Backgrounder on Hydraulic Fracturing: The Basic Facts

Newfoundland and Labrador

Department of Natural Resources

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Contents

Backgrounder on Hydraulic Fracturing: The Basic Facts

Introduction

This backgrounder is intended to explain and describe the process of hydraulic fracturing during the drilling for and production of oil and gas (see Figure 1). It will focus primarily on the technical aspects of fracturing. It is set out as a series of basic facts about hydraulic fracturing to provide residents of Newfoundland and Labrador with a better understanding of this controversial and complex topic.

As it becomes more widely used, hydraulic fracturing has become a contentious public policy issue, with concerns regarding the environmental and health effects of its use. This has led to many studies and much research on these effects, in trying to help better understand the impacts. It has also led to regulatory changes in many jurisdictions that seek to prevent or mitigate these potential effects.

The discussion is further complicated by the fact that in many cases it is unclear whether the concerns raised relate specifically to hydraulic fracturing, or more generally to the development of unconventional petroleum resources, or to other aspects related to all oil and gas development. This backgrounder will explain hydraulic fracturing and address many of the questions and concerns that have been raised.

Figure 1: A hydraulic fracturing operation in B.C.'s Horn River using multiple wells on a single pad (Picture Courtesy of Nexen, 2010)[1].

[1] Petroleum Technology Alliance Canada (PTAC) Report, June 2012, "The Modern Practices of Hydraulic Fracturing: A Focus on Canadian Resources, http://www.ptac.org/projects/42.

This backgrounder has been compiled from a number of sources, with two that have been particularly helpful being –

1. The Geological Society of America's "*GSA Critical Issue: Hydraulic Fracturing*", an electronic briefing which can be found on its website[2] and is provided by the GSA to "encourage and stimulate broader, informed participation in the public discourse … of issues that are likely to be impactful on the geosciences community and those for which the participation of geoscientists is important to an informed debate", and
2. The Nova Scotia Hydraulic Fracturing Independent Review and Public Consultation's "*Primer on the Process of Hydraulic Fracturing*"[3], prepared by Cape Breton University's Verschuren Centre for Sustainability in Energy and the Environment "to describe key aspects of the ***process*** of Hydraulic Fracturing to share with Nova Scotians".

These two documents have many references that can be reviewed by visiting their websites. Additional sources are used where necessary and appropriate, as identified in the document.

Why is Hydraulic Fracturing Used?

Reservoir Characteristics

Oil and natural gas are hydrocarbons found in subsurface sedimentary rock formations in the pore spaces between grains of rock, called reservoir rock. A necessary characteristic for a rock to be a hydrocarbon reservoir rock is that it have pore spaces that hold the hydrocarbons. Under favorable geologic conditions, the reservoir rock will be permeable as well as porous, allowing the hydrocarbons to flow freely from the pore spaces in the reservoir rocks to oil and gas wells and to the surface. Reservoir rocks which allow hydrocarbon production to freely flow are traditionally referred to as 'conventional' hydrocarbon reserves.

In some reservoir rocks, hydrocarbons are trapped within the microscopic pore spaces because the pore spaces are not connected; these rocks are called low-permeability reservoirs (see Figure 2). Low-permeability reservoirs are often composed of fine-grained rocks, such as shales, whose very small and poorly connected pore spaces are not conducive to the free flow of liquid or gas. Low-permeability is also found in some sandstones and carbonate rocks, such as limestone, which are often referred to as 'tight' formations. Geologists have long known that large quantities of oil and natural gas occur in these low-permeability formations, but economic recovery of these resources has generally been prevented or constrained by technical challenges. Hydraulic fracturing can enhance the permeability of these rocks by creating fractures in the reservoir rock, thereby connecting the pore spaces and allowing previously trapped oil and gas to flow to a well and be economically recovered.

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[2] See http://www.geosociety.org/criticalissues/hydraulicFracturing/index.asp, hereinafter referred to as GSA Posting.

[3] See http://www.cbu.ca/sites/cbu.ca/files/docs/hfstudy/Primer%20on%20Hydraulic%20Fracturing%20Process%2010th%20March%202014%20-%20For%20Public%20Consultation.pdf; hereinafter referred to as NS Primer.

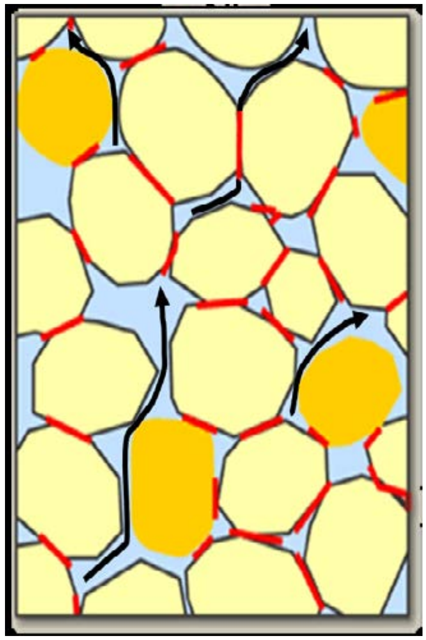

Figure 2: Schematic of rock grains, pore space, and permeability. The interconnection of spaces between grains allows flow of gas or other fluid. Modified by GSA from Bureau of Economic Geology, The University of Texas.[4]

What are Shale Gas and Shale Oil?[5]

Hydrocarbons that reside in the pore spaces of shale reservoirs are called 'shale gas' if in the gaseous phase or 'shale oil' if in the liquid state. While the terms are popularly used, they are often also referred to as 'unconventional resources'. The low-permeability reservoir rocks in which unconventional resources are found may include mudstone, siltstone, sandstones, and carbonates (limestones and dolomites) as well as shale. These rocks are formed from layers of clay, silt, sand and other sediments, including the organic remains of ancient plant and animal life that are deeply buried and cemented tightly by pressure and chemical processes over long periods of time (centuries and millennia).

When buried deeply underground for a sufficiently long time, the resulting pressure and temperature conditions cause the organic matter buried in the sedimentary layers to develop into gas and oil. Rocks that are especially tightly cemented exhibit poor connectivity, resulting in the gas or oil remaining trapped in the pore spaces of the rock, unable to escape the reservoir rock, or to flow only very slowly. Oil and gas in these difficult-to-produce reservoirs require special completion, stimulation and/or production techniques to achieve economic production, and are generally referred to as unconventional resource reservoirs.

