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LNG and Climate Change:

The Global Context

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TABLE OF CONTENTS

EXECUTIVE SUMMARY	4
1. INTRODUCTION	5
2. ENERGY MIX IN THE 450 SCENARIO	6
3. THE ROLE FOR NATURAL GAS	7
4. THE GREENHOUSE GAS INTENSITY OF NATURAL GAS	9
4.1 Reasons why methane from natural gas production is underestimated.....	10
4.2 Reasons why methane emissions are being undervalued	11
4.3 Natural gas sector emissions in British Columbia	11
5. SUMMARY	13
6. RECOMMENDATIONS FOR BRITISH COLUMBIA	14
ENDNOTES	16

EXECUTIVE SUMMARY

Developing a Liquefied Natural Gas (LNG) industry is currently a main focus of the British Columbia (BC) government. Despite concerns about the increase in domestic greenhouse gas (GHG) emissions that will result from this development, the February 2014 provincial speech from the throne claimed that exporting LNG is the “greatest single step British Columbia can take to fight climate change.” This paper explores the validity of this claim and examines the role of natural gas in the transition to a low-carbon future.

The argument that exporting LNG from BC to Asia helps to reduce GHG emissions typically hinges on two assumptions: 1) that the lifecycle GHG emissions of LNG are lower than those of coal; and 2) that increasing the natural gas supply will result in decreasing coal use. While there is debate about how the life cycle emissions of power from LNG and coal compare, the balance of evidence supports the first assumption as long as methane emissions are minimized. However, the global climate impact of LNG cannot be ascertained simply by comparing it to coal. The overall mix of natural gas, coal, nuclear, renewable energy and energy efficiency determines overall GHG emissions, and considering natural gas and coal in isolation misses this bigger picture.

This paper finds that the climate change policies that are required to give the world an acceptable chance of avoiding 2°C of warming would cause three main shifts in the global energy mix: 1) less demand for all fossil fuels relative to business as usual; 2) more demand for renewable and nuclear energy; and 3) less overall energy demand because of increasing energy efficiency and conservation.

Under such policies, this paper also finds that in long-term projections natural gas demand would peak around 2030 and drop below current levels by mid-century. The growth to the 2030 peak can be faster or slower than business as usual depending on whether or not energy infrastructure is underutilized before the end of its useful life.

In the absence of the policies needed to avoid 2°C of warming, natural gas demand does not peak and continues to increase beyond 2030 – until the end of the century in some models. In this scenario, natural gas, like other fossil fuels, does not contribute to a transition to a low-carbon economy, but rather reinforces the likely outcome of dangerous climate change.

We conclude that natural gas has a role to play in a world that avoids 2°C of warming, but that role is unlikely to materialize unless shaped by strong climate change policies in the jurisdictions that produce and consume the gas. Because these policies are not currently in place, claiming that natural gas, and specifically LNG from BC, is a climate solution is inaccurate. Making more natural gas available is unlikely to change that conclusion, unless the current gulf in international policy is bridged.

We offer three recommendations to the BC government to increase the likelihood that natural gas, and LNG from BC, can be a contributor to global efforts to avoid 2°C of warming: 1) apply a consistent, evidence-based, approach in assessing energy exports; 2) strengthen domestic efforts to reduce GHG emissions from natural gas and LNG development; and 3) play an increasingly proactive role on climate change and methane management globally.

1. INTRODUCTION

British Columbia's provincial government has consistently promoted the climate change benefits of exporting liquefied natural gas (LNG) to Asia. For example, the February 2014 provincial speech from the throne claims that exporting LNG is the “greatest single step British Columbia can take to fight climate change.”¹ Similarly, some proponents of LNG terminals and pipelines have used their environmental assessment applications to argue that the greenhouse gas (GHG) emissions from their projects are not significant — the primary rationale being that the exported LNG is enabling reductions in coal use for electricity generation in Asia, leading to lower GHG emissions.² This paper explores the validity of these claims and examines the role of natural gas in the transition to a low-carbon future.

The argument that exporting LNG from BC to Asia helps to reduce GHG emissions typically hinges on two assumptions: 1) that the lifecycle GHG emissions of LNG are lower than those of coal; and 2) that increasing the natural gas supply will result in decreasing coal use. While there is debate about how the life cycle emissions of power from LNG and coal compare, the balance of evidence supports the first assumption as long as methane emissions are minimized.³ The second assumption is flawed because it ignores the broader mix of energy sources with which LNG competes. The overall mix of natural gas, coal, nuclear, renewable energy and energy efficiency determines overall GHG emissions, and considering natural gas and coal in isolation misses this bigger picture.

Instead of offering a comparison limited to coal and natural gas, this paper looks at the broader energy mix, within which natural gas, like any other energy source, has a role to play. But the use of natural gas will ultimately need to diminish if GHG emissions are to decline significantly. In the context of natural gas as a ‘bridge fuel’, as it is often described, the question is, “how wide and how long should the bridge be?”

To answer that question, this paper compares the role of natural gas in two worlds: one that limits global warming to 2°C and provides an acceptable chance of avoiding dangerous climate change, and one that stays on a business as usual path.⁴ This comparison yields two distinct roles that natural gas can play: as part of an energy mix that helps avoid dangerous climate change, or as part of an energy mix that carries us further down the path to dangerous climate change.

