Environmental Impacts of Shale Gas Extraction in Canada

Executive Summary

Council of Canadian Academies
Conseil des académies canadiennes

Science Advice in the Public Interest

ENVIRONMENTAL IMPACTS OF SHALE GAS EXTRACTION IN CANADA

The Expert Panel on Harnessing Science and Technology to Understand the Environmental Impacts of Shale Gas Extraction

THE COUNCIL OF CANADIAN ACADEMIES
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This report was prepared for the Government of Canada in response to a request from the Minister of Environment. Any opinions, findings, or conclusions expressed in this publication are those of the authors, the Expert Panel on Harnessing Science and Technology to Understand the Environmental Impacts of Shale Gas Extraction, and do not necessarily represent the views of their organizations of affiliation or employment.

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Expert Panel on Harnessing Science and Technology to Understand the Environmental Impacts of Shale Gas Extraction

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Message from the President

The development of unconventional oil and gas resources — including shale gas — holds prospects for dramatically changing the global energy supply. Jurisdictions worldwide are weighing the potential benefits and impacts of this development. As the world's third-largest natural gas producer, fourth-largest exporter, and possessing vast shale gas resources of its own, Canada has a major stake in this new source of energy.

The Council of Canadian Academies was asked by the federal Minister of Environment to assemble an expert panel to assess the state of knowledge about the impacts of shale gas exploration, extraction, and development in Canada. In response, the Council recruited a multidisciplinary panel of experts from Canada and the United States to conduct an evidence-based and authoritative assessment supported by relevant and credible peer reviewed research. As with all Council panels, members were selected for their experience and knowledge, not to represent any particular stakeholder group. The report does not include recommendations, since policy prescription falls outside the Council's mandate.

This report and its findings come early in the conversation about the development of Canada's shale gas resources. Council assessments strive for consensus, which proved challenging in this case given the number of issues involved, the lack of evidence on some of those issues, and rapidly evolving industry practices. While this report is far from the last word on this topic, the Council believes the Panel has shed light on important matters that need further reflection.

The report focuses on Canada as a whole but points to significant regional characteristics and differences wherever these are relevant. It is the Council's hope that everyone engaged in and concerned about this topic will find value in the Panel's assessment. The Council believes that this report can inform both public discussions and a future environmental research agenda on a natural resource that could play an important role in the future of several provinces.

The Council is deeply appreciative of the contributions and assistance it received from numerous individuals and organizations throughout the course of its work. First and foremost the Council thanks the Expert Panel members who gave generously of their time and expertise for this challenging assessment, as well as the peer reviewers who commented on a draft of the report. The Council is grateful to Mark D. Zoback, Professor of Geophysics, Stanford University, and to Jennifer Miskimins, Associate Professor, Petroleum Engineering Department, Colorado School of Mines, for their insight and counsel throughout the assessment. The Council also wishes to acknowledge the many other individuals and organizations that provided helpful advice throughout this assessment.

Elizabeth Dowdeswell, **O.C.**, President and CEO
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Report Review

This report was reviewed in draft form by the individuals listed below — a group of reviewers selected by the Council of Canadian Academies for their diverse perspectives, areas of expertise, and broad representation of academic, industrial, policy, and non-governmental organizations.

The reviewers assessed the objectivity and quality of the report. Their submissions — which will remain confidential — were considered in full by the Panel, and many of their suggestions were incorporated into the report. They were not asked to endorse the conclusions, nor did they see the final draft of the report before its release. Responsibility for the final content of this report rests entirely with the authoring Panel and the Council.

The Council wishes to thank the following individuals for their review of this report:

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The report review procedure was monitored on behalf of the Council's Board of Governors and Scientific Advisory Committee by **Dr. John Hepburn, FRSC,** Vice-President, Research and International, University of British Columbia. The role of the report review monitor is to ensure that the panel gives full and fair consideration to the submissions of the report reviewers. The Board of the Council authorizes public release of an expert panel report only after the report review monitor confirms that the Council's report review requirements have been satisfied. The Council thanks Dr. Hepburn for his diligent contribution as report review monitor.

