Managing the Risks of Hydraulic Fracturing

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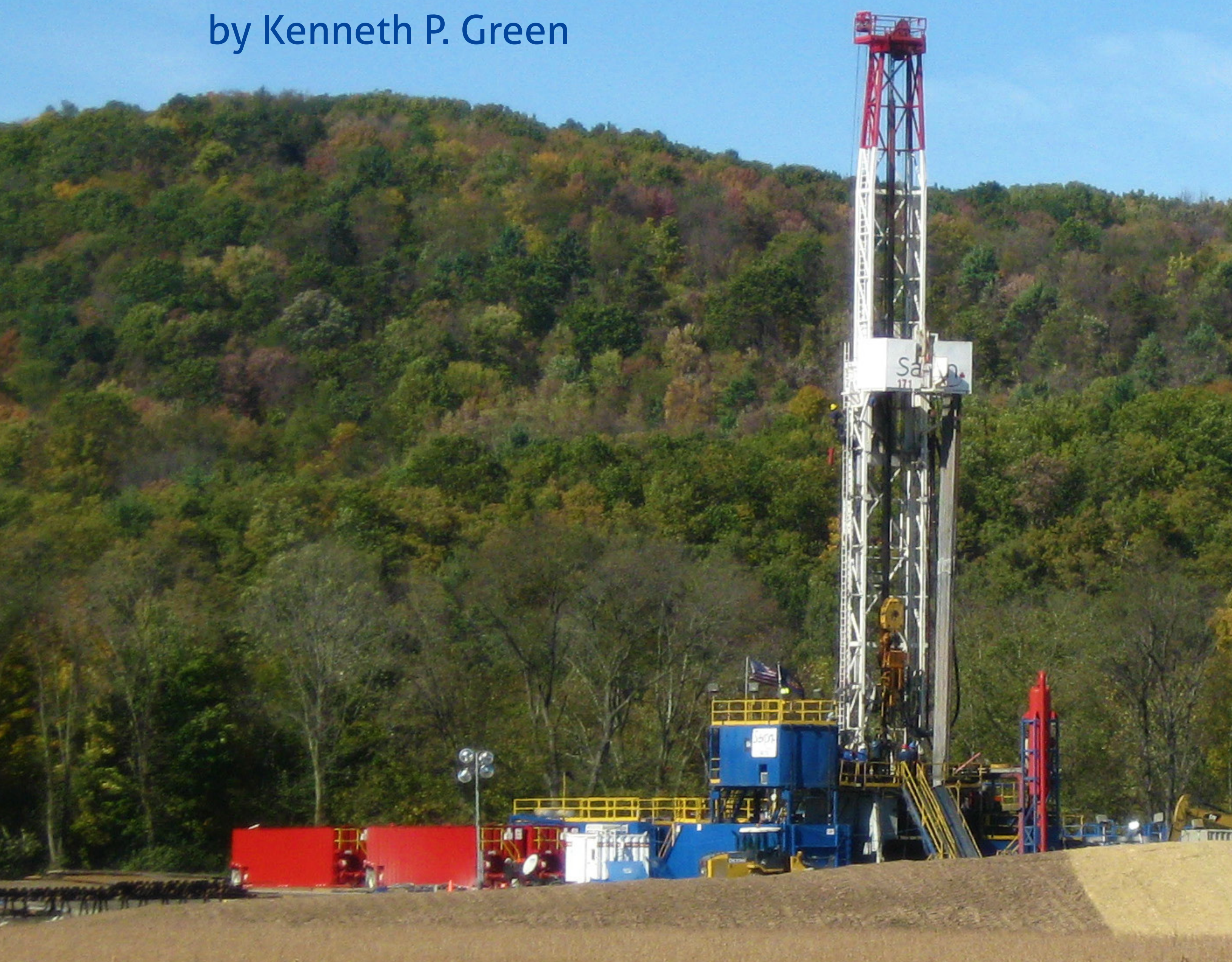

Contents

Executive summary

Hydraulic fracturing (fracking) is a relatively new application of several old technologies used in oil and gas extraction that has made it possible to unlock large quantities of natural gas and liquid hydrocarbons—fuels that can be used to access new and significant quantities of unconventional gas with consequent economic benefit to Canadians.

There is no question that the technology poses risks to water quality, air quality, and ecosystem health. Few large-scale human activities are entirely free of such risks. Hydraulic fracturing also poses a risk of increasing greenhouse gas emissions, and even a risk to seismic stability. Other issues which are real but not discussed here are water consumption (which is primarily a problem in water-stressed areas) and worker-safety issues related to engaging in hydraulic fracturing, which generally falls under its own set of laws, regulatory frameworks, and policy-development processes.

The literature on hydraulic fracturing risks, while increasing in volume, is not terribly conclusive and is sometimes contradictory: the most authoritative studies by governmental academies and agencies observe that robust data is sparse, and that vastly more information needs to be gathered. The reports considered in this bulletin—limited primarily to those of large-scale review panels or national laboratories—judge the risks to be modest and manageable with existing technologies.

The province of Alberta has been aggressive in the regulation of hydraulic fracturing, and the industry itself has also adopted voluntary self-regulation practices that should ensure safe operations. There is more to be done, and policy options that could further ensure responsible performance by industry include ensuring adequate levels of insurance, developing tracking technology that would allow for strict liability for companies that cause environmental damage, and development of independent certifying organizations that can exert public pressure to encourage responsible behavior. Obtaining such third-party verification could be required by government to attain permission to operate.

It goes without saying that little new knowledge is gained without experimentation; thus, bans and moratoria would seem to cut against the recommendation of gathering knowledge. By contrast, continuing to allow

hydraulic fracturing while improving on the current system of governmental and industry self-regulation would seem to be indicated.

The call for bans and moratoria are passionate, and no doubt heartfelt by those who fear the technology and/or oppose the product of that technology (hydrocarbons), but policymakers should ignore the siren song of the simplistic solution. Bans and moratoria may make it seem like one is taking action against risk, but they simply defer those risks to a later date, when activity invariably resumes. And to the extent that learning is foregone as well as hydraulic fracturing during a moratorium, bans may increase future risks rather than mitigate them.