While oil and gas recovered from unconventional reservoirs may often be referred to as an unconventional resource, it is really the reservoir and recovery techniques that are unconventional, not the oil or gas that is recovered. Shale gas, for example, consists primarily of methane - an odourless,

[4] GSA Posting.
[5] NS Primer.

colourless and flammable gas - although other natural gases and hydrocarbons are often present, just like the natural gas from conventional reservoirs.

How Are Wells Drilled To Access Shale Gas?

Wells drilled into low-permeability reservoirs are now usually, and increasingly so, horizontal wells. Traditional vertical wells may be drilled a thousand or more metres deep and penetrate a few (tens of, maybe hundreds of) metres of the reservoir rock. Horizontal wells are drilled vertically until they reach a kick-off point just above the target formation, and are then directed laterally so that as the well enters the reservoir it runs parallel to the reservoir rock formation, which is usually nearly horizontal, and follows the narrow layers of reservoir rock (see Figure 3). The horizontal legs of these wells may extend several thousand metres through the target reservoir rock, thereby accessing a far greater volume of the reservoir than a traditional vertical well that accesses the vertical thickness of the reservoir rock only once.

While more expensive than a vertical well, a horizontal well replaces the need for multiple, closely-spaced vertical wells to tap the same reservoir volume. Multiple horizontal wells can be drilled from one well pad, significantly reducing the total amount of land needed for the drilling platform and associated surface production equipment, even though a multi-well horizontal well pad is larger than a traditional single-well vertical well pad.

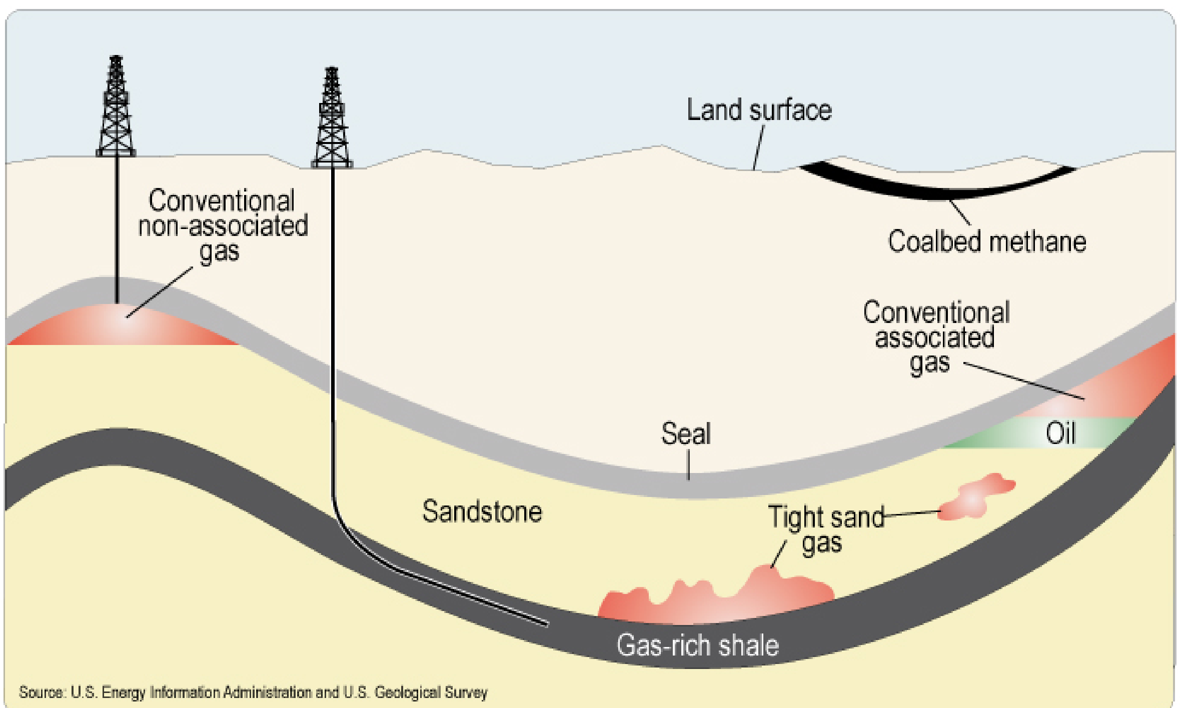

Figure 3: Schematic geology of natural gas resources.[6].

[6] http://www.eia.gov/todayinenergy/detail.cfm?id=110.

How Is Fracturing Accomplished?

Hydraulic Fracturing

Hydraulic fracturing (also known as ‘fraccing’ or ‘fracking’) is a technique to stimulate a reservoir after a well has been drilled to enhance the production of oil and gas from that reservoir. Hydraulic fracturing, or other forms of well stimulation, are part of `completing’ the well, which is the process of making the well ready for production.

Following the drilling and installation of casing in the well, holes are created along selected intervals of the well casing within the formation from which gas or oil is produced (the ‘production zone’) by using small explosive charges to perforate the casing. The need to perforate the casing in the production zone is not unique to hydraulic fracturing; it is part of completing all oil and gas wells and is necessary to allow the oil and gas to flow from the reservoir into the well for recovery. Completion techniques for horizontal wells may also include special downhole equipment including assemblies of sleeves and packers, as well as different techniques for cementing and perforating along the horizontal section of the well.

In low-permeability reservoirs, simply perforating the casing in the production zone is not sufficient to allow oil and gas to flow into the well. In hydraulic fracturing operations, large quantities of fluids are pumped at high pressure down the well in order to enter the target rock formation through the selected perforations (see Figure 4). The pressure used to inject the fluids is carefully assessed and planned to generate pressure in excess of the minimum stress fields of the reservoir rocks to open existing fractures and create new fractures in the formation. The fractures created may extend a hundred metres vertically and perhaps several hundred metres laterally into the rock, depending on the size and nature of the operation.

The objective of the operation is to optimize the extent of the fractures created within the formation, while preventing uncontrolled fracture growth. This optimization may be assisted by monitoring the fracturing operation with micro-seismic surveys to record the locations, geometry and dimensions of the fractures within the formation. These surveys show the orientation of the fractures and how far they extend in the formation. The surveys are especially used in initial fracturing operations in a new area to assist the engineers and drillers in designing and optimizing future fracturing programs to safely and effectively stimulate the reservoir.