We use scenarios that stabilize atmospheric concentrations of GHGs to 450 parts per million (ppm) to represent an acceptable chance of avoiding 2°C of warming, and contrast these results with Business As Usual (BAU) scenarios, which the IPCC projects to fall between 650 ppm and 850 ppm by 2100. The lower the concentrations of GHGs, the greater the likelihood that global temperature increases will stay below 2°C. For example, achieving a concentration of between 430 and 480 ppm by 2100 results in a 66% probability of staying below 2°C of warming, while between 530 and 580 ppm has a 33% chance.⁵

The main difference between these scenarios is that holding GHG concentrations in the atmosphere to 450 ppm, or 2°C, requires strong climate policies such as carbon pricing, phasing out fossil fuel subsidies, and GHG emissions standards for power plants as articulated by the International Energy Agency (IEA) and others.⁶ As such, we use the terms ‘450 policy scenarios’ and ‘BAU policy scenarios’ respectively.

Section 2 of the paper examines the shift in the global energy mix expected to occur if the world is successful in avoiding 2°C of warming, and highlights the role of natural gas within that shift. Section 3 explores the specific role for natural gas under various policy scenarios. Compounding

the challenge in understanding that role is the uncertainty associated with the life cycle GHG intensity of natural gas and how that intensity will change over time. Section 4 examines this uncertainty and its implications for understanding the role of natural gas in transitioning to a low carbon future. Conclusions and key findings are summarized in section 5 and recommendations appropriate for the policy domain are provided in section 6.

2. ENERGY MIX IN THE 450 SCENARIO

Understanding the global energy mix and how it differs between the BAU and 450 policy scenarios helps to situate natural gas in a broader context. The IEA’s World Energy Outlook 2013 offers a useful starting point and articulates three significant shifts that will occur if the world moves from a BAU to a 450 scenario: 1) less demand for all fossil fuels, 2) more demand for near zero-carbon energy sources, and 3) less overall energy use because of energy efficiency and conservation.

Figure 1 shows the energy demand for coal, oil, gas, nuclear and renewables in 2011 and in 2035 under the IEA’s current policies framework and the 450 scenario.⁷ The stronger climate policies associated with the 450 case lead to less fossil fuel use globally: coal, demand drops by 33%, while in the BAU case it increases by 44%. Over the same 2011 to 2035 timeframe, oil consumption drops by 13% in the 450 case and increases 24% in the BAU scenario. Natural gas increases in both scenarios by 2035 relative to 2011 demand, but the growth is slower in the 450 case — 20% instead of 57% in BAU. Also shown is the massive growth in near zero-carbon energy sources (nuclear and renewables) that partially enable the corresponding cuts in coal, oil and natural gas demand. Under BAU, nuclear and renewable energy are anticipated to increase by a still significant 56% between 2011 and 2035, but that growth relative to 2011 soars to 127% in the 450 policy scenario.

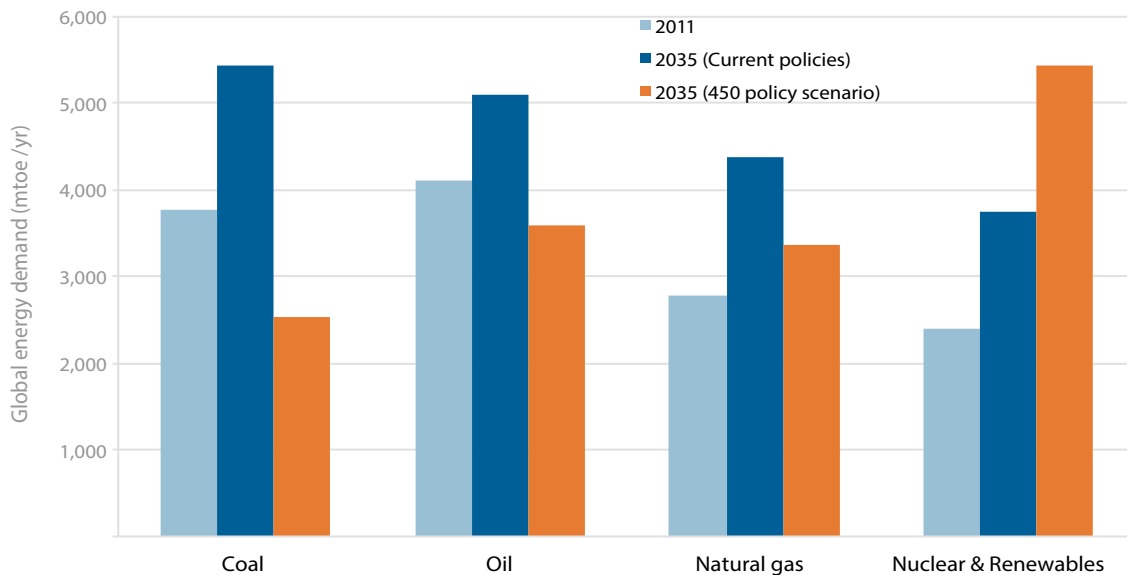


Figure 1. Projections for global energy demand in the IEA’s current policies scenario (equivalent to BAU) and 450 policy scenario

