May 2014

Report in Focus

ENVIRONMENTAL IMPACTS OF SHALE GAS EXTRACTION IN CANADA

The North American energy landscape is undergoing dramatic change. Unconventional oil and gas resources are fuelling an energy boom that is having profound economic, environmental, and social impacts across much of the continent, including Canada. At the forefront of this change is shale gas, which has been characterized as a "game changer" because it is abundant, often close to major markets, and relatively inexpensive to produce.

Shale gas development in Canada is more recent and has been proceeding more slowly than it has in the United States. Until now, development has been concentrated in British Columbia and, to a lesser extent, Alberta. Shale gas resources are also known to exist in Quebec, New Brunswick, and Nova Scotia, and are likely to be found in other regions. Where it occurs, shale gas development requires a large number of wells and an extensive supporting infrastructure. The scale and pace of such development, and the fact that it may occur in areas with little prior oil and gas industry experience, have led to much public concern in Canada and abroad about its environmental implications. In a country as environmentally, geographically, and socially diverse as Canada, the impacts of shale gas development will vary regionally. However, some concerns, particularly related to well integrity, are common across the country.

While tens of thousands of shale gas wells have been drilled across North America over the last two decades, mostly in the United States, there has been no comprehensive investment in the research and monitoring of environmental impacts. Data are currently limited and data that do exist are not always publicly available. Furthermore, there are differing interpretations about some of these data. As a result, many pertinent questions are hard to answer objectively and scientifically.

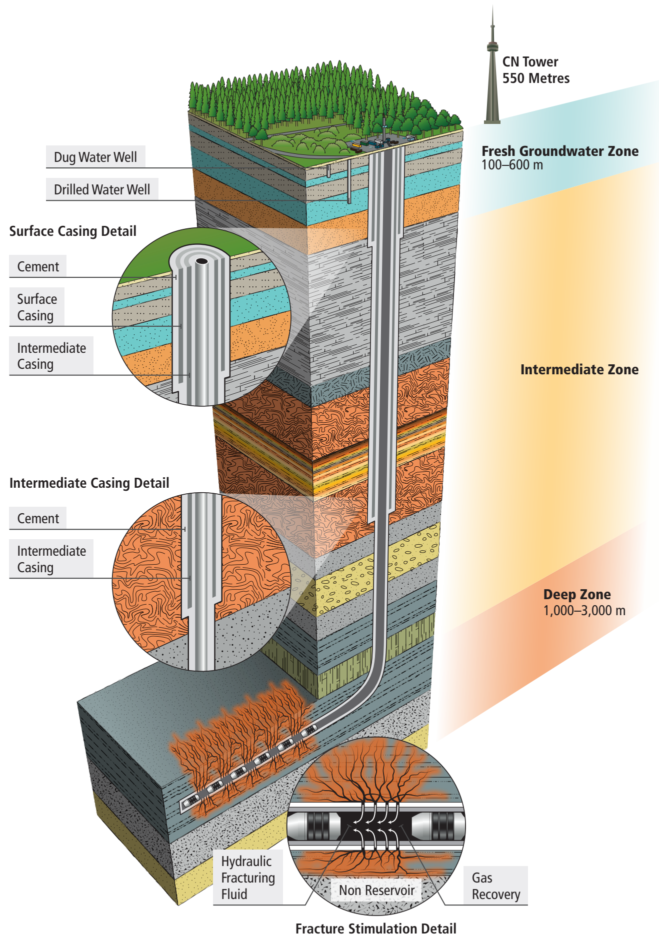

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Figure 1
Well Construction Diagram for a Shale Gas Well

Schematic of a shale gas well, illustrating the various geological layers through which a well is drilled and the relative depth at which hydraulic fracturing occurs. Some laterals (the horizontal part of the well) are much longer than shown in this diagram and can reach up to 3 kilometers. The first two insets show the various casings (the steel tubing) that are inserted into the well and cemented into place. The bottom inset highlights a stage, a section of pipe between two packers that has been perforated in order to inject the hydraulic fluid to fracture the shale.

CHARGE TO THE EXPERT PANEL

Environment Canada asked the Council of Canadian Academies (the Council) to conduct an in-depth, independent assessment to answer the following question:

> What is the state of knowledge of potential environmental impacts from the exploration, extraction, and development of Canada's shale gas resources, and what is the state of knowledge of associated mitigation options?