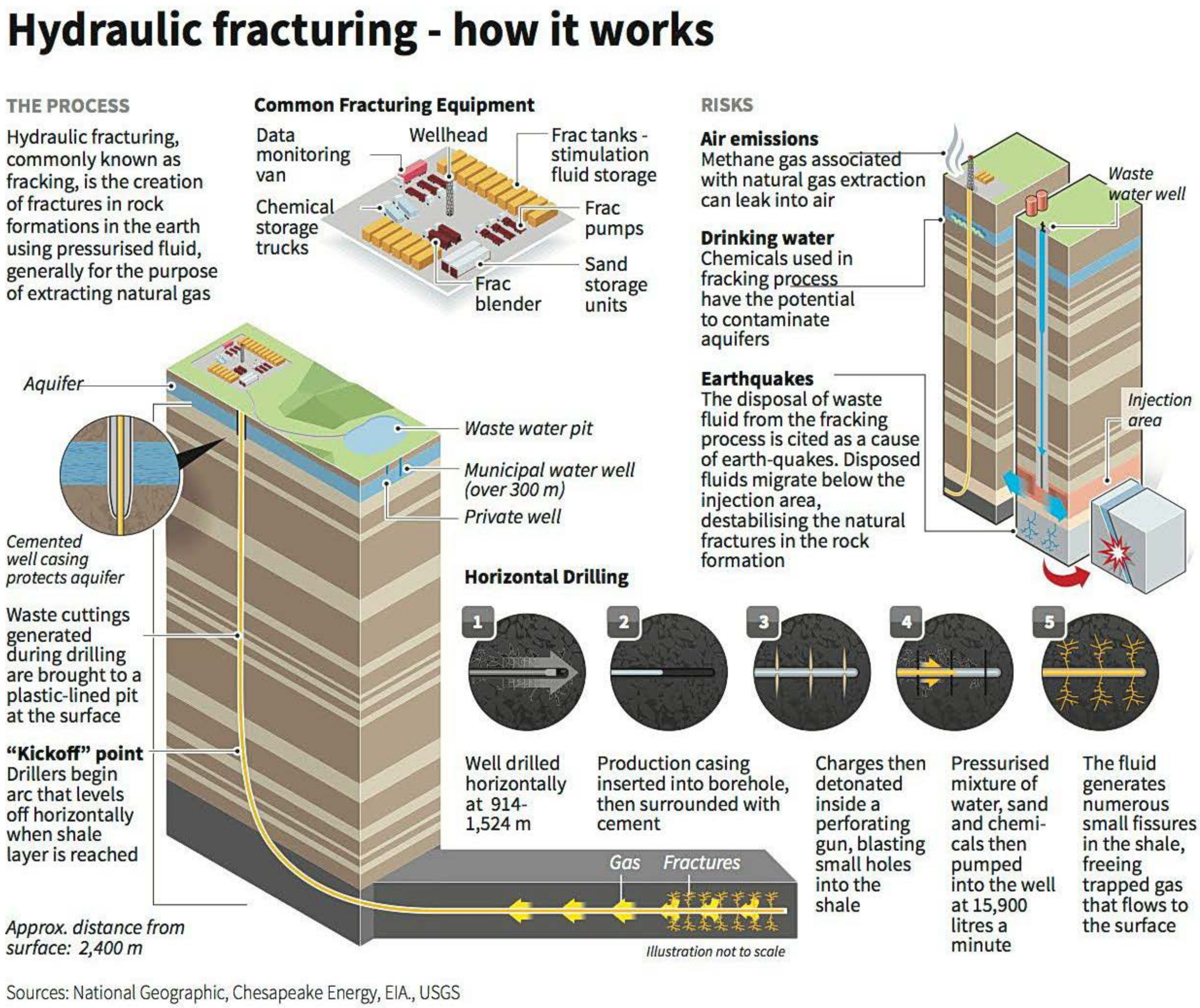

Figure 4: Hydraulic fracturing – how it works[7]

The appropriate pressure and fluid characteristics of the hydraulic fracturing operation are carefully planned and assessed to ensure the fractures are directed to, and do not extend beyond, the target reservoir rock. Proppant (appropriately sized grains of sand or another inert material such as ceramic beads) carried in the fluids remains in the newly opened or created fractures to keep them propped open after the pressure is released. This allows the hydrocarbons that were trapped in the pore spaces in the rock to flow through the newly created "propped" fractures to the well, thereby facilitating recovery of previously trapped hydrocarbons.

Horizontal wells have more contact with the reservoir rock than traditional vertical wells, and thus typically undergo larger operations and use larger volumes of water than that of vertical wells. In a horizontal well, the process of perforating the casing and injecting fluids to perform hydraulic fracturing usually occurs in several stages along the horizontal wellbore. These are sometimes referred to as

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[7] NS Primer.

'multi-staged treatments', and generally consist of 10 to 15 treatments, and sometimes as many as fifty. Hydraulic fracturing operations at each stage may take from twenty minutes to four hours to complete.

Well Integrity

Hydraulic fracturing of low permeability rocks is generally through horizontal or directional (non-vertical) wells which typically involve longer boreholes and much greater volumes of water than vertical oil and gas wells. Protecting the groundwater in aquifers above the target reservoir formation requires proper well design, construction and monitoring.

Proper well construction is an essential component of drilling and completing all wells, not just wells that undergo hydraulic fracturing. Well integrity is defined to be the "application of technical, operational and organizational solutions to reduce risk of uncontrolled release of formation fluids throughout the life cycle of a well".[8] Proper well design and construction are necessary to prevent hydrocarbons or fluids from leaking out of the well and entering other subsurface formations. Wells used to recover gas and oil resources from the reservoir rock have wellbores that progressively decrease in diameter as well depth increases. The wellbores are lined with steel casing that is joined together to form a continuous 'string' of casing (see Figure 5). The length of each casing string is site specific and dependent on the depth of the well and the types of formations it penetrates. Of particular importance is the depth of fresh groundwater aquifers, which are generally quite shallow relative to the production zone but still must be isolated from the wellbore. Regulators typically advise or instruct industry on the casing sizes and cementing depths required to ensure isolation of groundwater resources to avoid contamination during or after the drilling process.

Each well is drilled slightly oversized to allow the steel casing to be installed, leaving an open space – or 'annulus' -- between the casing and outer edge of the hole. This space is filled with cement through the necessary zones, as designated by the regulator, to achieve the required isolation. Also, the space between each progressively smaller casing string is cemented off. Pressure-testing the cement seal between the individual casing strings and the casing and the surrounding rock, or other methods of examining the integrity of wells, is often required to ensure an impermeable barrier is established and maintained. If necessary, remedial work to establish isolation must be undertaken before proceeding to the next wellbore section.

