - Moratoriums in some provinces, and banned in Quebec. Many parties influence moratoriums, like Council of Canadians and some First Nations. Despite this, there is no national moratorium on fracking yet (Minkow, 2017).
    - Government requires consultation of First Nations on decisions impacting their rights/title on land (Rivard et al., 2014).
    - In Alberta, Alberta Energy Regulator (a corporation) governs most aspects of oil and gas industry. In BC, this is governed by BC Oil and Gas Commission (a crown corporation) (Rivard et al., 2014).
    - Provincial and federal governments conduct research on environmental issues, and industry is moving towards more environmentally conscious practices, but practices are still mostly unregulated (Rivard et al., 2014).

Economics of Extraction - Mark

1, Introduction

In this part, I will pay my attention to the economic aspect of hydraulic fracturing. More specifically, I will focus on the cost and benefit. It is simply divided to two main ideas. The costs and the revenue. Within the cost part, I will talk about cost of construction and production cost comparison to other traditional extraction methods.

2, Cost

2-1 Cost of Construction

Over the period from 2006 to 2010, the average number of wells drilled per year was 43,237, with an average cost of $2.38 million per well (Fitzgerald, 2013).

Infrastructure development

According to U.S Energy Information Administration (2016), it was proved that 77% of total cost of wells is comprised by 5 key elements (JWN, 2016).

1,Rig related costs, about $0.9 million to $1.3 million, 12%-19% of well's total cost.
2,Casing costs, about $0.6 million to $1.2 million, 9%-15% of well's total cost.
3,Frack pumping costs, about $1.0 million to $2.0 million, 14%-41% of well's total cost.
4,Completion fluid costs, about $0.3million to $1.2 million, 5%-19% of well's total cost.
5,Proppant costs, about $0.8 to $1.8 million, 6%-25% of well's total cost.

2-2 Costs Compared to Traditional Extraction Methods

Conventional Production (Beattie, 2018):
Saudi Arabia: sometimes under $10/ barrel
Middle East and North Africa: around $20/ barrel
World average: $30 - $40/ barrel

Hydraulic Fracturing
$40/barrel without the higher drilling and fracking costs
could raise to $60 - 90/ barrel

It is obvious to find out that hydraulic fracturing cost more than conventional methods. Furthermore, there is a set of variability within the cost of fracturing. This means that every well has a different relationship between cost and revenue. From the range of $40 to $90/ barrel.

3 Direct Economic Revenue

By 2015, the number of hydraulically fractured wells grew to about 300,000. The production is about 4.3 million barrel per day, making up about 50% of the total oil output of the United States (EIA, 2016). Hausman and Kellogg (2015) also pointed out that economic well-being of consumers is about $74 billion per year over the period from 2007 to 2013.

4 **Conclusion**

In this part, we just simply calculated the cost and revenue of hydraulic fracturing in terms of economic cost and benefit. Real life situation would be more complicated, therefore some more factors should be taken into account.

Economics Impacts - Bentley

Impacts to Consumers

- The increase in supply of natural gas production from methods such as hydraulic fracturing has decreased the equilibrium price of gas, increasing consumer surplus
- Natural gas and the electricity it can generate both play a role as an important input in a variety of industrial processes. The decrease in price of natural gas benefits these industries by lowering their costs, and in turn benefit consumers due to cheaper products (Mason et al., 2015; Sovacool, 2014).
- Mason et al. notes that if price elasticity of demand was estimated to be -0.5, and assuming all extra natural gas output from January 2007 to January 2014 is a result of fracking, that there has been a $4.36 billion USD increase in consumer surplus from the increased natural gas output (Mason et al., 2015, p. 272)

Impacts to Producers

- Fracking has increased the recoverable reserves of natural gas, leading to a shift of the supply curve outward, increasing producer surplus (Mason et al., 2015, p. 272).
- Mason et al. suggest that fracking has a more elastic price elasticity of supply. Estimating at 0.1, they show that producer surplus from January 2007 to January 2014 is in the order of $9.60 billion (2015, p. 273).

Local and Regional Impacts

- Regional economies may receive varying results from the fracking resource boom. There can either be increased investment into nonextraction sectors, or increased local prices in the nonextraction sectors (Mason et al., 2015, p. 273)
- Many state-run gas monopolies particularly in Asia have weakened due to accelerated global shale gas production
    - Cheaper shale gas production forces these monopolies to match the cheap natural gas prices, creating a much more competitive global market (2014, p.253)
- Economic benefits from royalty payments to landowners, governments gaining revenue from taxes, impact fees, and permits, and an increase in local jobs (Mason et al., 2015; Sovacool, 2014; Lehr, 2016)
    - 360,000 direct jobs, 537,000 indirect supply industry jobs (equipment manufacturers, truckers, etc.) (Lehr, 2016, p. 707)
    - Estimated 850,000 induced jobs, supported by the paychecks of the oil and gas industry workers (movie theaters, grocery stores, etc.) (Lehr, 2016, p. 707)
    - The United States "In 2012, total tax revenue from unconventional oil and gas production were approximately $62 billion" (Lehr, 2016, p. 710). Expected to grow to $111 billion by 2020.