The Council assembled a multidisciplinary expert panel (the Panel) of Canadian and international experts to complete this assessment. When the Panel began its work, it was challenged by a lack of available literature and evidence on the environmental implications of shale gas development in many key areas. Over the course of the assessment, however, sources of evidence increased rapidly. The Panel relied on peer-reviewed literature and reports from government, industry, international bodies, and non-governmental organizations, in addition to workshops and conference attendance, and the Panel's own expertise and experience. Its report follows similar reviews completed by the Royal Society and Royal Academy of Engineering in the United Kingdom, and the Australian Council of Learned Academies. It should be noted that the Panel was not asked to determine the safety of shale gas development. Instead, the Panel's focus was on potential environmental impacts.

Key Findings

This report presents a comprehensive examination of the state of knowledge of potential environmental impacts of shale gas development in Canada. It reviews the use of new and conventional technologies in shale gas extraction, and examines several issues of concern including potential impacts on surface water and groundwater, greenhouse gas (GHG) emissions, cumulative land disturbance, and human health. The report also outlines approaches for monitoring and research, as well as mitigation and management strategies.

Well Integrity

Large-scale deep shale gas production only became possible in the mid-1990s when two technologies, horizontal drilling and high-pressure multi-stage hydraulic fracturing, were combined. A typical shale gas well starts vertically and is bent horizontally in order to intersect as much of the shale formation as possible (see Figure 1). Once the well is drilled and steel tubing (casing) cemented in place, hydraulic fracturing is done in stages to perforate the horizontal sections of the well. To fracture the shale, fluids containing "proppants" (usually sand) and other chemicals are injected at high pressure. The sand props open the fractures that have been created in the rock, allowing the trapped gas and some of the fracturing fluids to flow back up the well.

Natural gas leakage from wells due to inadequate cement seals is a long-recognized yet unresolved problem that continues to challenge engineers. Ensuring well integrity is the most important way to prevent gas and fluid leakage and protect the environment. Integrity is achieved through proper cementing processes that secure and seal the well in place. However, problems encountered during cementation, such as poor well centralization, inadequate mud displacement, and an irregular well hole, can negatively impact well integrity. Even after successful cementation, the degradation over time of both casing and the cement sheath can still cause some wells to leak. As a result, a small but unknown proportion of wells leak.

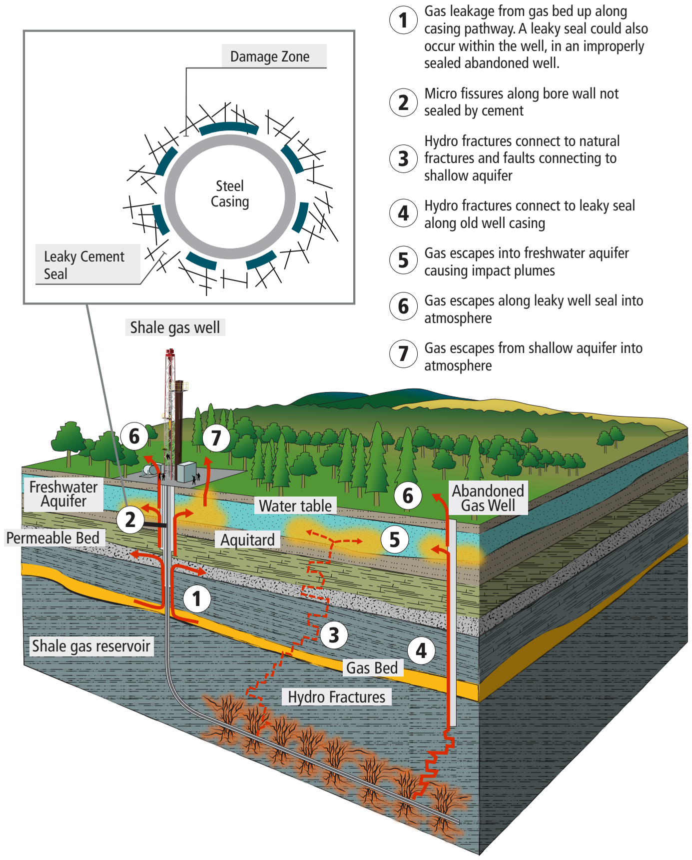
Concerns over well integrity apply to all wells, including existing and abandoned conventional oil and gas wells. However, as shale gas development requires a high density of wells to sustain a stable production rate, the need for well integrity increases, especially in areas that depend on groundwater for their potable water supply. See Chapter 3 of the report for more detail.