Wells drilled through rock formations containing high-pressure gas require special care in stabilizing the wellbore and the cement, or their integrity can be damaged. During drilling, a blowout preventer (BOP) is placed at the top of the well to automatically shut down fluid flow (influx) in the wellbore should any over-pressurized zones be encountered during drilling operations. This allows the well to be safely shut-in and the influx fluids to be circulated from the well.

[8] http://www.standard.no/en/PDF/FileDownload/?redir=true&filetype=Pdf&item=644901&category=4.

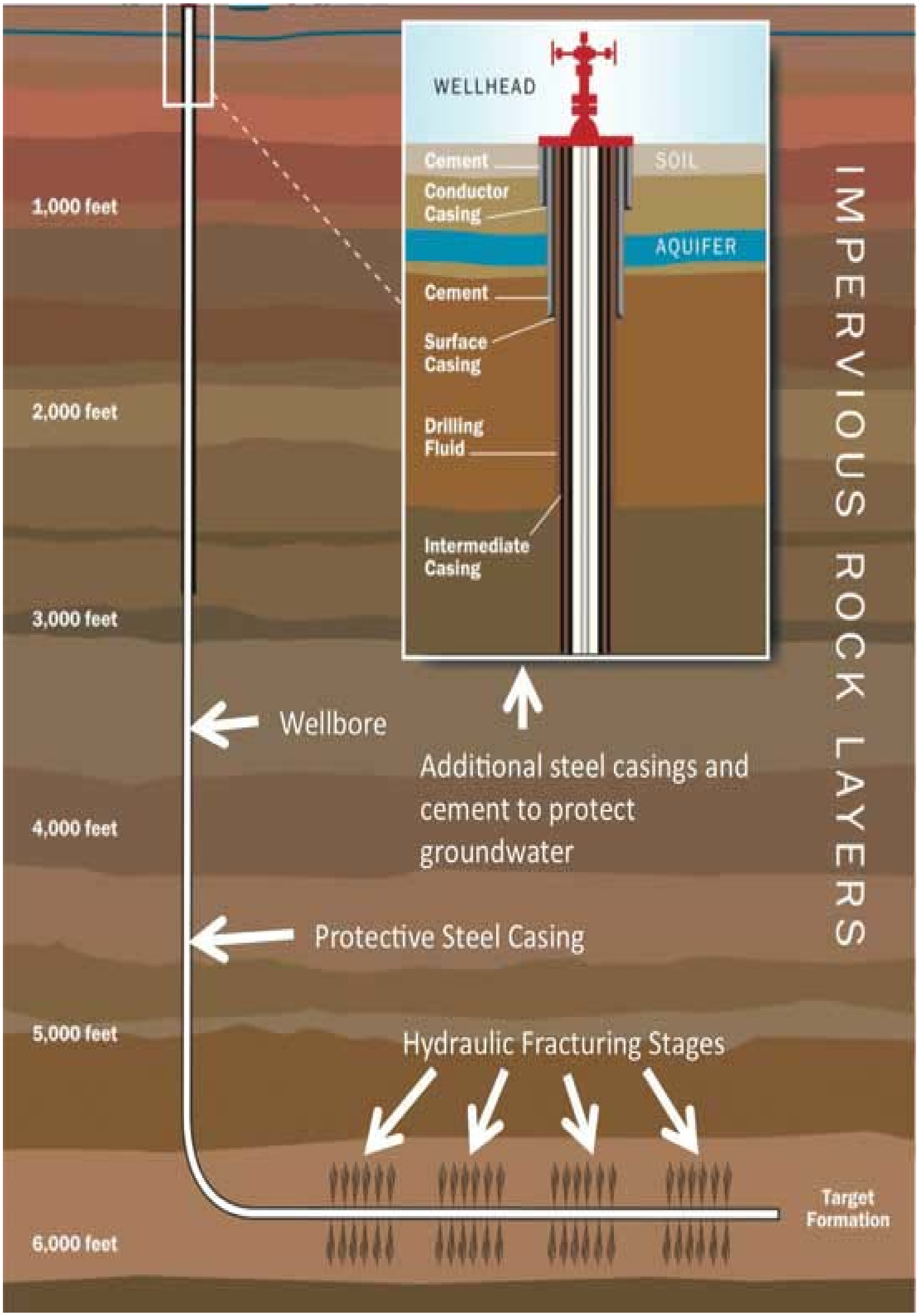
WELLHEAD
Cement
SOIL
Conductor Casing
AQUIFER
Cement
Surface Casing
Drilling Fluid
Intermediate Casing
IMPERVIOUS ROCK LAYERS
1,000 feet
2,000 feet
3,000 feet
4,000 feet
5,000 feet
6,000 feet
Wellbore
Additional steel casings and cement to protect groundwater
Protective Steel Casing
Hydraulic Fracturing Stages
Target Formation

Figure 5: Horizontal Well Construction; from U.S. EPA Study Progress Report, December 2012, modified by Kansas Geological Survey[9]

What is In the Fracturing Fluid?[10]

Hydraulic fracturing fluids are generally composed of water, 'proppants' and chemical additives, and are mostly water based. Most commonly fresh water is used, however treatments have also been performed using seawater. Chemical additives ensure the fracturing operation is effective and efficient, and serve many functions from limiting the growth of bacteria to preventing corrosion of the well casing (see Table 1). During multi-stage fracturing, different volumes of fracturing fluids may be injected with differing concentrations of proppant and chemical additives allowing each stage to address local geological conditions. Water and proppant typically comprise 98-99% of the total fluid volume and chemicals compose the remaining 1 to 2%.

Chemical additives in fracturing fluids are among the most controversial aspects of hydraulic fracturing. Table 1 summarizes the principal chemical additives used in fracturing fluids, their main compounds, the reason the additive is used in hydraulic fracturing operations, and some other common uses of these compounds.

Additive Type	***Main Compound(s)***	***Purpose***	***Common Use of Main Compound***
Diluted Acid (15% HCl)	Hydrochloric acid	Help dissolve minerals and initiate cracks in the rock	Swimming pool chemical and cleaner
Biocide	Glutaraldehyde	Eliminates bacteria in the water that produce corrosive by-products	Disinfectant; sterilizing medical and dental equipment
Breaker	Ammonium persulfate	Allows a delayed break down of the gel polymer chains that help suspend the proppant	Bleaching agent in detergent and hair cosmetics, manufacture of household plastics
Corrosion Inhibitor	N,n-dimethyl formamide	Prevents the corrosion of the pipe	Used in pharmaceuticals, acrylic fibers, plastics
Crosslinker	Borate salts	Maintains fluid viscosity as temperature increases	Laundry detergents, hand soaps, and cosmetics
Friction Reducer	Polyacrylamide	Minimizes friction between the fluid and the pipe	Water treatment, soil conditioner
	Mineral oil		Make-up remover, laxatives, and candy
Gel	Guar gum or hydroxyethyl cellulose	Thickens the water in order to suspend the proppant	Cosmetics, toothpaste, sauces, baked goods, ice cream

[9] GSA Posting.
[10] NS Primer.