Introduction: The policy challenge

According to the Canadian Society for Unconventional Gas, "marketable resources for shale gas in Canada are estimated to range from 700 to 1300 TCF (trillion cubic feet) of natural gas" (Heffernan and Dawson, 2010: 2). For context, the National Energy board estimate of marketable natural gas for all of Canada in 2013 was approximately 0.17 TCF.[1] At approximately $3.57 per thousand cubic feet (an average mid-range estimate of gas prices in North America), Canada's unconventional gas resources would have a market value of about $2.5 trillion at the low end, and about $4.6 trillion at the high end.[2]

The policy challenge, as with most natural resource issues, is to balance the concerns Canadians have over the potential adverse impacts of a proposed technology (in this case, hydraulic fracturing) with the potential that such technology has to improve the well-being of Canadians. To address such a challenge, Canadians must make decisions based on facts, not fears, and on pragmatic policy considerations, not ideological or philosophical considerations.

This study will examine the economic potential offered by the development of Canada's unconventional energy resources via hydraulic fracturing, and will examine some of the claims made against such technology involving air pollution, water pollution, greenhouse gas emissions, seismic instability, and exposure to chemicals used in the process of hydraulic fracturing.[3] This is by no means a comprehensive list—others have proposed a diverse raft of risks, some concrete such as ecosystem fragmentation, but many that relate

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1. Units converted by the author from <http://www.neb-one.gc.ca/nrg/sttstc/ntrlgs/stt/mrktblntrlgsprdctn-eng.html>.

2. Calculations by author using data on North American gas prices from <http://www.cmegroup.com/trading/energy/natural-gas/natural-gas.html>.

3. There are many hundreds of individual studies examining one proposed risk or another, and it is far beyond the capabilities of this author to find and synthesize the results of all such studies, more of which come out nearly every day. Thus, instead of risking claims of cherry-picking, or reliance on corporate or special-interest group reports, this study will draw its risk estimates primarily from large, governmentally-sponsored studies or panel reports by governmental bodies in Canada, the US, the UK, and other European jurisdictions where those studies were available to the author in English.

to subjective issues of social welfare, social justice, generational equity and so forth. I will leave the more abstract arguments to others and focus here on the concrete threats that have been raised to air, water, climate, human health, and geologic stability. In addition, this paper does not attempt a comprehensive literature review, which, given the diversity and dynamism of the literature, would tax the abilities of a much larger research institution. Instead, I will primarily rely on the reports of expert panels and expert groups such as national academies. I will conclude with a discussion of how society can best address the types of risks posed by hydraulic fracturing in a context that considers government regulation, industry self-regulation, and the use of innovative market-based mechanisms that could improve risk management without resort to brute-force policy options such as hydraulic fracturing moratoria.

The controversy over hydraulic fracturing

Hydraulic fracturing (colloquially called "fracking") is a technique for extracting natural gas and other hydrocarbons from shale (rock), and tight sand formations, such as sandstone, carbonates, and siltstone, or for increasing pore space and cracks for geothermal fluid transfer and heat extraction. While often presented as a new or largely unstudied technique, hydraulic fracturing is best understood as a combination and refinement of two well-known techniques: horizontal drilling, and the use of pressurized fluids to enhance the productivity of oil wells and the fluid capture of gas molecules.

Horizontal drilling, the process of drilling underground shafts horizontally, was first implemented in the US in the 1920s, while hydraulic fracturing, the injection of pressurized fluids to enhance oil and gas recovery, dates back to the late 1940s in the US (EIA, 1993; FracFocus, 2014a).

In the hydraulic fracturing process, wells are first drilled downward (up to several kilometers deep), and once the vertical well reaches a depth containing gas-bearing geologic formations (such as shale), the bore is curved to the horizontal, and a transverse well is drilled. These horizontal legs can also extend several kilometers in length. The well diameters are quite small: an initial borehole only seven inches in diameter is drilled downward, and then lined with layers of concrete and steel pipe at the upper levels where the well might pass through ground water formations. The final pipe that will return gas and associated liquids to the surface is only four inches in diameter.

Once both wells (horizontal and vertical) are drilled, a mixture of water, sand (proppant), and a small percentage of chemicals is injected into the well under high pressure (up to 10,000 PSI) in a series of stages moving backward from the end of the transverse well toward the horizontal leg of the well. The pressurized water introduces fractures into the shale formation surrounding the horizontal bore-hole; the sand introduced into the fractures under pressure keeps them from closing back up during operations. The fractures, newly propped open, allow gas and liquid hydrocarbons to flow into the transverse shaft, and up the vertical well shaft. The chemicals in the hydraulic fracturing slurry (primarily detergents used to reduce friction) account for a very small fraction (½ to 2 percent) of the total fluid used, and will be discussed more extensively below. The overall hydraulic fracturing process for an individual well takes between a week and 10 days.[4]

Hydraulic fracturing is the technique driving the ongoing energy boom in the United States, where over a million wells have been hydraulically fractured since the 1940s (Brantley and Meyendorff, 2013). A secondary source, FracTracker, which breaks hydraulic fracturing out by state, suggests that the number exceeds 1.1 million (Kelso, 2014).[5] According to the Canadian Association of Petroleum Producers, over 175,000 wells have been fracked in the provinces of Alberta and British Columbia (CAPP, 2012a).

A variety of interest groups argue that hydraulic fracturing is a dangerous new technology that poses major risks to human health and the environment. Some of these groups have lobbied for bans or moratoria on hydraulic fracturing (Council of Canadians, n.d.). They have been successful in several parts of the US and Canada (as well as in Europe). Here in Canada, hydraulic fracturing has been temporarily banned in parts of Quebec, and Nova Scotia, having instituted a two-year moratorium on hydraulic fracturing, recently introducing legislation to ban high-volume hydraulic fracturing indefinitely (Bertrand, 2012; MacDonald, 2012; Canadian Press, 2014).

In addition to these recent, high-profile moves against hydraulic fracturing, a variety of actions to oppose it have been taken across Canada. According to a summary report by the Council of Canadians (2014):

- In *British Columbia*, two aboriginal groups, the BC Assembly of First Nations and the Union of British Columbian Indian Chiefs, passed resolutions in 2012 calling for a moratorium on water licenses for fracking in Fort Nelson, BC, until "full regional baseline studies are completed, culturally significant land and water resources are protected, and other requirements are met" (p. 9). In 2013, the Sierra Club BC and the Wilderness Committee launched a lawsuit against both Encana and the province's Oil and Gas Commission, arguing that they are in violation of the province's Clean Water Act.