Water

The Panel placed significant focus on both groundwater and surface water during its review, and most experts agree that impacts on water raise the greatest environmental concern by shale gas development.

The greatest threat to groundwater is gas leakage from wells. While an area's natural assimilation capacity may limit the impacts of such leakage, this capacity varies. The potential impacts of leaking wells are not being systematically monitored, and predictions remain unreliable.

Potable groundwater can also be at risk if pathways for the migration of gases, and possibly saline fluids and fracturing chemicals, exist deep underground (see Figure 2). Leaky well casings can provide such pathways, as well as natural fractures in the rock, old abandoned wells, and permeable



Courtesy of G360 Centre for Applied Groundwater Research, University of Guelph

Figure 2
Conceptual Groundwater Contamination Pathways

There are several pathways by which potable groundwater could become contaminated by shale gas development, as shown in the schematic above. Note that this schematic is not to scale and does not imply that any of these pathways are necessarily present at any given site. The pathway marked by a dashed line is hypothetical as there is no known case of migration of hydraulic fracturing fluids from the deep shale zone to the groundwater level directly through the overburden rock.

geological faults. The migration of gases and saline fluids through these pathways over the long term could result in potentially substantial cumulative impacts on water quality. Currently, there is no known case of hydraulic fracturing fluid migration from deep shale gas zones to groundwater level directly through the rock.

Accidental surface releases of fracturing chemicals and wastewater may also affect shallow groundwater and surface water resources. The risks due to surface activities can be minimized if proper management practices are followed.

The amount of water needed for shale gas development is also a concern in some regions, not so much because of the absolute volume of water required, but the timing of its withdrawal. Depending on location, season and pre-existing uses, the additional demand related to hydraulic fracturing may stress available water resources. The shale gas industry is working to avoid such problems by storing water in advance, recycling water, or using non-potable deep saline water.

Wastewater disposal is another concern, especially in eastern Canada, where the accepted practice of deep-well injection of wastewater may not be geologically possible. For more detail on potential impacts on water, see Chapter 4 of the report.

Greenhouse Gas Emissions

How shale gas development affects climate change depends on its net contribution to global GHG emissions and this will only be determined by a well-to-burner analysis of its use relative to other energy sources. Overall, GHG emissions may be reduced if natural gas extracted from shale replaces coal in electricity generation. However, the potential climate change benefits of shale gas disappear if shale gas displaces low-carbon fuels, such as nuclear energy or renewables, including hydro-electricity. Low gas prices may also discourage investment in efficiency and renewable energies. These benefits also depend on rates of methane leakage in production and at transmission facilities, a subject of continuing inquiry. Therefore, the net impact of shale gas globally on GHG emissions will depend to a significant extent both on control of methane leakage, and on broader energy and climate policies.

Fields that produce shale gas with high carbon dioxide content (e.g., Horn River in northeast British Columbia) could become an important additional source of carbon dioxide emissions unless it is captured and used for enhanced oil recovery, or is sequestered in saline aquifers. Yet at this time, the experience and development of sequestration technology, and the extent of its application, are limited.

For a fuller picture of the potential impacts of shale gas development on GHG emissions, see Chapter 5 of the report.

Land Impacts and Seismic Events

Large-scale shale gas development may represent the start of several decades of industrial activity. Any assessment of the environmental effects of such development therefore cannot focus on a single well or well pad, but must also address cumulative and regional effects.

Multi-well pads and longer horizontal sections of the well can reduce the footprint of shale gas development (Figure 3), but the cumulative effects of the large number of wells and related infrastructure required for development (e.g., roads, compressor stations, pipeline rights-of-way, and staging areas) still impose substantial environmental impacts. These impacts