Elizabeth Dowdeswell, **O.C.**, President and CEO
Council of Canadian Academies

Executive Summary

Shale gas is natural gas that is tightly locked within low permeability sedimentary rock. Recent technological advances are making shale gas reserves increasingly accessible and their recovery more economically feasible. This resource is already being exploited in British Columbia and Alberta, and substantial recoverable reserves may exist in Quebec, New Brunswick, Nova Scotia, and elsewhere in Canada. Shale gas is being produced in large volumes in the United States, and will likely be developed in coming years on every continent except Antarctica. Depending on factors such as future natural gas prices and government regulations, further development of Canadian shale gas resources could potentially span many decades and involve the drilling of tens of thousands of hydraulically fractured horizontal wells.

This development is changing long-held expectations about oil and gas resource availability; several observers have characterized it as a *game changer.* Abundant, close to major markets, and relatively inexpensive to produce, shale gas represents a major new source of fossil energy. However, the rapid expansion of shale gas development in Canada over the past decade has occurred without a corresponding investment in monitoring and research addressing the impacts on the environment, public health, and communities. The primary concerns are the degradation of the quality of groundwater and surface water (including the safe disposal of large volumes of wastewater); the risk of increased greenhouse gas (GHG) emissions (including fugitive methane emissions during and after production), thus exacerbating anthropogenic climate change; disruptive effects on communities and land; and adverse effects on human health. Other concerns include the local release of air contaminants and the potential for triggering small- to moderate-sized earthquakes in seismically active areas. These concerns will vary by region. The shale gas regions of Canada can be found near urban areas in the south and in remote regions in the northwest, presenting a large diversity in their geology, hydrology, land uses, and population density. The phrase *environmental impacts from shale gas development* masks many regional differences that are essential to understanding these impacts.

To understand the risks associated with shale gas development in Canada, the Minister of Environment on behalf of Environment Canada asked the Council of Canadian Academies (the Council) to assemble a panel of experts to address 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 assessment of environmental impacts is hampered by a lack of information about many key issues, particularly the problem of fluids escaping from incompletely sealed wells. If wells can be sealed, the risk to groundwater is expected to be minimal, although little is known about the mobility and fate of hydraulic fracturing chemicals and wastewater in the subsurface. The pertinent questions are difficult to answer objectively and scientifically, either because the relevant data have not been obtained; because some relevant data are not publicly available; or because existing data are of variable quality, allow for divergent interpretations, or span a wide range of values with different implications.

Two issues of particular concern to panel members are water resources, especially groundwater, and GHG emissions. Both relate to well integrity. Many of the operational procedures used in shale gas extraction are similar to those used in conventional oil and gas extraction. Thus industry experience is relevant to understanding these issues.

Natural gas leakage from improperly formed, damaged, or deteriorated cement seals is a long-recognized yet unresolved problem that continues to challenge engineers. Leaky wells due to improperly placed cement seals, damage from repeated fracturing treatments, or cement deterioration over time, have the potential to create pathways for contamination of groundwater resources and to increase GHG emissions. The issue of well integrity applies to all well types, including water and conventional gas or oil wells. Several factors make the long-term impact related to leakage greater for shale gas development than for conventional oil and gas development. These are the larger number of wells needed for shale gas extraction; the diverse chemicals used in hydraulic fracturing operations; the potential development of shale gas resources in rural and suburban areas that rely on groundwater resources; and possibly the repetitive fracturing process itself.

ENVIRONMENTAL IMPACTS

Water

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 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. The risks due to surface activities will likely be minimal if proper precautionary management practices are followed. 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).

Greenhouse Gas Emissions

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.

Other Impacts

Land

Large-scale shale gas development may represent the start of several decades of production and the drilling of tens of thousands of wells in Canada. This development will have both local and dispersed land effects. The assessment of the environmental effects of shale gas development cannot, therefore, focus on a single well or well pad, but must also consider regional and cumulative effects.