Iron Control	Citric acid	Prevents precipitation of metal oxides	Food additive, flavoring in food and beverages; Lemon Juice ~7%Citric Acid
KCl	Potassium chloride	Creates a brine carrier fluid	Low sodium table salt substitute
Oxygen Scavenger	Ammonium bisulphite	Removes oxygen from the water to protect the pipe from corrosion	Cosmetics, food and beverage processing, water treatment
pH Adjusting Agent	Sodium or potassium carbonate	Maintains the effectiveness of other components, such as crosslinkers	Washing soda, detergents, soap, water softener, glass and ceramics
Proppant	Silica, quartz sand, ceramic beads	Allows the fractures to remain open so the oil or gas can escape	Drinking water filtration, play sand, concrete, brick mortar
Scale Inhibitor	Ethylene glycol	Prevents scale deposits in the pipe	Automotive antifreeze, household cleansers, and de-icing agent
Surfactant	Isopropanol	Used to increase the viscosity of the fracture fluid	Glass cleaner, antiperspirant, and hair color
Note: The specific compounds used in a given fracturing operation will vary depending on company preference, source water quality and site-specific characteristics of the target formation. The compounds shown above are representative of the major compounds used in hydraulic fracturing of shales.			

Table 1: Modified from Fracturing Fluid Additives, Main Compounds and Common Uses[11]

In some countries the chemical combinations used in fracturing fluid are considered trade secrets; but disclosure is being increasingly required. In Canada, regulators in B.C., Alberta and NWT have moved to full disclosure, with fracturing reports on all wells undergoing hydraulic fracturing operations being published on www.fracfocus.ca, including information on chemicals used, concentrations and purpose of use. In Newfoundland and Labrador, current regulations require the submission of “end of well” reports and completion reports detailing the activities carried out at the well, including use of chemicals.

What Comes Back When Fracturing is Completed?

Once the injection process is completed, internal reservoir pressures cause fluid to return to the surface through the wellbore. Some of the fracturing fluids remain in the subsurface and some return to the surface, called ’flowback water’, along with oil, natural gas and water that were naturally present in the producing formation. The natural formation water that is produced, called ’produced water’, is often highly saline, and non-potable. The hydrocarbons are separated from the returned fluid at the surface, and the flowback and produced water is collected in tanks for treatment or injection. Handling and disposal of returned fluids is a normal part of oil and gas drilling operations, and is not limited to hydraulically fractured wells.

The flowback water includes:

- injected water, sand (or other proppants) and injected chemicals,

[11] http://energy.gov/sites/prod/files/2013/03/f0/ShaleGasPrimer_Online_4-2009.pdf.

- natural gas or oil, and
- some produced water which is naturally occurring water from the reservoir, which may contain salty brines, metals, nutrients, naturally-occurring radioactive materials (NORMs), and other organic compounds which are brought to the surface with the flowback water.

Typically 25 to 75% of the injected fracturing fluid flows back to the surface when the well is produced, depending on formation properties, the fracturing program design and the type of fracturing fluid used. Flowback water will continue to return to the surface over the producing lifetime of the well but mainly occurs in the early stage of production.

On-site systems separate the hydrocarbons (oil and natural gas, including any liquefied petroleum gases in the natural gas -- eg, butanes and propane) from the water and sand in the flowback waters, before directing the recovered hydrocarbons into the pipeline or storage tanks. 'Green completion technologies' and restrictions on flaring and venting are actively being put in place to reduce venting or flaring of the gases.

Because shale tends to contain more uranium than other types of rocks, Normally Occurring Radioactive Materials (NORMs) may be found in flowback water from wells drilled into shale reservoirs. Components such as wellheads, separation vessels, pumps, and other processing equipment can become contaminated with NORMs, and can be found in the drilling mud, sludge, and tank bottoms. This can create a potential radiation hazard to workers, the general public, and the environment if certain controls are not established. Monitoring and management of NORMs is required. NORMs may also be present in waste fluids from the conventional oil and gas industry, as well as certain mining industries, so NORM management is not unique to shale gas or hydraulic fracturing operations.

How is the "Flowback Water" Handled?[12]

Before treatment, disposal or recycling, flowback water is typically stored on site in tanks, which may also hold drilling muds, sludge and slimes. Ultimately, flowback water will be sent to a treatment facility, or disposed of by injection into a deep formation through a disposal well. (See Figure 6). Pre-treatment can take place on-site, although this is typically expensive. Injection of waste fluids into deep porous and permeable rock formations is generally the preferred and primary disposal option for waste fluids from the oil and gas industry, as well as other industries. Disposal wells are often non-producing oil and gas wells in depleted reservoirs, but wells can be drilled specifically for disposal if it is more economic or necessary to do so. In the most active unconventional resource production areas in Alberta and British Columbia, systematic studies of deep saline aquifers have been completed or are in progress to identify the best zones for both saline water sourcing and flowback/produced water disposal. Alternatively, where wastewater cannot be injected into a disposal well, because appropriate reservoirs are not available or because the wastewater requires treatment, the wastewater must be transported to off-site treatment facilities.

Water is generally co-produced in equal or larger volumes than oil and gas over the life of a well. Thus, fluid handling and disposal are issues for all oil and gas wells, not only those undergoing hydraulic fracturing. Appropriate water management practices and regulatory oversight are required to prevent

[12] NS Primer.

or minimize accidental leaks and spills of wastewaters. Most unconventional resource production operations now employ integrated operational practices which minimize water use and recycle wastewater where possible.

Figure 6: Water cycle in hydraulic fracturing; from U.S. EPA's Study of the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources, Progress Report, 2012.

Hydraulic Fracturing Issues

Water Quality

Fracturing fluids include a variety of chemical additives, as discussed above, all of which are added for a specific purpose and to make the fracturing treatment more effective. The exact mix of additives depends on the formation to be fractured. These additives typically comprise 1 to 2% by volume of fracturing fluids. Some chemical additives could be hazardous, but are safe when handled according to requirements, and as shown in Table 1 many of these additives are common chemicals. However, fracturing fluids may still contaminate surface and drinking water (see Figure 7) because of:

- surface spills prior to injection;
- subsurface migration of injected fluids due to inadequate well integrity; and
- surface spills of flowback and produced water.