Data source: IEA⁸

Figure 2 provides a different representation of the same IEA projections to illustrate the importance of energy efficiency and conservation. The figure compares the change in 2035 demand between the BAU and 450 policy scenarios. The biggest contrast between the two scenarios—and the biggest enabler of lower fossil fuel demand—is a decrease in overall energy demand because of energy efficiency and conservation.⁹ In 2035, total forecast energy use (coal, oil, natural gas, renewables and nuclear) in the 450 scenario is 14,907 mtoe (million tonnes of oil equivalent). This is 20% lower than the 18,646 mtoe forecast for total energy demand in BAU. Of the 5,431 mtoe less coal, oil and natural gas used in 2035 in the 450 policy scenario (compared to BAU), nuclear and renewables make up 1,692 mtoe and energy efficiency and conservation make up the remaining 3,739 mtoe.

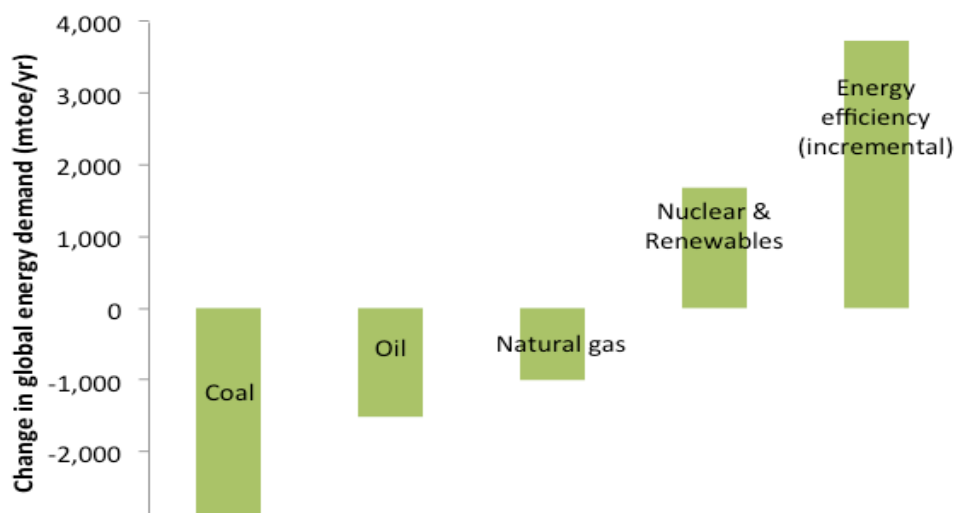


Figure 2. Projections for changes in global demand for different energy sources in 2035 between the IEA's current policies scenario (equivalent to BAU) and the 450 policy scenario.

Data source: IEA¹⁰

3. THE ROLE FOR NATURAL GAS

The 450 policy scenario clearly results in a global shift away from fossil fuel use and toward near zero-carbon energy sources. This section explores in more detail the potential role for natural gas within that shift.

Two distinct pathways dictate the ways in which natural gas demand could unfold over this century: standard stock turnover and accelerated stock turnover.^{11,12} In the standard pathway, energy infrastructure (e.g. power plants) is replaced at the end of its useful life. The accelerated pathway allows energy infrastructure to be replaced prior to the end of its useful life. A primary implication of the latter is that coal is phased out faster, replaced in part by natural gas in the short to medium term, and that natural gas is then phased out faster than would have normally been the case.

Starting with the standard pathway, natural gas use in BAU and 450 policy scenarios from three prominent energy-economy models (MiniCam, MERGE and IGSM)¹³ sheds light on the specific role of this energy source over the coming century.¹⁴ Looking at the BAU scenario over this time

frame (blue lines in Figure 3), we see a range of possible trajectories for natural gas use, with the general trend being increasing use until the middle of the century, after which demand either continues to increase, or declines slightly depending on the model.

In the 450 scenarios (orange lines in Figure 3), natural gas use under conditions of standard stock turnover still increases in the short term, but not as quickly or for as long as with BAU policies. In all of the 450 policy results, natural gas demand declines after 2030, dropping below 2000 levels between 2040 and 2050. The rate of decline is also steeper than in the BAU examples. In other words, the climate policies associated with a 450 ppm outcome guide natural gas demand up from its current levels until 2030, and then drive demand down.¹⁵ But in the absence of such policies, demand for natural gas (and coal and oil) will almost certainly drive GHG concentrations above 450 ppm and the target of a 2°C limit to global warming cannot be met.