4. There are dozens of versions of "hydraulic fracturing 101" scattered across the internet. This simplified description uses information drawn primarily from the recent report of the Council of Canadian Academies (2014), which conducted an extensive investigation into the safety of hydraulic fracturing. That CCA report will, in fact, dominate this study, as it essentially constitutes the Canadian baseline report for assessing such risks. Indeed, a more recent report by a Nova Scotia research group relies heavily on the findings of the CCA report for its own analysis. In relying on the CCA, I am not endorsing the entirety of their report. The CCA takes a highly precautionary view of risk, and casts an extremely broad net when considering risks. However, for the basic summations of the individual risks I discuss here, I accept the findings of their report as generally valid.

5. Most of the wells that have been fracked in previous decades were vertical wells, but the process is comparable to hydraulic fracturing now being conducted in horizontal wells.

- In the *Yukon*, the Council of Yukon First Nations passed a resolution declaring traditional territories to be "frack-free" in 2013, while the Vuntut Gwitchin First Nation voted to ban hydraulic fracturing until it was "proven safe," and the Kaska First Nation has come out against hydraulic fracturing (p. 10).

- In the *Northwest Territories*, the Dene Nation passed a resolution calling for a moratorium on hydraulic fracturing in 2011, pending further research and the emplacement of regulatory requirements and safeguards.

- In *Alberta*, the Alberta Association of Municipal Districts and Counties passed a 2013 resolution calling on the Alberta government to "report on the impacts of seismic activity, require mapping of all aquifers, and "protect surface and groundwater supply by imposing a minimum wellbore casing depth below aquifer zones" (p. 14).

- In *Nova Scotia*, the Mi'kmaq Warriors Society and other Indigenous communities set up a partial blockade on the Canso Causeway in 2012 to highlight their concerns with the dangers of hydraulic fracturing. The Council's Inverness County Chapter continued to advocate for an anti-hydraulic fracturing bylaw; due to intense community pressure, Inverness County Council passed the first bylaw banning hydraulic fracturing in Canada in May 2013. In November 2013, the Union of Nova Scotia Municipalities passed a resolution calling for a province-wide moratorium on hydraulic fracturing.

- And in *Newfoundland and Labrador*, the provincial government (via Minister of Natural Resources Derek Dalley), stopped accepting applications for onshore or offshore use of hydraulic fracturing in 2013, creating a de facto moratorium in the province.

Subsequent to the Council of Canadians report, the government of Nova Scotia has decided to ban "high volume hydraulic fracturing" for onshore oil and gas development, while the newly elected government in New Brunswick has promised a referendum on the subject (MacDonald, Michael, 2014; CBC, 2014).

Hydraulic fracturing for natural gas in Canada holds the promise of generating significant economic benefits to Canadians. Canada holds very large reserves of unconventional natural gas that could be exported to areas of the world that endure much higher natural gas prices than are enjoyed in Canada and the United States, if LNG facilities are made available.

The rationale for and benefits of hydraulic fracturing

Canada controls large discovered unconventional natural gas formations and reserves, the development of which carries significant economic promise. The Canadian Society for Unconventional Gas (CSUG) estimates that Canada has almost 4,000 trillion cubic feet of natural gas in conventional and unconventional deposits combined, and marketable gas from unconventional resources of between 700 and 1300 trillion cubic feet (Heffernan and Dawson, 2010).[6]

Table 1, from the CSUG report, summarizes CSUG's estimate of Canada's potentially marketable natural gas resources by type, province, and geologic formation.[7] A more recent study, by the US Energy Information Administration, that examines areas not addressed in the CSUG report, places Canada's technically recoverable shale gas resources at 573 TCF, or 1.7 times CSUG's upper range estimate for shale gas (EIA, 2013). The EIA also estimates that Canada has 8.8 billion barrels of technically recoverable shale oil.

At approximately $3.57 per thousand cubic feet (an average mid-range estimate of gas prices in North America) Canada's unconventional gas resources would have a market value of about $2.5 trillion at the low end, and about $4.6 trillion at the high end.[8]

Prices in Asia, a prime export market for Canadian natural gas, are much higher than those in the US. As this study was written, natural gas prices in Japan were nearly five times higher, at $17.17 USD/MMBtu.[9]

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6. The marketable gas estimate is essentially the estimated recoverable portion of shale gas, tight gas, and coal seam gas less losses likely to be incurred during processing and for fuel use.

7. In the context of the CSUG estimate it is important to note that "marketable" resources are not the same thing as proved, commercially viable reserves but, rather, the portion of the estimated gas in place believed to be recoverable with known technology, adjusted for normal processing and fuel use losses.

8. Calculations by author using data on North American gas prices from <http://www.cmegroup.com/trading/energy/natural-gas/natural-gas.html>.

9. Japanese gas prices from <http://ycharts.com/indicators/japan_liquefied_natural_gas_import_price>.

Table 1
Canada's marketable unconventional gas resources

	Low estimate (trillion cubic feet)	High estimate (trillion cubic feet)
Natural gas from coal/coalbed methane		
British Columbia	4	8
Alberta	27	117
Saskatchewan	<1	<1
Maritimes	3	4
Total	*34*	*129*
Tight gas		
Jean Marie (BC)	11	23
Montney (BC portion)	77	166
Other BC	59	132
Cretaceous Deep Basin (Alberta)	69	155
Total	*215*	*476*
Shale gas		
Horn River	75	170
Cordova Embayment	30	68
Colorado Shale	4	14
Utica	7	42
Maritimes Basin	11	49
Total	*128*	*343*
Total unconventional marketable gas resources	**376**	**947**
Total marketable resources, including conventional	733	1304

Source: Heffernan and Dawson, 2010.