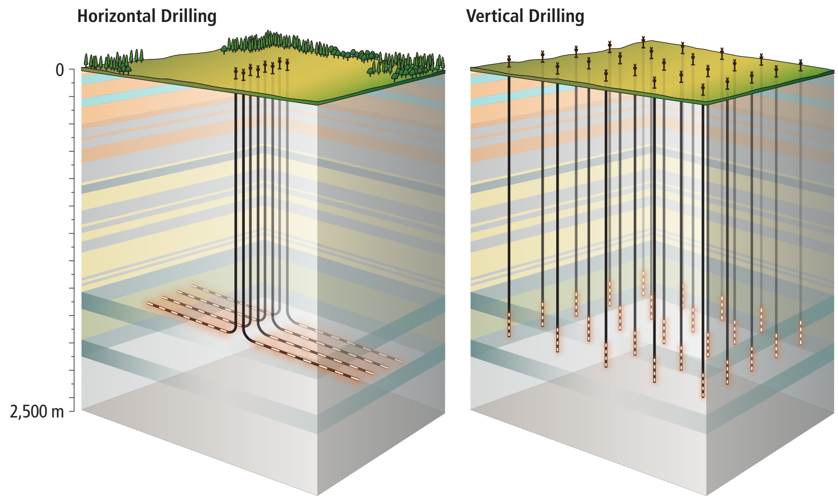


Figure 3
A Multi-Well Pad Versus a Cluster of Single Well Pads

Schematic illustration of horizontal shale gas wells and vertical wells. Through the use of multiple wells on a single pad and longer laterals, a greater area is covered by each well pad, reducing the needed pad density.

may include deforestation, the destruction of habitat, and adverse effects on existing land uses, such as agriculture.

Most experts judge the risk of seismic events triggered by hydraulic fracturing to be low and micro-seismic monitoring during operations can diminish this risk further. The risk of seismic events posed by wastewater injection is greater but still low, and can be minimized through careful site selection, monitoring, and management.

Human Health

Human health and well-being may be affected by the various environmental effects resulting from shale gas development. Health impacts are not well understood and additional research is required.

Shale gas development will provide economic benefits for communities nearby, but it may also adversely affect water and air quality, and in turn, community well-being. Possible community impacts include a rise in income inequality, health and safety issues related to a large increase in truck traffic, and the difficulty in adapting local services to the influx of a transient workforce.

Psychosocial impacts have also been reported. Lack of transparency and conflicting messages can lead to the perception that industry or authorities are not forthcoming, which can augment concerns about individual quality of life, and contribute to feelings of anxiety about the future. These risks are particularly relevant to the ability of Aboriginal peoples to maintain their traditional way of life, and several First Nations have expressed concerns about possible impacts on their well-being, quality of life, and rights.

Monitoring and Research

Reliable and timely information is essential to manage the environmental effects of shale gas development. In most instances, shale gas development has proceeded without the collection of sufficient environmental baseline data. This makes it difficult to identify and characterize impacts, or to dismiss impacts that are inappropriately associated with development. Past monitoring indicates that gas leakage into aquifers and the atmosphere is frequent enough to raise concern. Nevertheless, possible environmental and health effects of shale gas development may take decades to become apparent, underlining the need for long-term monitoring.

The Panel noted, however, that the research needed to support science-based decisions around environmental impacts of shale gas development is only just beginning in most of Canada and will need a collaborative effort among industry, government, academia, and the public in order to be effective. See Chapter 8 of the report for more details.

Effective environmental surveillance and flexible management approaches are key at this early stage for shale gas development in Canada.

Mitigation and Management

The shale gas industry has made considerable progress mitigating some environmental impacts. Over the past decade, industry has reduced water use, land disruption, the volume and toxicity of chemicals used, and methane emissions.

Properly designed management strategies can support responsible shale gas development. These strategies include the deployment of sound technologies, rigorous safety management by industry, effective government oversight, regional planning, and public engagement. Provinces are ultimately responsible for their own regulations, monitoring, and enforcement, but they also face common challenges related to the unknown and long-term nature of some impacts and insufficient baseline environmental information.

Shale gas development also poses challenges for governance. Benefits of development are primarily regional, while adverse impacts are mostly local and cut across several layers of government.

Some provincial governments are engaged in a "go-slow" approach for shale gas development. This approach allows for additional data collection, adaptation to the implications of new information, and the integration of multidisciplinary expertise. For more detail, see Chapter 9 of the report.

CONCLUSION

Well-targeted science is required to ensure a better understanding of the environmental impacts of shale gas development. This requires ongoing research and monitoring to gather and evaluate data, draft effective regulations, and build public trust. Currently, authoritative data about potential environmental impacts are neither sufficient nor conclusive. Science alone, however, will not address all relevant concerns because the actual impacts of shale gas development will depend on the manner in which it is managed and regulated.

The Panel acknowledges that shale gas promises significant economic benefits, but these must be weighed against possible adverse impacts on people and ecosystems.