Social & Cultural - Hugo

Author(s)	Publication year	Social findings
Hirsch et al.	2018	Individual and collective mental health issues in communities affected by fracking including; anxiety, depression, fear and worry. Fracking also poses a threat to physical health like; fatigue, headaches, delirium, confusion and an increased rate of cancer. These problems are related to elements like light, water and noise pollution. Also, the destruction of landscapes and ways of life, due to a rapid industrialization.
Kameshwari et al.	2018	Up to twenty-nine carcinogenic substances derived from the process of hydraulic fracturing, affecting human health. Poor waste administration of the residual fluid to perform fracking, deriving in threats to human food sources like agriculture, fisheries and wildlife.
Grecu, E., Aceleanu, M. I., & Abulescu	2018	Study case regarding hydraulic fracturing in Romania. While some areas in Romania have water scarcity issues like Barlad's city, fracking is still taking place there. Contamination of water with carcinogen agents and other chemicals, that can not be quantified in monetary units.
Scott et al.	2011	The process of fracking does not necessarily help the local communities nearby to develop in a consistent way, and create environmental externalities, while other places receive most of its benefits. A comparison between global and local scales in relation to fracking pros and cons.
Sovacool, B. K.	2014	The conversion of rural or suburban areas into heavy industrial zones, due to fracking installations. While there is already a water management problem worldwide, fracking requires substantial amounts of water to take place, and 1.7 billion people live in areas where groundwater ecosystems are under threat. In short, fracking reduces water availability, quality and threatens watershed ecosystems and functions.

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Appendix A:

Figure 1

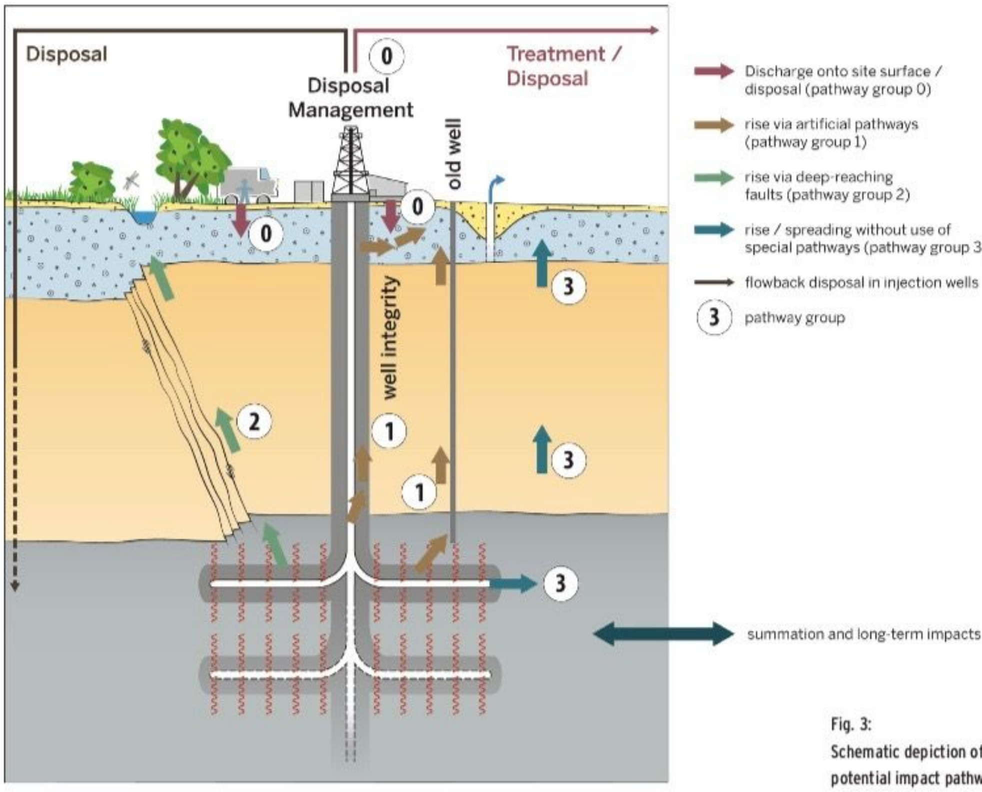

Fig. 3:
Schematic depiction of
potential impact pathways