Shale gas development requires extensive infrastructure that includes roads, well pads, compressor stations, pipeline rights-of-way, and staging areas. While the use of multi-well pads and longer horizontal laterals reduces the environmental impact, compared to individual well sites, the cumulative effects of the large number of wells and related infrastructure required to develop the resource still impose substantial impacts on communities and ecosystems. Furthermore, the performance of the infrastructure, operations, and closure procedures will likely be geology- and operator-specific and require monitoring for potential fluid migration over long time scales to assess impacts. Since the degree of future land reclamation from shale gas development is uncertain, consideration should be given to the risks and financial liability that arise. Land impacts may include deforestation, the destruction and fragmentation of wildlife habitat, and adverse effects on existing land uses such as agriculture and tourism. It is difficult to estimate these impacts without information on the location, pace, and scale of future shale gas development.

Human Health and Social Impacts

The health and social impacts of shale gas development have not been well studied. While shale gas development will provide varied economic benefits, it may also adversely affect water and air quality and community well-being as a result of the rapid growth of an extraction industry in rural and semi-rural areas. Potential community impacts include health and safety issues related to truck traffic and the sudden influx of a large transient workforce. Psychosocial impacts on individuals and on the communities have been reported related to physical stressors, such as noise, and perceived lack of trustworthiness of the industry and government. If shale gas development expands, risks to quality of life and well-being in some communities may become significant due to the combination of diverse factors related to land use, water quality, air quality, and loss of rural serenity, among others. These factors are particularly relevant to the ability of Aboriginal peoples to maintain their traditional way of life; several First Nations have expressed concerns about the possible impacts of shale gas development on their quality of life and their rights.

Air Contaminants

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.

Seismic Events

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. Micro-seismic 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.

PUBLIC ACCEPTABILITY

The potential impacts of shale gas development, as well as strategies to manage these impacts, need to be considered in the context of local concerns and values. More specifically, the manner in which residents are engaged in decisions concerning shale gas development will be an important determinant of their acceptance or rejection of this development. To earn public trust, credible multidisciplinary research will need to be conducted to understand existing impacts and predict future impacts. Public acceptance of large-scale shale gas development will not be gained through industry claims of technological prowess or through government assurances that environmental effects are acceptable. It will be gained by transparent and credible monitoring of the environmental impacts.

LIMITS TO OUR KNOWLEDGE AND UNDERSTANDING

The technologies used by the shale gas industry have developed incrementally over several decades. This gradual evolution has obscured the full implications of the large-scale deployment of these technologies. Society's understanding of the potential environmental impacts has not kept pace with development, resulting in gaps in scientific knowledge about these impacts.

In most instances, shale gas extraction has proceeded without sufficient environmental baseline data being collected (e.g., nearby groundwater quality, critical wildlife habitat). This makes it difficult to identify and characterize environmental impacts that may be associated with or inappropriately blamed on this development.

Some of the possible environmental and health effects of shale gas development may take decades to become apparent. These include the creation of subsurface pathways between the shale horizons being fractured and fresh groundwater, gas seepage along abandoned wells, and cumulative effects on the land and communities. Similarly, monitoring strategies, data, and information on the effectiveness of mitigation measures take time to develop, acquire, and assess.

Few peer-reviewed articles on the environmental impacts of shale gas development have been published. The reasons include the young age of the industry (about 20 years old in the United States and only half that in Canada); the proprietary nature of much industry information (in part because technologies are evolving rapidly and are still being tested); the confidentiality surrounding settlement of damage claims; and the absence of U.S. regulations for many of the chemical additives used in hydraulic fracturing (the industry therefore has not had to monitor its impact). Where peer-reviewed studies have been published, they do not necessarily agree (e.g., on the extent of fugitive methane emissions).

Information concerning the impacts of leakage of natural gas from poor cement seals on fresh groundwater resources is insufficient. The nature and rate of cement deterioration are poorly understood and there is only minimal or misleading information available in the public domain. Research is also lacking on methods for detecting and measuring leakage of GHGs to the atmosphere.

Full disclosure of chemicals and the chemical composition of flowback water is a necessary but insufficient step in the assessment of the environmental risks associated with drilling and fracturing. Information is also required on potentially hazardous chemicals produced down-hole by chemical interactions under high temperature and pressure. This includes information on concentration, mobility, persistence in groundwater and surface water, and bio-accumulation properties, for each chemical on its own and as a mixture. This represents a major gap in understanding of the potential environmental and human impacts of hydraulic fracturing, and of how to mitigate accidental releases of chemicals or flowback water to the environment.