In particular, because the fluids are injected into the subsurface under high pressure, there are concerns that some fracturing fluids could move through the wellbore or fractures created in the reservoir rock and ultimately migrate up and enter fresh water aquifers in shallower formations. In addition, there are concerns that geologic faults, previously existing fractures, or poorly plugged, abandoned wells could provide conduits for these fluids to migrate into and contaminate aquifers.

Regulations regarding well integrity are largely designed to ensure the protection of potable, non-saline and useable groundwater. Well integrity is achieved by drilling and completion practices that include surface casing, cementing surface casing, production casing and cementing production casing. Most of these possible paths are mitigated by proper well integrity. However, because of the level of concerns being expressed, the risks of contaminating groundwater due to hydraulic fracturing are continuing to be studied. Setbacks are established to maintain distance between water wells and drilling operations.

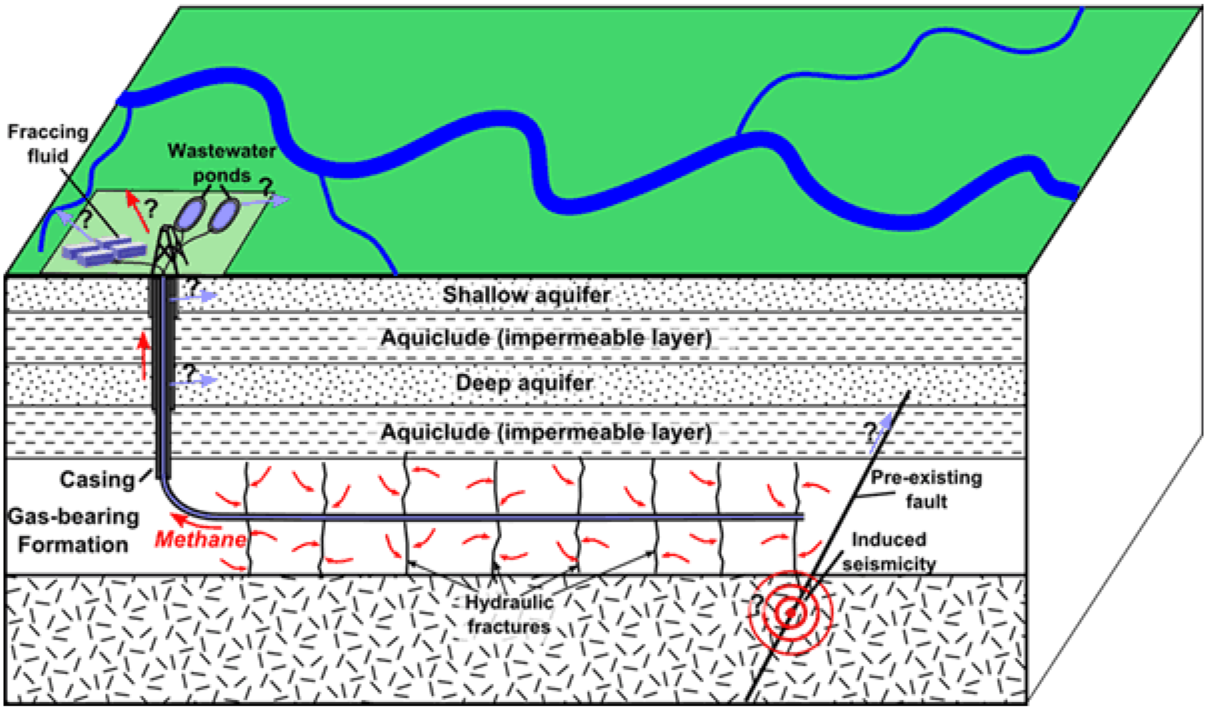

Figure 7: Diagram of possible fluid migration pathways and other environmental concerns with hydraulic fracturing. Source: Mike Norton, Wikimedia Commons.[13]

Hydrocarbon-bearing rock formations are typically deep relative to the freshwater aquifers. The thick sequences (hundreds to thousands of metres) of mostly low to very low permeability rock layers between an aquifer and hydrocarbon-bearing rock formations may provide a physical barrier that prevents fracturing fluids and naturally migrated hydrocarbons from reaching the aquifer. There may be a need to locate and properly plug abandoned or "orphaned" oil and gas wells and unused water wells as a further measure to protect near-surface aquifers.

Methane has been detected in some water wells in jurisdictions with oil and gas development, although it is not always clear whether this is caused by hydraulic fracturing. It is often challenging to distinguish contamination from natural seepage into groundwater unrelated to oil and gas development from contamination due to aspects of drilling unrelated to hydraulic fracturing, or from contamination directly caused by hydraulic fracturing. The methane may come from gas-producing rock layers below and close to the aquifer and be unrelated to the deeper fractured zone; it may reflect well integrity failure, but not be directly related to the hydraulic fracturing; it may be a result of hydraulic fractures being partly contained in a complex geologic environment. The origin of methane occurring in groundwater can be identified by chemical analysis of the methane. Best management practices suggest acquiring water quality samples prior to hydraulic fracturing to provide a baseline comparison. B.C.'s Oil and Gas Commission notes "there has never been an instance of groundwater contamination due to hydraulic fracturing in British Columbia".[14]

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[13] GSA Posting.
[14] http://www.bcogc.ca/whats-new/water#t6783n8122.

Water Use[15]

Hydraulic fracturing, particularly when applied through horizontal wells, can use as much as 50,000 m^3 of water per well, though 7,500 to 20,000 m^3 is more typical. B.C.'s Oil and Gas Commission reported that "In 2013, the average water use was 8,356 m^3/well (206 wells) in the Heritage Basin, 10,907 m^3/well (197 wells) in the north Montney, 79,069 m^3/well (18 wells) in the Horn River Basin, and 20,106 m^3/well (1 well) in the Liard Basin".[16] However, the volume of water used by the oil and gas industry is relatively small in comparison to use by other industries. The B.C. Oil and Gas Commission states that "The Mining and Petroleum segment of B.C. accounts for one per cent of total surface water allocated by sector"[17]. These sectors include conservation and land improvement, industrial and commercial, waterworks, agriculture and aquaculture.

U.S. studies[18] have found that water used for drilling and hydraulic fracturing shale gas wells in the U.S. represents less than 1% of total water usage in the areas where major shale gas deposits are being developed. However, where drilling rates are high and particularly in areas with water shortages, water use for hydraulic fracturing can become significant. The U.S. Environmental Protection Agency is studying the potential competition of hydraulic fracturing with drinking water supplies, both current and future demands in two basins, one humid (Susquehanna River Basin, Pennsylvania) and one semi-arid (Upper Colorado River Basin, Colorado)[19].

