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An overview of Canadian shale gas production and environmental concerns

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ABSTRACT

Production of hydrocarbons from Canadian shales started slowly in 2005 and has significantly increased since. Natural gas is mainly being produced from Devonian shales in the Horn River Basin and from the Triassic Montney shales and siltstones, both located in northeastern British Columbia and, to a lesser extent, in the Devonian Duvernay Formation in Alberta (western Canada). Other shales with natural gas potential are currently being evaluated, including the Upper Ordovician Utica Shale in southern Quebec and the Mississippian Frederick Brook Shale in New Brunswick (eastern Canada).

This paper describes the status of shale gas exploration and production in Canada, including discussions on geological contexts of the main shale formations containing natural gas, water use for hydraulic fracturing, the types of hydraulic fracturing, public concerns and on-going research efforts. As the environmental debate concerning the shale gas industry is rather intense in Quebec, the Utica Shale context is presented in more detail.

1. Introduction

Natural gas is often considered a transition fuel for a low-carbon economy because it is abundant, efficient, and cleaner burning than other fossil fuels. Over the past decade, shale has been heralded as the new abundant source of natural gas in North America. The combination of technological advancements in horizontal drilling and in multi-stage hydraulic fracturing ("fracking" in industry jargon) techniques, as well as the progressive decline in conventional oil and gas reserves in North America, made shale gas the "energy game changer" over the last years. In addition, the fact that recoverable reserves of natural gas and oil in shales have been estimated to be large enough to potentially free the United States from a decade-long dependence on oil imports, and replace nearly all coal-generated electricity (Soeder, 2013), has probably largely contributed to making shale gas exploration and production increasingly appealing in this country. The United States was the first to economically produce shale gas from the Barnett Shale more than a decade ago; in 2013, there are over 40 000 producing shale gas wells spread across 20 states. However, natural gas prices have significantly decreased over the past several years, so that many shale dry gas plays (without liquid hydrocarbon production) are currently at the lower limit of economic profitability.

Shale gas formations targeted by industry are generally located more than 1 km deep and under pressures sufficient to allow natural flow. Vertical wells must progressively be deviated to the horizontal to reach the target zone because the latter is typically relatively thin (50–100 m). Therefore, the horizontal part (termed a "lateral") optimizes natural gas recovery by allowing the borehole to be in contact with the producing shale interval over significantly longer distances (and thus over a much larger surface area) compared to a vertical borehole. Almost all shale reservoirs must be fractured to extract economic amounts of gas because their permeability is extremely low, which impedes gas flow towards the production well. To increase their permeability, shales are typically fractured with fluids injected under high pressure, usually through a cemented liner or production casing that was selectively perforated. The fracking fluid used is specific to each operator and differs from one shale formation to another, depending, among other things, on the pressure gradient, brittleness (Poisson ratio and Young's modulus), clay content and overall mineralogy, horizontal stresses, and gas to oil ratio (GOR). Historically, the most common fracking fluid used by the shale gas industry has been slickwater (a simple mixture of water, proppants (usually sand), friction reducers and other chemical additives) due to its low cost and effectiveness. More recently, shale reservoirs appear to be increasingly stimulated with a hybrid treatment consisting of slickwater used in alternation with a cross-linked gel purposely designed for a specific viscosity, with hybrid slickwater energized with N_2 or CO_2, or with hydrocarbons such as gelled propane.

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Micro-seismic events induced by fracking operations are now being routinely recorded on a fraction of the wells drilled in a new exploitation area using ultra-sensitive seismographs placed either in an adjacent gas well, as a** buried array or as a surface array. These techniques allow the estimation of fracture height and half-lengths from which a stimulated reservoir volume can be calculated, which helps assess the effectiveness of the stimulation. Generally, induced fractures are reported to extend less than 300 m vertically (Davies et al., 2012; Fisher and Warpinski, 2012).

Hydraulic fracturing has been used to stimulate production wells in conventional oil and gas reservoirs (mostly in vertical wells) in North America for more than 60 years. However, in the case of horizontal shale gas wells, the stimulation process requires greater amounts of water, sand and chemicals for a given well, and this mixture must be injected at higher rates and pressures, and a much larger volume of rock is involved compared to conventional reservoirs. Hence, more powerful equipment is required on site (pumper trucks) and much more truck traffic for the transportation of water and sand is involved (if a local source is not available). Due to the horizontal drilling technology and multi-stage fracturing, these activities are taking place several times on multi-well pad sites, instead of taking place in multiple vertical wells on the surface. Environmental concerns are mainly related to seven issues that are themselves related to six main activities, as summarized in Table 1.

This paper presents the historical context and current state of shale gas development in Canada (Section 2), geological contexts of main Canadian shale plays containing dry gas (Section 3), facts on hydraulic fracturing (Section 4), water usage by this industry (Section 5), as well as various research initiatives implemented to investigate different environmental issues mentioned above and to characterize the shale formations themselves (Section 6). Then, public concerns (Section 7) and regulation related to drilling and fracturing (Section 8) are briefly discussed. Finally, the historical background and social context of the Utica Shale (southern Quebec) are described in more detail. Although only limited Utica Shale exploration has taken place, it has raised environmental concerns amongst the general public that have led to a temporary *de facto* moratorium on hydraulic fracturing in Quebec.