Shale gas development also raises social impacts about which little is known. In contrast to thinly populated northern British Columbia, shale gas development in eastern Canada would take place in populated rural and semi-rural areas. Many of the people living in these areas rely on private water wells.

MONITORING APPROACHES

Reliable and timely information, including characterization, underpins the implementation of a risk management framework. Although monitoring is no substitute for effective prevention practices, it is the means by which environmental and human health impacts are identified, making it possible for mitigation measures to be designed and implemented.

Monitoring that has been done indicates that gas leakage into aquifers and the atmosphere is frequent enough to raise concern. Given the likely future density of gas wells, shale gas development is expected to have a greater long-term impact than conventional oil and gas development.

Appropriate environmental monitoring approaches for the anticipated level of shale gas development have not yet been identified. Monitoring programs will have to be adapted to advances in technologies and to the location, scale, and pace of future development. To gain public trust, monitoring needs to engage both the people living in affected areas and independent experts. The public will have greater faith in monitoring if it can influence the design, can access the results, and can comment.

The Panel notes that the research needed to support improved science-based decisions concerning cumulative environmental impacts has not yet begun, except in Quebec, and is unlikely to occur without a concerted effort among industry, government, academia, and the public in each of the provinces with significant shale gas potential.

MITIGATION OPTIONS

Managing the environmental impacts of large-scale shale gas development will require not only the knowledge provided by characterizing water and ecological systems prior to development and environmental monitoring, but also a robust management framework.

Provinces are responsible for their own regulations, monitoring, and enforcement. They face challenges related to unknown characteristics of impacts, inadequate baseline environmental information, and governance. There can be advantages in "go-slow" approaches to allow for additional data collection, to permit adaptation to the implications of new information, and to encourage integration of multidisciplinary expertise. But there may also be some negative impacts of development that cannot be eliminated, and the scientific basis for identifying areas that are particularly vulnerable has not been established.

The shale gas industry has made considerable progress over the past decade in reducing water use by recycling, reducing land disruption by concentrating more wells at each drilling site, reducing the volumes of the toxic chemicals it uses, and reducing methane emissions during well completions. Other impacts, however, such as cumulative effects on land, fugitive GHG emissions, and groundwater contamination, are more problematic. This is the case because available mitigation technologies are untested and may not be sufficient; scientific understanding is incomplete; and the design of an adequate regulatory framework is hampered by limited information. Shale gas development poses particular challenges for governance because the benefits are mostly regional whereas adverse impacts are mostly local and cut across several layers of government.

An effective framework for managing the risks posed by shale gas development would include five distinct elements:

(i) *Technologies to develop and produce shale gas.* Equipment and products must be adequately designed, installed in compliance with specifications, and tested and maintained for reliability.
(ii) *Management systems to control the risks to the environment and public health.* The safety management of equipment and processes associated with the development and operation of shale gas sites must be comprehensive and rigorous.
(iii) *An effective regulatory system.* Rules to govern the development of shale gas must be based on appropriate science-driven, outcome-based regulations with strong performance monitoring, inspection, and enforcement.
(iv) *Regional planning.* To address cumulative impacts, drilling and development plans must reflect local and regional environmental conditions, including existing land uses and environmental risks. Some areas may not be suitable for development with current technology, whereas others may require specific management measures.
(v) *Engagement of local citizens and stakeholders.* Public engagement is necessary not only to inform local residents of development, but to receive their input on what values need to be protected, to reflect their concerns, and to earn their trust. Environmental data should be transparent and available to all stakeholders.

These elements would need to be supported by environmental monitoring programs to supply credible, science-based information to develop and apply regulations.

The Canadian regulatory framework governing shale gas development is evolving and remains untested. The rights of Aboriginal peoples may be affected in several provinces and need to be protected. Advanced technologies and practices that now exist could be effective to minimize many impacts, but it is not clear that there are technological solutions to address all of the relevant risks, and it is difficult to judge the efficacy of current regulations because of the lack of scientific monitoring. The research needed to provide the framework for improved science-based decisions concerning cumulative environmental impacts has barely begun. Because shale gas development is at an early stage in Canada, there is still opportunity to implement management measures, including environmental surveillance, that will reduce or avoid some of the potential negative environmental impacts and permit adaptive approaches to management.