Drilling companies are working on increased use of recycled water used in hydraulic fracturing, and use of saline water that is unsuitable for drinking. Many energy companies are treating and reusing produced and flowback water.

Community and Surface Effects

Hydraulic fracturing, if performed near residences, towns or villages, may subject the inhabitants to disturbances and nuisances. The drilling of wells can cause disturbances, and the requirement for large amounts of water and material and pressure equipment in hydraulic fracturing operations will exacerbate these effects.

The effects of hydraulic fracturing operations on nearby residents, communities and municipalities have been reduced and mitigated in other jurisdictions by:

1. locating well and pad sites (setbacks) to minimise impacts on the local community, heritage sites, existing buildings and land use, and environmentally sensitive areas;
2. using multi-well pads where possible to minimize surface footprints and community disturbances;
3. managing noise by restricting noise levels;

[15] GSA Posting
[16] "2013 Annual Report on Water Use for Oil and Gas Activity", http://www.bcogc.ca/node/11263/download, p.18.
[17] http://www.bcogc.ca/sites/default/files/documentation/fact-sheets/waterusefinal_4.pdf.
[18] Massachusetts Institute of Technology – The Future of Natural Gas, 2011, http://mitei.mit.edu/publications/reports-studies/future-natural-gas.
[19] http://www2.epa.gov/sites/production/files/2014-03/documents/summary_of_the_technical_roundtable_on_epas_study_of_the_potential_impacts_of_hydraulic_fracturing_on_drinking_water_resources_december_9_2013.pdf.

4. managing vehicular traffic by controlling traffic patterns and timing; and
5. providing satisfactory financial security to remedy potential damages inflicted.

Methane Venting and Emissions[20]

Industry and regulators are developing and implementing new technologies and regulations to reduce methane released during completion and production. By January 2015, for example, the U.S. Environmental Protection Agency (EPA) will require all new natural gas wells in the U.S. to include green completion measures to reduce emissions. Green completions, or reduced emission completions, take place during the clean-up stage of the completion, after hydraulic fracturing operations. The clean-up involves removing the water necessary to fracture the well. During the period of initial flowback of fracturing fluids from the well, natural gas is produced with the flowback water. What makes the well completion 'green', or environmentally friendly, is the separation of the gas from the water, using portable separation equipment if necessary, and placing the gas in a pipeline instead of flaring or venting it to the atmosphere. A pipeline must be in place to perform a green completion, so the goal is to have a pipeline in place by the date of the final fracturing job on any given well.

Additional new requirements also will impact tanks, pneumatic devices, leak detection and leak control.

Canada has been a leader in reducing venting and flaring in its oil and gas industry, and provided much of the model and impetus for the World Bank's *Global Venting Reduction Strategy*,[21] in which NL is a participant.

Is Horizontal Drilling/Hydraulic Fracturing New?

The technology combination of hydraulic fracturing, the use of horizontal wells, and the chemistry of the fracturing fluid is rapidly evolving and its use is quickly expanding. Hydraulic fracturing and horizontal wells are not new practices for the oil and gas industry, although their use is now rapidly increasingly and the technologies are continuously improving. Millions of 'fracs' have been carried out to date throughout the world. The first fracturing in the U.S. was conducted in the 1940s and the practice was commercialized by 1950. In Canada, fracturing was used in the Pembina oil and gas field in Alberta in the early 1950s, and has been widely used throughout Western Canada since the late 1970s to recover gas and oil from low-permeability sandstone reservoirs.

It is difficult to get accurate statistics of the number of fractures performed in Canada to date, but the Petroleum Services Association of Canada states that over 175,000 fracturing operations have been carried out in wells in Alberta and B.C. to date.[22] In Western Newfoundland, a fracturing treatment occurred in the Flat Bay area in 2004. No hydraulic fracturing has occurred in Newfoundland and Labrador since 2004, however, additional work has been proposed for several areas of western NL where hydraulic fracturing potentially could be used to stimulate production.

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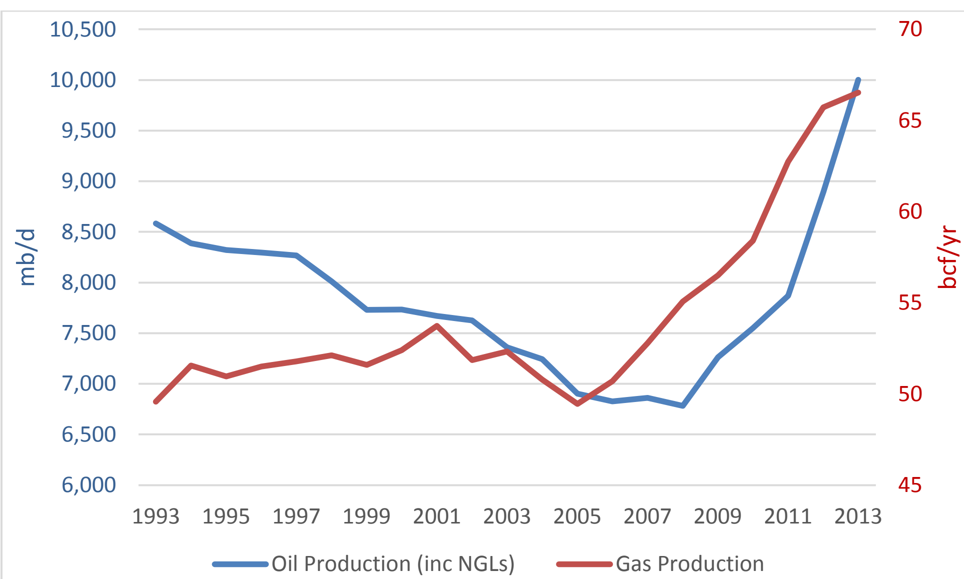
[20] API, Hydraulic Fracturing: Unlocking America's Natural Gas Resources, July 2014, http://www.api.org/oil-and-natural-gas-overview/exploration-and-production/hydraulic-fracturing/~/media/Files/Oil-and-Natural-Gas/Hydraulic-Fracturing-primer/Hydraulic-Fracturing-Primer-2014-highres.pdf.
[21] http://siteresources.worldbank.org/EXTGGFR/Resources/canada_cip.pdf.
[22] http://www.oilandgasinfo.ca/fracopedia/hydraulic-fracturing-explained/.