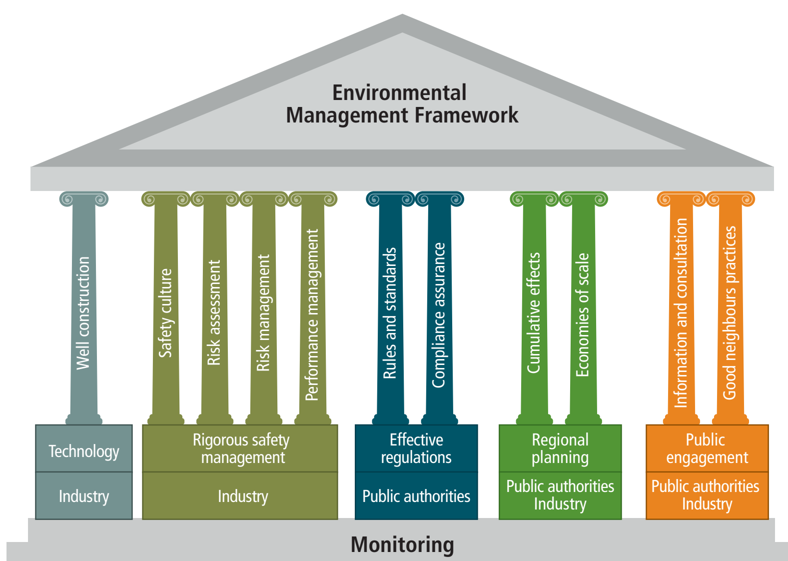


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Figure 4
Environmental Management Framework

An environmental management framework for shale gas development rests on a solid foundation of environmental monitoring and is supported by five distinct pillars or elements: technology, management systems, regulatory oversight, regional planning, and public engagement. The implementation of such a framework requires a collaborative approach by industry and relevant public authorities.

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OTHER COUNCIL REPORTS THAT MAY BE OF INTEREST:

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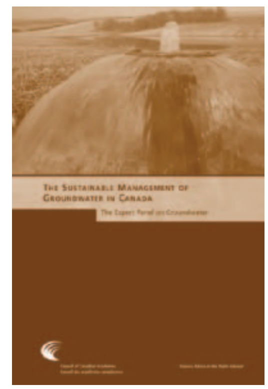

THE EXPERT PANEL ON HARNESSING SCIENCE AND TECHNOLOGY TO UNDERSTAND THE ENVIRONMENTAL IMPACTS OF SHALE GAS EXTRACTION: John Cherry, FRSC (Chair), Director of the University Consortium for Field-Focused Groundwater Contamination Research, Associate Director of G360 – Centre for Applied Groundwater Research, and Adjunct Professor in the School of Engineering at the University of Guelph (Guelph, ON); **Michael Ben-Eli**, Founder & Director of the Sustainability Laboratory (New York, NY); **Lalita Bharadwaj**, Associate Professor, Toxicologist, School of Public Health, University of Saskatchewan (Saskatoon, SK); **Richard Chalaturnyk**, Professor of Geotechnical Engineering, Department of Civil and Environmental Engineering, University of Alberta (Edmonton, AB); **Maurice B. Dusseault**, Part-Time Professor of Engineering Geology, Department of Earth and Environmental Sciences, University of Waterloo (Waterloo, ON); **Bernard Goldstein**, Professor of Environmental and Public Health, Graduate School of Public Health, University of Pittsburgh (Pittsburgh, PA); **Jean-Paul Lacoursière**, Associate Professor, Chemical Engineering Department, University of Sherbrooke (Sherbrooke, QC); **Ralph Matthews**, Professor, Department of Sociology, University of British Columbia (Vancouver, BC); Professor Emeritus of Sociology, McMaster University; **Bernhard Mayer**, Professor of Isotope Geochemistry, Department of Geoscience, University of Calgary (Calgary, AB); **John Molson**, Canada Research Chair in Quantitative Hydrogeology of Fractured Porous Media, Department of Geology and Geological Engineering, Laval University (Quebec, QC); **Kelly Munkittrick**, Director, Monitoring, Canada's Oil Sands Innovation Alliance (Calgary, AB); **Naomi Oreskes**, Professor, Department of the History of Science, Harvard University (Cambridge, MA); **Beth Parker**, Director, G360 Centre for Applied Groundwater Research, University of Guelph (Guelph, ON); **Paul Young, FRSC**, Vice President (Research) & Professor of Geophysics, University of Toronto (Toronto, ON).

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This *Report in Focus* was prepared by the Council based on the Report of the Expert Panel on Harnessing Science & Technology to Understand the Environmental Impacts of Shale Gas Extraction.