As table 1 shows, shale gas potential is highest in Alberta and BC, where the Montney Formation holds the most massive shale gas potential:

> The Montney Formation's marketable, unconventional petroleum potential has been evaluated for the first time in a joint assessment by the National Energy Board, the British Columbia Oil and Gas Commission, the Alberta Energy Regulator, and the British Columbia Ministry of Natural Gas Development. The thick and geographically extensive siltstones of the Montney Formation are expected to contain 12,719 billion m^3 (449 TCF) of marketable natural gas, 2,308 million m^3 (14,521 million barrels) of marketable [natural gas liquids (NGLs[10])], and 179 million m^3 (1,125 million barrels) of marketable oil. (NEB, 2013: 1)

10. Lightweight hydrocarbons such as ethane, propane, and butane.

The NEB estimates that the Montney's marketable unconventional gas resource is one of the largest in the world:

> To further illustrate the size of the Montney, total Canadian natural gas demand in 2012 was 88 billion m^3 (3.1 TCF), making the Montney gas resource equivalent to 145 years of Canada's 2012 consumption. In addition, the Montney is already considered one of Canada's most economic gas plays. Even though it is only in the early stages of development, its 2012 production rose to an average of 48.6 million m^3/d (1.7 Bcf/d) out of total Canadian marketable gas production of 392.7 million m^3/d (13.9 Bcf/d). (NEB, 2013: 4)

Table 2 shows the range of estimated values (as of 2012) for the Montney Formation.

Table 2

Ultimate potential for Montney unconventional petroleum in BC and Alberta

	In-place			Marketable		
Hydrocarbon type	Low	**Expected**	High	Low	**Expected**	High
Natural gas, billion m^3	90,559	**121,080**	153,103	8,952	**12,719**	18,257
(trillion cubic feet)	(3197)	**(4,274)**	(5,405)	(316)	**(449)**	(645)
NGLs, million m^3	13,884	**20,173**	28,096	1,540	**2,308**	3,344
(million barrels)	(87,360)	**(126,931)**	(176,783)	(9,689)	**(14,521)**	(21,040)
Oil, million m^3	12,865	**22,484**	36,113	72	**179**	386
(million barrels)	(80,949)	**(141,469)**	(227,221)	(452)	**(1,125)**	(2,430)

Source: NEB, 2013.

Some Eastern Canadian provinces also have potentially large shale gas formations. According to Natural Resources Canada (2012), Quebec is one of them: "With an estimated recoverable resource between 18 and 40 trillion cubic feet if fully developed, Quebec's shale gas deposits would have a market value between \$70 billion and \$140 billion at current natural gas prices."

The Canadian Energy Research Institute (2013), dug further into Quebec's shale gas potential, estimating the economic benefits of developing Quebec's Utica shale formation resource under a range of production estimates. Their key findings for Quebec's shale potential were:

- Over the period 2012–2036 the estimated capital investment in Québec is \$7.9 billion and \$23.8 billion for the 500 MMCFPD [million cubic feet per day] and 1,500 MMCFPD cases, respectively, for base case drilling intensity.

- Total Canadian GDP impact as a result of investment is estimated to be $37.3 billion and $112.0 billion for the 500 MMCFPD and 1,500 MMCFPD cases, respectively, for base case drilling intensity. Roughly 54 percent is realized in Québec, 40 percent in Alberta, and the remaining 6 percent is spread over the rest of Canada.

- Canadian employee compensation is estimated to total $12.9 billion and $38.7 billion for the 500 MMCFPD and 1,500 MMCFPD cases, respectively, for base case drilling intensity. Approximately 63 percent of the wages will be earned in Québec, 30 percent in Alberta, and the remaining 7 percent is spread over the rest of Canada.

- Employment in Canada (direct, indirect and induced) is expected to grow by 293,000 and 880,000 person-years for the 500 MMCFPD and 1,500 MMCFPD cases, respectively, over the time period for base case drilling intensity. Roughly 69 percent is realized in Québec, 23 percent in Alberta, and the remaining 8 percent is spread over the rest of Canada.

- Tax revenue in Québec from development of the Utica Shale is estimated to total $7.0 billion and $21.0 billion over the 25-year period for the 500 MMCFPD and 1,500 MMCFPD cases, respectively, for base case drilling intensity.

- Tax revenue in Alberta from development of the Utica Shale is estimated to total $3.0 billion and $9.1 billion over the 25-year period for the 500 MMCFPD and 1,500 MMCFPD cases, respectively, for base case drilling intensity.

- Supply cost for the Utica Shale base case is estimated to be $5.35/MCF (thousand cubic feet) for base case drilling intensity.

(CERI, 2013: 23–24)

By all measures, Canada's shale gas and oil potential is significant, and development of those resources could generate significant wealth for Canadians.

The major risks of hydraulic fracturing

Water pollution

Hydraulic fracturing affects water supplies in several ways: the hydraulic fracturing process consumes a considerable amount of fresh water even net of reinjection; it injects considerable quantities of chemicals into the ground that have the potential to migrate into groundwater; and it produces considerable amounts of wastewater contaminated with a range of substances that range from non-toxic, to toxic, to radioactive. The risks to groundwater are among the greatest concerns for critics of hydraulic fracturing.

Table 3 shows the types of chemicals used in hydraulic fracturing, along with descriptions of what the various chemicals do. For a much more complete list, readers are directed to FracFocus, a public registry of chemicals used in hydraulic fracturing operations.[11]

Environmental activists have focused extensively on water risks, and these have been the focus of high-profile anti-hydraulic fracturing films such as Gasland. Greenpeace (EU) warns that:

> [Hydraulic fracturing] could cause the contamination of surface and groundwater (including drinking water) with toxic chemicals used in fracking fluids, and increasing the concentration in such water of methane and hazardous and radioactive materials that naturally occur in shale and coal. (Greenpeace, 2012)

The Council of Canadian Academies warns that:

> Accidental surface releases of fracturing chemicals and wastewater, and changes in hydrology and water infiltration caused by new infrastructure, may affect shallow groundwater and surface water resources. A risk to potable groundwater exists from the upward migration of natural gas and saline waters from leaky well casings, and possibly also natural fractures in the rock, old abandoned wells, and permeable

11. <http://fracfocus.org/chemical-use/why-chemicals-are-used>.

Table 3

Types of chemicals used in hydraulic fracturing

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

Source: FracFocus, 2014b.