While the first horizontal well was drilled in the 1930s, such wells became increasingly common since the late 1990s. This was made possible by the advances in equipment and information technology in recent decades which has allowed drilling operations to be conducted with much greater precision. It is reported that 73% of wells in Canada were drilled horizontally in the first quarter of 2014, up from 66% in the first quarter of 2013 and 55% in 2012[23]. Canadian companies are not only drilling increasingly more horizontal wells, they also drill longer and longer laterals, with average lengths now approximately 2000 metres. In Eastern Canada, 9 horizontal wells have been drilled in Nova Scotia and New Brunswick with a total of 6 hydraulically fractured.

Effects of Hydraulic Fracturing on Industry Economics

North America's natural gas resources have been increasing over the past decade, mainly due to application of hydraulic fracturing in the recovery of natural gas from unconventional resources. This application has made economic recovery of previously trapped and undeveloped resources become a reality. It has made natural gas a relatively abundant and substantially less expensive fuel, especially in North America. It has created the potential for North America to become an exporter of natural gas (proposals exist for LNG exports from both U.S. and Canada) and for opening up new reserves of natural gas in other parts of the world.

Figure 8 shows that U.S. oil and gas production have increased dramatically as a result of new reservoirs of shale oil and shale gas being opened using hydraulic fracturing. U.S. gas production had been fairly stable in recent decades, while U.S. oil production had been in decline since its peak in 1970. After building LNG import terminals in recent years to ensure adequate supplies of gas into the future, the U.S. is now set to become an LNG exporter. China has recently surpassed the U.S. as the world's largest net importer of oil, and the U.S. is poised to overtake Russia and Saudi Arabia and regain its long lost status as the largest producer of oil.



[23] http://www.horizontal-drilling-canada-2014.com/.

Figure 8: U.S. Oil and Gas Production 1993 to 2013[24]

While the dominant impacts of using hydraulic fracturing have been felt in the U.S. so far, these impacts are already spreading to global oil and gas markets, and this is before any extensive use of hydraulic fracturing in other parts of the world.

Summary

The magnitude of unconventional oil and gas resources is enormous, and generally involves use of hydraulic fracturing in its recovery. Public concerns associated with hydraulic fracturing include the consumption of fresh water; treatment, recycling, and disposal of produced water; disclosure of chemical additives to fracture fluids; onsite storage and handling of chemicals and wastes; potential groundwater and surface water contamination; air emissions/air pollution; induced seismicity; and increased community impacts such as noise, traffic and drilling "footprints".

This has resulted in hydraulic fracturing risks developing a very high public profile, to the point that its use is prohibited or highly restricted in some jurisdictions. It has also led to increasingly tight regulation in many other jurisdictions which is serving to reduce the risks associated with use of hydraulic fracturing, although it has not eased the level of public concern in some jurisdictions.

The risks associated with use of hydraulic fracturing, if it is allowed, must be reduced and controlled through the use of sound engineering and mitigation practices that occur as a result of modern and enlightened regulatory requirements, clear guidelines and best management practices. The level of public concern regarding hydraulic fracturing has placed pressure on regulators and industry to respond, to ensure the regulations and regulatory approaches as well as the technology are capable of dealing with the issues arising from hydraulic fracturing and to demonstrate to the public that this is the case.

[24] 2014 BP Statistical Review of World Energy http://www.bp.com/en/global/corporate/about-bp/energy-economics/statistical-review-of-world-energy.html.

Glossary[25]

Aquifer: A body of permeable rock or sediment that is saturated with water and yields useful amounts of water.

Carbonate rock: A rock composed primarily of carbonate minerals (minerals containing the CO_3 anionic structure, such as calcite). Common carbonate rocks are limestones and dolomites.

Casing: The hard metal or plastic pipe that lines the well, prevents a borehole from caving in, and provides a barrier to the outside rock and groundwater.

Chloride: A chemical compound with one or more chlorine atoms bonded within the molecule; a salt of hydrochloric acid. Table salt is sodium chloride (NaCl).

Fault: A fracture or fracture zone along which rock layers have moved.

Fine-grained: A geologic term to describe a rock texture, referring to its mineral or rock fragment components.

Formation: A basic unit of rock layers distinctive enough in appearance, composition, and age to be defined in geologic maps and classifications.

Flowback water: The fracturing fluid that returns to the surface through the wellbore during and after a hydraulic treatment.

Fracture: A crack or break in the rock.

Fracturing fluids: The water and chemical additives used to hydraulically fracture the reservoir rock, and proppant (typically sand or ceramic beads) pumped into the fractures to keep them from closing once the pumping pressure is released.

Hydraulic fracturing: A process to propagate fissures in a subsurface rock layer with the injection of pressurized fluid through a wellbore, especially to extract oil or gas.

Hydrocarbon: An organic compound made of carbon and hydrogen, found in coal, crude oil, natural gas and plant life.

Induced Seismicity: Seismic events that can be attributed to human activity. Seismicity can be induced by geothermal energy extraction, mining, dam building, fluid disposal and hydraulic fracturing.

Kick-off point: The depth at which the vertical drill hole is deviated for directional drilling so the wellbore can enter the target zone roughly horizontal.

Methane: A colourless, odourless and flammable gaseous hydrocarbon (CH_4).

[25] Modified from GSA Posting.

Permeability: The capacity of a rock for transmitting a fluid. Permeability depends on the size and shape of pores in the rock, along with the size, shape, and extent of the connections between pore spaces.

Pore space: The spaces between grains in a rock that are unoccupied by solid material.

Produced water: The naturally occurring fluid in a formation that flows to the surface through the wellbore, throughout the entire lifespan of an oil or gas well. It typically has high levels of total dissolved solids with leached out minerals from the rock.

Proppant: Solid material used in hydraulic fracturing to hold open the cracks made in the reservoir rock after the high pressure of the fracturing fluids is reduced. Sand, ceramic beads, or miniature pellets “prop” open the cracks to allow for freer flow of oil or gas.

Reservoir rock: The oil or gas bearing rock, typically a fractured or porous and permeable rock formation.

Seismic event: An earth vibration, such as an earthquake or tremor.

Shale: A fine-grained sedimentary rock that formed from the compaction of finely layered silt and clay-sized minerals (“mud”).

Shale gas: natural gas locked in tiny bubble-like pockets within shale or other layered, sedimentary rock.

Tight oil or gas reserves: Hydrocarbons dispersed in rocks of low permeability and porosity, which makes it more difficult to recover than conventional hydrocarbon deposits.

Wellbore: A hole that is drilled to explore and recover natural resources, such as oil, gas, or water.