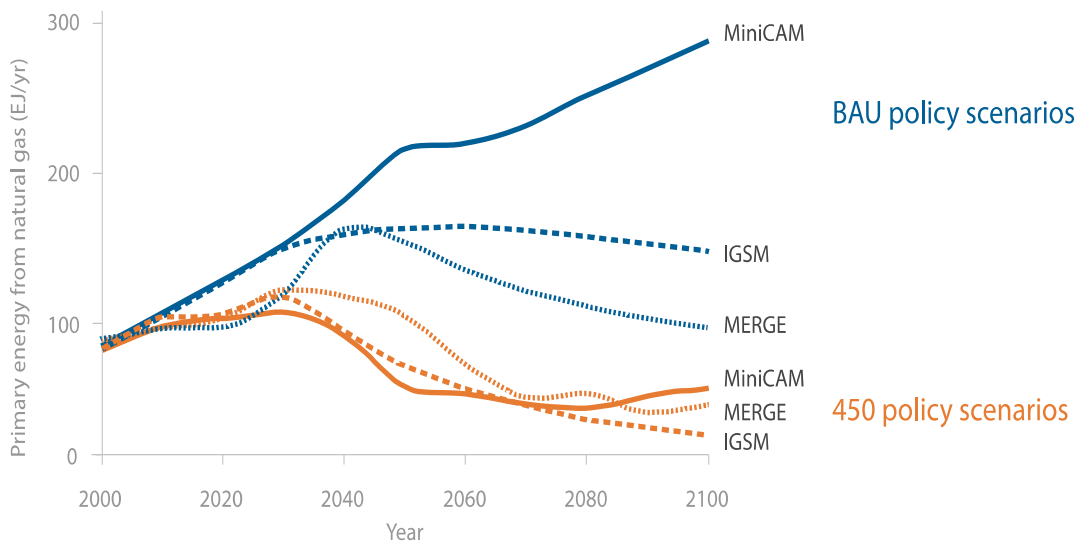


Figure 3. Comparison of natural gas use in BAU and 450 policy scenarios under three different models with standard stock turnover

Adapted from: Levi¹⁶

With accelerated stock turnover, the picture is significantly different. Figure 4 compares the standard and accelerated 450 policy scenarios using the same three models. In the accelerated case natural gas use increases rapidly in the short term, even above BAU projections, and peaks more quickly (between 2020 and 2030). This short-term increase in demand slightly delays the adoption of near zero-carbon sources, but it also enables a faster phase-out of coal, to <5% of global energy demand by 2020. Beyond 2030, more demand is met by near zero-carbon sources of energy. Beyond 2050 the flat or declining trajectories are similar to the projections for the standard stock turnover case.

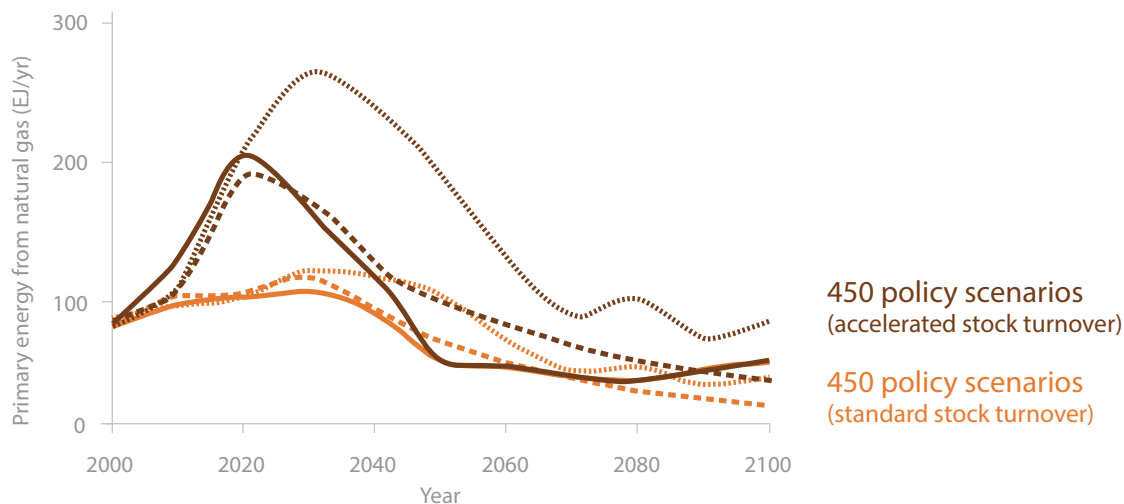


Figure 4. Comparison of natural gas use in standard and accelerated stock turnover for 450 policy scenarios under three different models. Solid lines show results from MiniCAM model, medium-dash lines show results from IGSM model, and small-dash lines show MERGE model.

Adapted from Levi¹⁷

The accelerated stock turnover pathway aligns with a 450 policy scenario only if two major conditions are met. First, the increase in natural gas use must be accompanied by an essential elimination of coal use in the same 2020-2030 time frame. Second, the increase in natural gas use must be immediately followed by a rapid ramp-down in favour of near zero-carbon energy sources. This would entail shutting down natural gas infrastructure prior to the end of its useful life.

A significant question underlying the accelerated stock turnover pathway is what policies and economic conditions could lead to under-utilization of coal and natural gas infrastructure? Both industry and investors typically expect that projects will be able to operate for their useful life at close to design capacity. Significant adjustments in policy and/or economic conditions (such as imposition of price on carbon emissions) would be needed for those expectations to change. Without such adjustments, the near-term elimination of coal and associated rapid increase in gas supply are unlikely to occur.

4. THE GREENHOUSE GAS INTENSITY OF NATURAL GAS

The potential role for natural gas in 450 policy scenarios depends on the life cycle GHG emissions from natural gas used in different models and how those emissions shift over time. The life cycle GHG emissions include extracting, processing and transporting the gas, liquefying and regasifying in the case of LNG, and combusting the gas to supply heat, generate electricity, or move vehicles. If actual values for such GHG emissions (either today or in the future) are materially lower than assumed in models, then the role for natural gas in meeting the 2°C limit is likely larger. Conversely, if those emissions are materially higher than assumed, then the role for natural gas is likely smaller.