> faults. These pathways may allow for migration of gases and possibly saline fluids over long time scales, with potentially substantial cumulative impact on aquifer water quality. (CCA, 2014: xii)

However, as the CCA observes, it is quite unclear whether or not these releases will ultimately cause harm:

> However, not enough is known about the fate of the chemicals in the flowback water to understand potential impacts to human health, the environment, or to develop appropriate remediation. Monitoring, assessment, and mitigation of impacts from upward migration are more difficult than for surface activities.
>
> The greatest threat to groundwater is gas leakage from wells for which even existing best practices cannot assure long-term prevention. The degree to which natural assimilation capacity can limit the impacts of well leakage is site specific due to variability in the magnitude of natural gas fluxes (or loadings) and aquifer hydro-geochemical compositions. These potential impacts are not being systematically monitored, predications remain unreliable, and approaches for effective and consistent monitoring need to be developed.
>
> On average, about one-quarter to half of the water used in a single hydraulic fracturing treatment returns up the well to the surface after stimulation. This return flow, or flowback, is a potentially hazardous waste because it typically contains hydrocarbons including variable amounts of benzene and other aromatics, fracturing chemicals, and potentially hazardous constituents leached from the shale (e.g., salts, metals, metalloids, and natural radioactive constituents). Although flowback water is now commonly re-used in later fracturing treatments, a fraction eventually remains that poses technical challenges for treatment where deep wastewater injection for disposal may not be feasible (e.g., eastern Canada). (CCA, 2014: xiii–xiv).

> The literature on groundwater impacts has grown markedly in the past three years, though the data are generally limited and commonly do not support definitive conclusions. (CCA, 2014: 62).

Finally, regarding risks to surface waters, the CCA concludes that:

> The risks due to surface activities will likely be minimal if proper precautionary management practices are followed. (2014: xiii).

And though New York currently has a ban on hydraulic fracturing, it is ostensibly not due to risks to water resources, at least, not according to the NY State Health Department:

> Chapters 5 and 6 contain analyses that demonstrate that no significant adverse impact to water resources is likely to occur due to underground vertical migration of fracturing fluids through the shale formations. The developable shale formations are vertically separated from potential freshwater aquifers by at least 1,000 feet of sandstones and shales of moderate to low permeability. In fact, most of the bedrock formations above the Marcellus Shale are other shales. That shales must be hydraulically fractured to produce fluids is evidence that these types of rock formations do not readily transmit fluids. The high salinity of native water in the Marcellus and other Devonian shales is evidence that fluid has been trapped in the pore spaces for hundreds of millions of years, implying that there is no mechanism for discharge of fluids to other formations.
>
> Hydraulic fracturing is engineered to target the prospective hydrocarbon-producing zone. The induced fractures create a pathway to the intended wellbore, but do not create a discharge mechanism or pathway beyond the fractured zone where none existed before. The pressure differential that pushes fracturing fluid into the formation is diminished once the rock has fractured, and is reversed toward the wellbore during the flowback and production phases. Accordingly, there is no likelihood of significant adverse impacts from the underground migration of fracturing fluids.
>
> No significant adverse impacts are identified with regard to the disposal of liquid wastes. (NYSHD, 2011: 11–12).

Finally, according to a recent review in the journal *Science*, "[s]ince the advent of hydraulic fracturing, more than 1 million hydraulic fracturing treatments have been conducted, with perhaps only one documented case of direct groundwater pollution resulting from injection of hydraulic fracturing chemicals used for shale gas extraction" (Vidic et al., 2013: 6).

Conventional air pollution

The hydraulic fracturing process uses a considerable amount of energy to drill wells, pressurize the injected materials, move concrete and equipment to the drilling site, and so on. The process itself first injects and then brings to the surface a variety of volatile chemicals that can, if not trapped and safely handled, escape into the atmosphere. Not surprisingly, these activities result in the emission of pollutants much the same as those involved in any other major construction activity. The CCA report on hydraulic fracturing notes that:

> The emission of air pollutants from shale gas development is similar to conventional gas, but higher per unit of gas produced because of the greater effort required. These pollutants include diesel-use emissions, hydrocarbons, volatile organic compounds (e.g., benzene), and particulate matter. The main regional air emission issue is the generation of ozone which in some circumstances could adversely affect air quality. (CCA, 2014: xvi)

The United States Environmental Protection Agency is also concerned about air pollutants resulting from hydraulic fracturing, observing that:

> There have been well-documented air quality impacts in areas with active natural gas development, with increases in emissions of methane, volatile organic compounds (VOCs) and hazardous air pollutants (HAPs) … (EPA, 2014)

As the CCA explains:

> The air emissions attributable to shale gas development typically come from the same sources (e.g., drilling rigs, truck engines, gas compressors, holding ponds, vents, and flares) as those associated with conventional gas production and, indeed, other forms of mining and industrial activity. The main difference is that these sources may be produced more intensively in shale gas development (due to longer drilling times, more trucks being used, more powerful pumps, and bigger holding ponds) because of the added effort required to extract gas from shale. (CCA, 2014: 113)

It comes as no surprise that the hydraulic fracturing process results in some air pollutant emissions. But there is a key distinction to be made between emissions, exposures, and risk. Emissions that do not reach a vulnerable population do not turn into exposures, and those non-exposures do not turn into risks. What matters is whether or not hydraulic fracturing processes are producing enough additional emissions to pose additional risk to susceptible populations and ecosystems. And on this front, the evidence is limited, at least in Canada.

The CCA observes that we are still collecting information on localized air pollution incidents:

> Information is needed on the location of future wells, the planned infrastructure, and the anticipated scale of development to assess the impact of air emissions. In parts of Canada, this information is not available. For example, in Quebec, the BAPE [Quebec's Office of Public Hearings on the Environment] reached no conclusion on the impact of shale gas development on ambient air quality in the province because of insufficient information on the location and level of activities associated with this development (BAPE, 2011b). In addition, baseline observations of air quality are lacking in several regions where development has taken place or may take place. (CCA, 2014: 115-116)

A strategic environmental assessment on shale gas conducted for the government of Quebec found that the risk of widespread pollution is small, and can be remedied by the use of existing technologies:

> Without measures to control and reduce atmospheric emissions, shale gas development could have a significant impact on air quality, both locally and regionally (in sub-regions with a high density of development activity).
>
> Modeling shows that emissions control and the use of advanced combustion engines would eliminate violations of air quality standards in the vicinity of sites, during all phases of development, with the exception of nitrogen dioxide (NO_2) during fracturing. NO_2 concentrations would exceed the standard at up to 300m from the centre of a multiwell site. The use of electric motors (with power from the existing grid) would reduce emissions even further. If advanced combustion engines were used, ozone emissions would be a small percentage of provincial emissions: 0.2% for scenario 3, and around 2% for scenario 5, relative to provincial emissions in 2011. (Quebec, 2014: 18)

A study conducted by the Australian Council of Learned Academies observes that existing air pollution studies focused on the intense levels of hydraulic fracturing in places like Texas might not usefully apply to other jurisdictions:

> Debate between industry and academic research on the nature and levels of emission of benzene and other pollutants has focused on the very high density drilling for shale gas west of Dallas, Texas (Duncan,

> 2012). That example has given some indication of how emissions from processes associated with shale gas production can affect air quality. The air emissions are from diesel generators, compressors, and the very high-density traffic transporting waste material such as contaminated water and residue. It is unlikely that such high intensity of gas production will develop in Australia. Moreover, even with the described high intensity of production in parts of the United States, benzene measurements over time at the Barnett gas field have shown that maximum benzene concentrations are at or, more likely, below long-term recommended levels. (ACLA, 2013: 165)

Finally, a study written by Argonne National Laboratory in the US suggests that more evidence is needed, but at present the estimated pollutant levels are below the level of health concern:

> Several state emission inventories have shown that oil and natural gas operations are significant sources of local air pollution (e.g., the 2008 Colorado emission inventory showed that they accounted for 48% of VOCs, 18% of NOx, and 15% of benzene) and that shale gas operations may lead to increased levels of ozone and [Hazardous Air Pollutants] (HAPs) near these areas (Wells 2012).
>
> However, uncertainty about the impacts of these emissions exists, as air quality is highly dependent on local conditions. For example, in some areas VOC emissions will not be the primary driver of ozone formation; therefore, detailed modeling is required to understand the impact of emissions on local air quality. In addition, while elevated levels of benzene emissions have been found near production sites, concentrations have been below health-based screening levels, and with little data on how these HAP emissions impact human health, further examination is needed (Alvarez 2012). (Clark et al., 2013: 8)

Greenhouse gas emissions

Hydraulic fracturing uses a considerable amount of energy, and, as hydraulic fracturing locations are generally remote, that energy has to be generated on-site. That means, for the most part, using conventional power generators fueled by diesel fuel, natural gas, or other fossil fuels, combustion of which leads to the emission of greenhouse gases. In addition, once the fracturing has been done and the well begins to yield gas and other hydrocarbons, there can be some leakage to the atmosphere of methane and other greenhouse gases, particularly if a well has been drilled improperly. And of course, when burned, the fuels produced by hydraulic fracturing also lead to the emission of greenhouse gases. The latter issue is really a matter of relative comparisons between fracked hydrocarbons and hydrocarbons produced in other ways.

On the matter of fuel displacement, the CCA's view is mixed:

> To the extent that natural gas extracted from shale replaces oil and coal in energy use, particularly in electricity generation, it may reduce the environmental impact of fossil fuels and help to slow anthropogenic climate change. Whether shale gas development will actually reduce GHG emissions and slow climate change will depend on several variables, including which energy sources it displaces (viz., coal and oil vs. nuclear and renewables), and the volume of methane emissions from gas leakage at the wellhead and in the distribution system. Experts disagree about these matters. Some conclude that downstream GHG benefits may be offset by upstream leakage, as well as the risk that gas undercuts the markets for lower carbon alternatives and fosters lock-in to high carbon infrastructure. Others argue that shale gas could provide a bridge to a low-carbon future. Furthermore, fields that produce gas with high carbon dioxide content, such as Horn River, could become an important additional source of carbon dioxide emissions unless the carbon dioxide is captured and used for enhanced oil recovery or is sequestered in saline aquifers. (CCA, 2014: xiv)

And fracked natural gas doesn't seem to be particularly dissimilar from conventionally produced gas. Natural Resources Canada (2012) has written that "[m]ost prospective shale gas plays have low carbon dioxide content, similar to typical conventional gas production. Therefore, as more shale gas development occurs, the greenhouse gas emissions per unit of shale gas produced and consumed should be similar to that from conventional natural gas production and use." The Australian Council of Learned Academies also examined the question of relative emissions:

> On average, a shale gas-fuelled, baseload combined cycle gas turbine (CCGT) plant will produce 23% more life cycle GHG emissions per MWh, when compared with a conventional gas-fuelled CCGT, and will produce life cycle GHG emissions per MWh that are 53%, 66% and 69% of the emissions produced from coal combusted in a subcritical, supercritical or ultra-supercritical pulverised coal plants respectively. However, it should be noted that gas-fired electricity generation will generally replace existing coal-fired boilers that are less efficient sub-critical facilities and hence the comparison with this type of boiler is most relevant to the present analysis.

> On average a shale gas-fuelled open cycle gas turbine (OCGT) plant will produce 12% more life cycle GHG emissions per MWh, when compared with a conventional gas fuelled OCGT, and will produce life cycle GHG emissions per MWh that are 71%, 88% and 93% of the emissions produced from coal combusted in a subcritical, supercritical or ultra-supercritical pulverized coal plant, respectively. (ACLA, 2013: 146)

Then there is the issue of methane leakage. Several authors have claimed that hydraulic fracturing would increase natural gas emissions to the atmosphere due to leakage during the hydraulic fracturing process, and at the beginning of gas recovery. Methane is considered to be one of the more potent of the greenhouse gases.