2. General context

Over 500 000 oil and natural gas wells have been drilled to date in Canada, of which more than 375 000 are located in Alberta (CAPP, 2012). Petroleum development began in eastern Canada in 1858, where a 15.5 m (51 ft) oil well was dug (not drilled) in Oil Springs, Ontario. This well became the first commercial oil well in North America. Natural gas was discovered in Ontario in 1859, but commercial gas was not produced in the province until 1889. In the late 1800s, some production of natural gas from unconsolidated Quaternary sands for local industrial purposes took place for a short period in the Trois-Rivières area (between Montreal and Quebec City, in southern Quebec). This very small reservoir was, however, rapidly depleted. At that time, shallow conventional hydrocarbons were targeted, mainly in overburden (often at the bedrock/overburden contact). In western Canada, the first gas discovery was accidentally made while drilling for water near Medicine Hat, Alberta, in 1883. A second well was drilled the following year that produced enough gas to light and heat several buildings. The discovery of the world-class Leduc oil field in 1947 by Imperial Oil made the Western Canada Sedimentary Basin the center of Canada's petroleum exploration and production. The industry started constructing a vast pipeline network in the 1950s, to start developing domestic and international markets. Canada is now the third largest producer of natural gas in the world (1720 billion m^3 or 60 200 billion ft^3 or Bcf for 2012; National Energy Board, 2012) and the 4th largest exporter, with the U.S. currently being its sole international market.

Canada's production of "primary" energy, i.e. energy found in nature before conversion or transformation, totalled 16 495 petajoules (PJ) in 2010. Fossil fuels accounted for the greatest share of this production, with crude oil representing 41.4%; natural gas, 36.5%; and coal, 9.2% (NRCan, 2011). The remainder (12.9%) comes from renewable energy sources. About 95% of the natural gas was produced from conventional sources, and the remaining 5% was from unconventional sources such as coal bed methane and shale gas. Recent exploration and exploitation of numerous shale gas plays in Canada have caused a sharp increase in both estimated in-place resources and natural gas reserves. The portion of shale gas in the Canadian energy production could significantly increase in future years because of several factors, notably the large and continuous nature of unconventional reservoirs and declining conventional (oil and gas) production. There are indeed a number of shale gas formations at various stages of exploration and development across the country (British Columbia, Alberta, Yukon, Northwest Territories, Quebec, New Brunswick and Nova Scotia). Fig. 1 shows the distribution of the main shale formations targeted by the industry. In many cases, these formations produce variable volumes of liquids associated with natural gas. Because of higher viscosities and size of the molecules, liquids are commonly produced from slightly coarser lithologies interbedded with the shales. As dry gas is currently not economical in many cases, it is the production of liquids that is currently carrying the cost of the shale gas development or exploration.

The first shale gas production in Canada came from the Montney Play Trend (tight gas and shale gas) in 2005 and the Horn River (exclusively shale gas) in 2007, both located in northeastern BC, where drilling activities have rapidly expanded (Figs. 2 and 3). Industry interest for other Canadian shale and tight sand plays started around the same period in British Columbia, Alberta, New Brunswick and Quebec, as illustrated in Fig. 2. As of the end of 2012, over 1100 wells have been either drilled for shale gas exploration and production or exploited for gas (gas also being a common by-product of tight oil or tight sand wells) mostly in BC and AB. Fig. 2 provides the number of wells for shale and tight sand gas in Canada,[1] as well as estimates of shale gas production in BC. Shale gas production for Alberta is not shown since it represents less than 1% of BC production; Alberta shale gas production in 2011 corresponded to about 0.1% of total gas production in the province. The AB shale and tight sand wells shown in Fig. 2 were largely drilled for liquids (condensates and oil); gas was a by-product. Fig. 3 shows the production increase of unconventional wells in BC over the last eight years. About 65 to 70% of total BC wells currently being drilled target the Montney Formation (Fig. 1), especially its liquid-rich domain. This expansion of tight reservoir wells is not, however, without controversy, and this topic will be discussed later in the section. Nonetheless, compared to the U.S., unconventional gas development in Canada is still in its nascent stages.

Table 1
Issues and activities of concern relative to the shale and tight gas industry (http://www.rff.org/centers/energy_economics_and_policy/Pages/Shale-Matrices.aspx).

Environmental concerns	Activities
1. Water quantity	1. Site development and drilling preparation
2. Water contamination	2. Drilling activities
3. Management of fracking and flowback fluid storage	3. Completion and hydraulic fracturing
4. Radioactive wastes	4. Well operation and production
5. Nuisances (noise, trucking, light)	5. Fracturing fluids, flowback, and produced water storage and disposal
6. Atmospheric emissions/air quality	6. Other activities (e.g. plugging and abandonment)
7. Induced seismicity	

[1] British Columbia does not distinguish between shale and tight sand gas because they are part of a continuum of very low permeability reservoirs in which economic production can only be achieved through hydraulic fracturing.