Natural gas is composed of approximately 95% methane, a powerful greenhouse gas whose leakage and release during the production of gas present a significant climatic concern.* That observation is of particular relevance to British Columbia given the extensive shale gas exploitation either underway or planned in the province's northeast.

Much of the analysis on methane emissions from natural gas has been done to help compare the GHG intensities of natural gas and coal. For example, according to the Council of Canadian Academies, "The general trend of recent studies suggests that the earlier estimates by Howarth et al., (2011) might be too high, but whether or not actual rates are low enough to preserve the overall GHG benefits of shale gas over coal remains a subject of study."¹⁸

While methane emissions may be high enough in some cases to make natural gas more GHG intensive than coal, a recent review of research from the past 20 years concluded that average methane emissions are likely higher than reported in GHG inventories, but not likely to be as high as the worst-case scenarios estimated or observed in different studies.¹⁹ The sources of such considerable uncertainty and reasons why actual methane emissions are likely higher than reported in GHG inventories is discussed further in section 4.1. Moreover, a very high global warming potential (GWP, section 4.2) offers a second reason why life cycle GHG emissions are likely being understated for natural gas. Section 4.3 puts both the uncertainty issue and GWP into a BC context.

4.1. Reasons why methane from natural gas production is underestimated

Brandt et. al.²⁰ found that emissions inventories consistently underestimate methane emissions from natural gas production, indicating that life cycle GHGs are likely higher than reported, although not high enough to be more GHG intensive than coal. Their explanation is that the inventories miss specific sources with much higher than average emissions if, as is often the case, they are derived from small sample sizes that are not representative of the full range of practices. These so called 'super-emitters' skew the average emissions intensity upwards relative to reported inventories. For example, Allen et. al. conducted an extensive study that examined a large number of sources from different gas producing regions across the United States but drew samples from a relatively small number of companies, making unclear the applicability of the results across multiple producers.²¹

Inventories can also be underestimating emissions when (or if) they miss some sources, especially those without a specific point of release, such as methane that migrates to the surface outside of a well casing.^{22,23} Similarly, estimating methane emissions at the well drilling stage can be problematic. One study found emissions to be two to three orders of magnitude greater than estimated; such a discrepancy could arise when methane is released from small volumes of gas that sit closer to the surface than in the deeper targeted formation.²⁴

Many of the sources of uncertainty in methane emissions also offer opportunities to reduce GHG emissions. For example, a specific source of variability in GHGs is well completion practices for unconventional gas production. Methane that flows from a well during completion can be

* Methane emissions from the production of natural gas attracts much of the attention today, but all of the GHG emissionsources along the life cycle could shift up or down over time. For example, using more energy efficient turbines for electricity generation or reducing methane leaks from gas distribution systems will lower the intensity. Conversely shifting to natural gas resources that are more GHG intensive to extract will raise the intensity. This broader set of uncertainties is outside the scope of this paper.

vented to the atmosphere, flared, or captured for use (referred to as conservation), and there is thus a wide range in GHG emissions per well depending on which of these practices is or are employed.²⁵ Regulations that reduce emissions during completions, as the US Environmental Protection Agency has required starting in 2015²⁶, will minimize GHG emissions from that portion of the life cycle. This step is consistent with the priorities of the International Energy Agency which has listed minimization of methane emissions from oil and gas production as one of its top four short-term actions to keep the 2°C global warming target alive.²⁷

4.2. Reasons why methane emissions are being undervalued

GWP is a relative measure of the amount of heat one kilogram of a specified GHG in the atmosphere can trap, relative to the same mass of carbon dioxide emitted at the same time. The GWP is calculated over a specific time interval, typically 100 years, with calculations over 20 years becoming increasingly common.

Methane is an extremely potent GHG in the short term but breaks down relatively quickly through chemical interactions with hydroxyl ions in the atmosphere. Thus, its longer-term importance relative to carbon dioxide—a very long-lived greenhouse gas—is less. The 20-year GWP of methane is 86, indicating that 1 kg of methane will trap 86 times more heat than a kilogram of CO₂ in the two decades following emission. The 100-year GWP is significantly lower, and has been repeatedly revised in recent years as understanding of the behavior of greenhouse gases in the atmosphere has improved. Where the Third Assessment report of the IPCC in 2001 recommended a GWP of 21 for methane, based on a 100-year timeframe, the Fourth Assessment in 2007 recommended a value of 25 and the Fifth Assessment in 2013 established 34 as being more appropriate.

National and provincial GHG inventories in Canada are now being updated to use the 2007 figure. GHG estimates that utilize the out of date GWPs for methane will necessarily understate the net emissions impact when expressed in carbon dioxide equivalents.