The Argonne National Laboratory considered the question of leakage and found that the risk has largely been solved:

> More recently, reduced emissions completions, or "green completions," which capture and separate natural gas during well completion and workover activities, have become a key technology to limit the amounts of methane, VOCs, and HAPs that can be vented during the flowback period without the disadvantages of flaring. RECs use portable equipment that allows operators to capture natural gas from the flowback water. After the mixture passes through a sand trap, a three-phase separator removes natural gas liquids and water from the gas, which is then sent to sales pipelines for distribution. Fortunately, REC operations have been found to be very cost-effective even with low natural gas prices (EPA, 2011b).
>
> Numerous other cost-effective technologies have been developed to reduce natural gas leakage, such as plunger lift systems, dry seal systems, and no-bleed pneumatic controllers. Through the use of these technologies and practices, with RECs having the highest priority, the Natural Resources Defense Council estimates that nearly 90 percent of the natural gas leakage could be addressed (Harvey et al. 2012). In addition, to further reduce the emission impacts at well sites in densely populated areas, electric motors could be used instead of internal combustion engines. (Clark et al., 2013: 12–13)

And the assessment report for the government of Quebec found that the leakage rate for fracked gas production would be about 3 percent, considerably lower than estimates ranging up to 9 percent cited by environmental groups (e.g., David Suzuki Foundation, 2013):

> The life cycle analysis (section 2.1) provided an estimate of the total GHGs that would be generated by a shale gas site in Québec. That

> includes emissions from combustion engines, compressors, gas pipelines and flare stacks, natural gas emissions during drilling and completion operations, and fugitive emissions from equipment, over all phases of exploration and exploitation.
>
> With a fugitive emissions rate of 3%, the shale gas industry could increase Québec's total GHG emissions by 3% per year (in the small-scale scenario) or up to 23.2% per year (in the large-scale scenario).
>
> Fugitive emissions of methane would be the main contributor to the GHG total, accounting for 62 to 84% of a site's emissions based on a fugitive emissions rate on the order of 3%.
>
> With a fugitive emissions rate of just 0.5%, the GHG total would be 70% lower than with a rate of 3%. (Quebec, 2014: 19)

Earthquakes

Finally, opponents of hydraulic fracturing have claimed that the action of hydraulic fracturing—injecting fluid underground at high pressure—causes increases in seismic activity. They point to recent earthquakes in Oklahoma, Ohio, and elsewhere (Associated Press, 2014). But there is little conclusive evidence linking increased seismic activity to hydraulic fracturing.

According to the CCA:

> Although hydraulic fracturing operations can cause minor earthquakes, most of the earthquakes that have been felt by the public have been caused not by the hydraulic fracturing itself, but by wastewater re-injection. Most experts judge the risk of hydraulic fracturing causing earthquakes to be low. Microseismic monitoring during operations can diminish this risk further. The risk by injection of waste fluids is greater but still low, and can be minimized through careful site selection, monitoring and management. (CCA, 2014: xvi)

And the National Research Council of the National Academies found that:

> 1. The process of hydraulic fracturing a well as presently implemented for shale gas recovery does not pose a high risk for inducing felt seismic events.
> 2. Injection for disposal of wastewater derived from energy technologies into the subsurface does pose some risk for induced seismicity, but very few events have been documented over the past several decades relative to the large number of disposal wells in operation.
>
> (NRCNA, 2013: 1)

Managing the risks of hydraulic fracturing

So what do we do when faced with the sort of risks discussed above, risks which are real, but incompletely quantified and qualified, and that can seemingly be managed (but not entirely eliminated) with existing technology? Do we try to eliminate all such risks, as the proponents of hydraulic fracturing bans would suggest, or do we try to manage the risks in a pragmatic way while still working to secure the benefits of the activity?

As with managing any risks, we face a menu of options that range from the most proscriptive (moratoria), to more adaptive management via government regulation, industry self-regulation, and regulatory alternatives such as the use of stricter property rights and liability laws to create disincentives for resource developers to take unwarranted risks.

Existing government regulation

A glance at newspaper headlines would lead one to believe that hydraulic fracturing is almost unregulated in Canada. On the contrary, Canada has a set of strict regulatory controls from the federal to the provincial level that govern virtually all aspects of hydraulic fracturing. As the Canadian Society for Unconventional Resources observes, "Canadian regulators and the natural gas industry are focused on the protection of surface and groundwater and the mitigation of risk. All Canadian jurisdictions regulate the interface between water and the natural gas industry, and the application of evolving hydraulic fracturing techniques for unconventional gas development is no exception" (n.d.: 6).

At the federal level, hydraulic fracturing is regulated under the Canadian Environmental Assessment Act, via the National Energy Board, and through the Canada Oil and Gas Operations Act (Energy Law BC, n.d.).

In British Columbia, hydraulic fracturing is regulated by the BC Oil and Gas Commission, under the Oil and Gas Activities Act, SBC 2008, c. 36 (Energy Law BC, n.d.). Provincial regulations include the Oil and Gas Activities Act General Regulation, Environmental Protection and Management Regulation, and the Oil and Gas Activities Act Drilling and Production Regulations.

In Alberta, regulation of hydraulic fracturing falls under the aegis of the Alberta Energy Regulator, which regulates unconventional oil and gas production as it does all other oil and gas production in the province. Its website (AER, n.d.) lists 14 separate regulatory directives covering virtually all aspects of hydraulic fracturing, including:

- Directive 008: Surface Casing Depth Requirements
- Directive 009: Casing Cementing Minimum Requirements
- Directive 020: Well Abandonment
- Directive 031: REDA Energy Cost Claims (formerly Directive 031: Guidelines for Energy Proceeding Cost Claims)
- Directive 035: Baseline Water Well Testing Requirements for Coalbed Methane Wells Completed above the Base of Groundwater Protection
- Directive 038: Noise Control
- Directive 044: Requirements for Surveillance, Sampling, and Analysis of Water Production in Hydrocarbon Wells Completed Above the Base of Groundwater Protection
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- Directive 058: Oilfield Waste Management Requirements for the Upstream Petroleum Industry
- Directive 059: Well Drilling and Completion Data Filing Requirements
- Directive 083: Hydraulic Fracturing – Subsurface Integrity

Industry self-regulation

But as Hoover Institute Senior Fellow Terry Anderson and his colleague Carson Bruno point out, purely regulatory approaches have their limitations: they can be cumbersome, and lend themselves to regulatory capture (where the regulators come to have more in common with the industry than the public), and they also create barriers to entry for new competition that may have superior technologies and safer processes. They also, to an extent, protect companies from full liability—companies are rarely prosecuted if they are following the rules government has set for them. Anderson and Bruno observe that there are alternative safeguards that can be put in place to minimize risk taking, and to indemnify against potential accidents. Some of these safeguards involve the enforcement of property rights as well as the insurance of strict liability for those who would engage in hydraulic fracturing (which will be discussed shortly). Another is industry self-regulation, which is also extensive in Canada (Anderson and Bruno, 2014).

According to the Canadian Association of Petroleum Producers (CAPP, 2012b), the oil and gas industry in Canada has accepted a set of guiding principles that include:

- Safeguard the quality and quantity of regional surface and groundwater resources, through sound wellbore construction practices, sourcing fresh water alternatives where appropriate, and recycling water for reuse as much as practical.

- Measure and disclose water use with the goal of continuing to reduce the effect on the environment.

- Support the development of fracturing fluid additives with the least environmental risks.

- Support the disclosure of fracturing fluid additives.

- Continue to advance, collaborate on, and communicate technologies and best practices that reduce the potential environmental risks of hydraulic fracturing.

CAPP (n.d.) publishes operating procedures that cover: fracturing fluid disclosure; risk assessment and management; baseline groundwater testing; wellbore construction and quality assurance; water sourcing, measuring, and reuse; and fluid transport, handling, storage and disposal. Even seismic risk is to be assessed, monitored, and mitigated. CAPP also strongly supports the role of the energy regulator in conjunction with its own best practices.

Going beyond regulation and ensuring responsibility

As Anderson and Bruno also point out, however, governmental and self-regulation combined may not address all of the risks of hydraulic fracturing, nor assure that entities that engage in misconduct and cause environmental damage can be held liable.

One of the challenges in applying property rights and legal liability in areas like hydraulic fracturing is that it can be hard to know who is directly responsible for a given environmental impact. One might monitor for water pollution in an aquifer, and detect some evidence of pollution, but how does one know who to prosecute for the violation when multiple operators might be operating in the same area?

Anderson and Bruno observe that, even here, new technologies may allow the use of strictly defined property rights and strongly enforced punishment for those who might be inclined to cut corners. For example, advances in the use of isotopic tracers could allow for the identification of individual sources of environmental contamination, creating an incentive for all operators to use maximum care when engaging in risky operations, and perhaps to eschew high-risk activities entirely out of their own understanding of the economic risk to their future livelihood.

Anderson and Bruno also point to better practices in pricing water as a non-traditional approach to mitigating some of the risk of excessive water consumption in water-scarce areas, and to creating incentives for fracturing methods that use less or no water. Finally, Anderson and Bruno point to examples of private sector entities that can be created to bring additional pressure to bear on companies to encourage their best behavior. Independent for-profit (or not-for-profit) entities can be created to offer certifications on their operations, akin to the Underwriters Laboratory in the United States. Governments could mandate such third-party certification as a necessary step in obtaining permission to operate.

Conclusion

Hydraulic fracturing is a new application of old technologies that has unlocked large quantities of natural gas and liquid hydrocarbons—fuels that can be used to generate equally large quantities of economic benefit to Canadians. There is no question that the technology poses some risk to air quality, water quality, and ecosystem health. It also poses a risk of increasing greenhouse gas emissions. Other issues which are real but not discussed here are water consumption and worker-safety issues related to engaging in hydraulic fracturing.

But the literature on the risks of hydraulic fracturing, while voluminous, is not clear. The most authoritative studies by governmental academies and agencies suggest that more information needs to be gathered, but at present the risks are judged to be modest and manageable with existing technologies.

Canada has a robust regulatory process that covers the entire range of hydraulic fracturing processes at both federal and provincial levels. In addition, the industry, through its trade association, has stringent self-regulation that exceeds regulatory requirements. More research is needed to fully define the environmental impacts of hydraulic fracturing, as well as the risks it may pose to human and ecological health; and, of course, research is continuing both in Canada and around the world. The risks of hydraulic fracturing will become clearer over time.

In the meantime, there are additional measures that can be implemented to further minimize risk, including requiring adequate levels of insurance, developing tracking technology that would allow for strict liability for companies that cause environmental damage, and the development of independent certifying organizations that can exert public pressure to encourage responsible behavior.

It goes without saying that one can gain little new knowledge (including of risks and how to best address them) if one stops experimenting. Bans and moratoria would seem to cut against the recommendation of gathering knowledge. By contrast, a strategy of governmental regulation, industry self-regulation, and the addition of innovative market incentives for superior performance would be a better approach for Canada. At the very least, this would allow us to develop knowledge about the activity and what risks are really associated with it, both generally and for each specific site, while allowing

Canadians to access the immense benefits of economic development in this area. Such an approach would also allow for innovation in protection and risk reduction, as individuals search for better and safer ways to develop this valuable resource.

Even the most recent studies of hydraulic fracturing safety call for variations on the "proceed with caution" theme. As a report of the Nova Scotia Independent Panel on Hydraulic Fracturing observes:

> Consistent with the analyses of the report of the Chief Medical Officer of New Brunswick (Cleary, 2012), a review by Public Health England (Kibble et al., 2014), a report by the European Parliament (2011) and the Report of the Council of Canadian Academies (2014), we noted that a number of the potential long-term and cumulative public health impacts of hydraulic fracturing and its associated activities and technologies are simply unknown at the present time. However, there is currently no evidence of catastrophic threats to public health in the short-to-medium term that would necessitate the banning of hydraulic fracturing outright. (Wheeler et al., 2014: 308)

The call for bans and moratoria are passionate, and no doubt heartfelt by those who fear the technology and/or oppose the product of that technology (hydrocarbons), but policymakers should ignore the siren song of the simplistic solution. Bans and moratoria may make it seem like one is taking action against risk, but they simply defer those risks to a later date, if and when activity resumes, which—given the vast economic potential of shale gas and oil—it most likely will.

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The Fraser Institute maintains a rigorous peer review process for its research. New research, major research projects, and substantively modified research conducted by the Fraser Institute are reviewed by experts with a recognized expertise in the topic area being addressed. Whenever possible, external review is a blind process. Updates to previously reviewed research or new editions of previously reviewed research are not reviewed unless the update includes substantive or material changes in the methodology.

The review process is overseen by the directors of the Institute's research departments who are responsible for ensuring all research published by the Institute passes through the appropriate peer review. If a dispute about the recommendations of the reviewers should arise during the Institute's peer review process, the Institute has an Editorial Advisory Board, a panel of scholars from Canada, the United States, and Europe to whom it can turn for help in resolving the dispute.