Application of the 20-year GWP to determination of the life-cycle impact of methane reflects increasing concern about climate tipping points that focus more directly on short-term reduction opportunities. But when the focus is on longer-term warming, which is most dependent on cumulative emissions over the century or more, a longer-term GWP is appropriate for use. Both approaches are legitimate, and it is increasingly common to see results reported with both 20-year and 100-year GWPs.²⁸ Indeed, Shoemaker et. al. (2013) argue for the establishment of a dual track approach that is focused on reducing short and long-term climate forcing agents in parallel, as opposed to trading one against another.²⁹

4.3. Natural gas sector emissions in British Columbia

We now turn our attention to BC's natural gas sector to provide local context to the broader debate about the GHG intensity of natural gas. The BC government has one of the more detailed facility-level emissions inventories, which was created in 2008 as a result of the Greenhouse Gas Reduction (Cap and Trade) Act. The first year of reporting was 2010, and information is now available by company and activity, including different sources of emissions within the natural gas sector.³⁰ A high-level breakdown of the sector in 2013 is shown in Figure 5. This distribution

does not account for the GHG emissions from LNG terminals that would accompany any LNG development in BC, which would likely increase the share of combustion emissions nor does it account for any shifts that would result from increased upstream production.

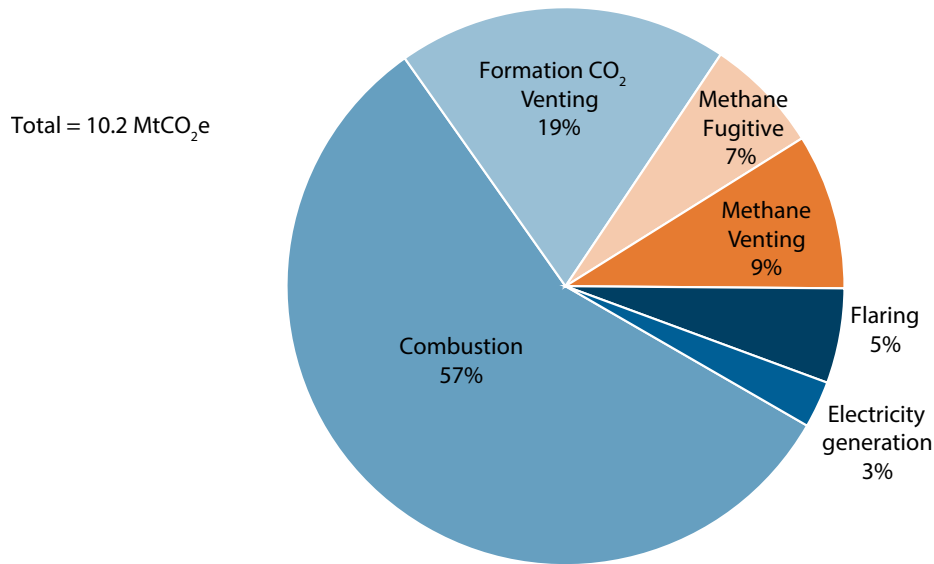


Figure 5. Natural gas sector GHG emissions in British Columbia, 2013

Data source: BC Ministry of Environment³¹

There is minimal uncertainty around the combustion and flaring of natural gas or of formation carbon dioxide emissions; all are either metered or calculated based on fuel consumption, and all specific sources over 25,000 tonnes per year are required to be verified by a third party. The methane venting and fugitive methane sources (accounting for 16% of the total) are a mix of metering and estimates based on past studies, and as a result do represent a greater source of uncertainty.

While Figure 5 appropriately assigns estimates to most sources of GHG emissions from the natural gas industry, recent analyses suggest that it does not capture all sources fully. For example the province undertook in 2013 a study on pneumatic devices, which allowed estimated emissions to be compared with actual emissions for that source. The results were consistent with Brandt's²⁰ findings: the GHG inventory was underestimating emissions. Indeed, the work showed that actual emissions from pneumatic devices were more than 90% higher than currently reported in the inventory (0.4 million tonnes). That adjustment alone will increase overall emissions from the natural gas sector by 4%.³²

Methane released from well completions remains another important factor that varies considerably depending on the practices employed. In BC, drilling and completion are currently estimated to account for 3% of emissions from the natural gas sector. This is much lower than estimates that assume a significant amount of methane venting, which is the most GHG-intensive practice for well completions. In BC, the Oil and Gas Commission regulations make venting a last option in emergency situations or where it isn't economic to capture and use the natural gas and flaring isn't feasible. That doesn't mean there aren't opportunities to reduce emissions from well completions, but the potential will be smaller than situations where venting is more common.

The carbon dioxide-equivalent emissions in Figure 5 are calculated using a 100-year GWP of 21, which is based on the 2001 estimate from the IPCC. The province only reports 100-year GWPs and has indicated that it will be updating the 2001 value to 25 (as per international guidance) in 2014.³³ If the global warming potential of 34 from the IPCC's Fifth Assessment Report is used, emissions (expressed in carbon dioxide equivalents) from the natural gas sector would rise by 10%.

A final issue in assessing the GHG intensity of natural gas extracted in BC is the amount of carbon dioxide that is naturally present along with natural gas in the stratigraphic formation. The raw gas needs to be processed to remove the formation carbon dioxide in order to meet pipeline specifications. Typically, the CO₂ extracted from the raw gas is vented directly to the atmosphere. Gas from the Horn River Basin in the Fort Nelson area contains 12% formation CO₂ whereas gas from the Montney Basin (Dawson Creek area) has about 1% CO₂. Extraction activity is currently more focused in the Montney because of proximity to services and infrastructure and because the gas is rich in liquids and thus more profitable to extract. It is not certain how the balance between basins will shift over time, but if activity in the Horn River increases relative to the Montney, the amount of formation CO₂ extracted and released will grow unless carbon capture and storage technology is utilized.

5. SUMMARY

1. The scenarios that give the world an acceptable chance of avoiding 2°C of warming rely on adoption of strong climate change policies around the world.
2. Within the context of global climate change policies currently in place, describing LNG exports as the “greatest single step British Columbia can take to fight climate change” is inaccurate. Instead of leading with LNG and natural gas strategies, jurisdictions – BC included – need to lead with emissions reduction policies. Natural gas does have a role to play in a world that that avoids 2°C of warming, but that role is unlikely to materialize unless shaped by strong emissions reduction policies in the jurisdictions—including British Columbia—that produce and consume the gas. That role will ultimately also be smaller than in a BAU world where growing consumption of all fossil fuels, including coal and oil, pushes the global climate inexorably toward a different, and much warmer, state. Making more natural gas available is unlikely to change those conclusions.
3. Avoiding 2°C of warming will result in a significant shift of the global energy mix away from all fossil fuels relative to a BAU scenario (the path we are now on). Model projections indicate that in scenarios that avoid 2°C of warming, demand for coal and oil drops relative to current levels, while natural gas demand grows, but less quickly than BAU. The drop in fossil fuel demand will be matched by increased demand for renewable and nuclear energy, and greater investment in energy efficiency.
4. Scenario modeling yields two pathways that natural gas use can follow if we are to have an acceptable chance of avoiding 2°C of warming. The first assumes that energy infrastructure will be fully utilized until the end of its useful life (standard stock turnover). The second depends on conditions that would allow for energy infrastructure to be underutilized before the end of its useful life (accelerated stock turnover). In the standard turnover case natural gas use increases less quickly than BAU until 2030, and then declines after that. In the accelerated turnover scenario, natural gas demand increases faster than BAU between now and 2030 to enable coal to be phased out over the same period. That increase is immediately followed by a rapid ramp-down that would

entail shutting down natural gas infrastructure prior to the end of its useful life. In both the standard and accelerated pathway cases, global natural gas demand drops below current levels by mid-century.

5. The role of natural gas in 450 policy scenarios depends on the life cycle emissions of greenhouse gases and how those evolve over time. There remains material uncertainty about these emissions that requires resolution through additional research.
6. Methane emissions from natural gas production are an important source of uncertainty in the life cycle, and current estimates likely understate its contribution to the life cycle GHGs. This implies that life cycle GHG emissions from natural gas (expressed in carbon dioxide equivalents) are potentially higher than currently reported, meaning the role for natural gas in a world that avoids 2°C of warming would be smaller.
7. Opportunities exist to use technologies and practices to reduce life cycle GHG emissions from natural gas, including from methane. Acting on these opportunities would enhance the role that natural gas could potentially play in 2°C policy scenarios.

6. RECOMMENDATIONS FOR BRITISH COLUMBIA

1. Apply a consistent, evidence-based, approach in assessing energy exports:

- a) Acknowledge that the BC government cannot state with any degree of confidence that extracting and combusting natural gas from British Columbia helps reduce global GHG emissions in line with efforts to avoid 2°C of warming. While plausible, that is not the likely outcome based on current climate change policies around the world. This claim is largely based on the assumption that a comparison limited to coal and natural gas is sufficient to assess global climate impact. This paper has shown that the broader energy mix must be considered to determine before a given energy source can be considered a climate solution.
- b) Consider how medium to long-term demand for different energy exports will shift in different climate policy scenarios and how that shifting demand will impact the provincial and local economies. For natural gas, there is likely to be growth in demand in the short-term, followed by a likely drop in demand (potentially rapidly) post-2030 in scenarios that are in line with efforts to avoid 2°C of warming.

2. Strengthen domestic efforts to reduce GHG emissions from natural gas and LNG development.

These efforts help to push down the GHG intensity of natural gas from BC such that its potential role in world taking efforts to avoid 2°C of warming is maximized. They also strengthen BC's ability to work with other gas producing jurisdictions to take comparable actions. Steps that should be taken include:

- a) Supporting or undertaking studies to improve understanding of methane emissions from upstream natural gas production in BC to identify errors in the current GHG inventory. These studies should also investigate opportunities to reduce those GHG emissions.
- b) Implementing climate change policy to reduce the emissions of methane and formation carbon dioxide from natural gas development in BC. These sources account for 35 per cent of the GHG emissions from BC's natural gas sector and there is no climate policy currently in place to

encourage or require them to be reduced. Applying the carbon tax to these emissions, where they can be accurately measured, would be an important first step that could be applied in very short order.

3. Play an increasingly proactive role on climate change and methane management globally:

a) Engage with other jurisdictions to share BC's successes and challenges on climate policy implemented to date, such as BC's carbon tax and the clean electricity requirements. These are both good examples of the types of policies needed globally and BC should be an active proponent of comparable approaches. Finding opportunities to work collaboratively with other jurisdictions (as BC has done through the Pacific Coast Collaborative) allows partners to share resources and experiences, reduces competitiveness concerns and increases the potential benefits. These multi-jurisdiction efforts also increase the likelihood of a global deal that is urgently needed to avoid 2°C of warming.

b) Work with other natural gas and LNG producing jurisdictions to establish stronger policies for methane management. As with climate policy generally, the stronger BC's policies are domestically, the more effective such efforts become elsewhere.

ENDNOTES

1. BC, 2014 Speech from the Throne, <http://engage.gov.bc.ca/thronespeech/>
2. For example, see environmental assessment applications for Westcoast Connector Gas Transmission Project, Section 4.1.4.5 (2014) and Pacific Northwest LNG Project, Section 7.6 (2014).
3. See: National Energy Technology Laboratory, Life Cycle Greenhouse Gas Perspective on Exporting Liquefied Natural Gas from the United States, DOE/NETL-2014/1649 (2014), 10.
4. Limiting the global average temperature increase to 2°C is considered to provide an acceptable chance of avoiding dangerous climate change, and it is the goal that has been broadly agreed upon by the global community. The two-degree target was formally adopted through the UNFCCC process in 2009 at Copenhagen and has been supported since then – recognizing that there are still perspectives that say even 2°C is too much warming and others that argue that 2°C is no longer achievable.
5. IPCC, AR5, Working Group III, Ch 6, p.35
6. The policies the IEA articulates for OECD countries includes: cap-and-trade system for industrial emissions, economy-wide carbon pricing, phase out of fossil fuel subsidies, renewable portfolio standards, financing to non-OECD countries, GHG emissions standards on power plants, renewable transportation fuel standard and vehicle efficiency targets.
7. The IEA's current policies scenario accounts for policies already enacted as of mid-2013, and is considered a BAU policy scenario for the purposes of this paper.
8. International Energy Agency, World Energy Outlook 2013 (2013). Chart compiled from data in Annex A.
9. The change in energy efficiency shown in Figure 2 represents the incremental change in energy efficiency in the 450 scenario over the BAU scenario. This should not be interpreted to mean that there is no increase in energy efficiency in the BAU scenario, but that the increase is accelerated in the 450 scenario.
10. International Energy Agency, World Energy Outlook 2013 (2013). Chart compiled from data in Annex A.
11. Michael Levi, "Climate Consequences of Natural Gas as a Bridge Fuel," Climate Change (2013).
12. Levi (2013) describes how he arrived at the accelerated scenarios as being based on a standard scenario, where natural gas consumption is increased, and coal, energy savings, and zero carbon energy are decreased such that annual CO₂ emissions remain unchanged but so that natural gas, rather than zero-carbon energy and energy savings, displaces coal insofar as possible.
13. MiniCAM (Brenkert et. al. 2003 – USDoE (now GCAM)), MERGE (Manne et. al. 1995 - Stanford), IGSM (Prinn et. al. 1995 - MIT)
14. Michael Levi, "Climate Consequences of Natural Gas as a Bridge Fuel," Climate Change (2013).
15. The conclusion that less natural gas is used in 450 policy scenarios relative to BAU scenarios holds across a broader range of models, including the IEA projections discussed in section 2. McCollum et. al. provide another example in their application of 12 energy-economy models (BET, MERGE, REMIND, WITCH, TIAM-WORLD, MESSAGE, GCAM, POLES, IMAGE, IMACLIM, GRAPE and EC-IAM) to assess cumulative global natural gas use from 2010–2100 in a range of BAU and 450 policy scenarios. D. McCollum et al. Fossil Resource and Energy Security Dynamics in Conventional and Carbon-Constrained Worlds. Climatic Change (2014) Supplementary Material.
16. Levi (2013) "Climate Consequences of Natural Gas as a Bridge Fuel," Figure 2.
17. Levi (2013) "Climate Consequences of Natural Gas as a Bridge Fuel," Figure 2.
18. Council of Canadian Academies (2014). 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.
19. Brandt et. al. (2014). Methane leaks from North American natural gas systems. Science (Volume 343).
20. Ibid.
21. Allen et. al. 2013. Measurements of methane emissions at natural gas production sites in the United States. Proceedings of the National Academy of Sciences. This limitation is acknowledged and discussed on an FAQ by the studies main sponsor, Environment Defense Fund: <http://www.edf.org/climate/methane-studies/UT-study-faq#11> (accessed July 2, 2014).
22. Dusseault et. al., 2014. Towards a Road Map for Mitigating the Rates and Occurrences of Long-Term Wellbore Leakage. University of Waterloo and Geofirma Engineering Ltd. paper.
23. Studies that measure overall methane emission levels from a gas production field can help to identify these gaps, but they can also overestimate the methane emissions associated with natural gas production because they will often include methane from other sources. Common examples are methane released by livestock or from oil production.
24. Caulton et.al, 2014. Toward a better understanding and quantification of methane emissions from shale gas development. Proceedings of the National Academy of Sciences.
25. Venting is the most GHG intensive practice, followed by flaring and then conservation.

26. US Environmental Protection Agency, Oil and Natural Gas Sector: Standards of Performance for Crude Oil and Natural Gas Production, Transmission, and Distribution. Background Technical Support Document for Proposed Standards (2011), 4.18. <http://www.epa.gov/airquality/oilandgas/pdfs/20110728tsd.pdf>
27. International Energy Agency, Redrawing the Energy-Climate Map (2013).
28. For example, the IPCC's fifth assessment report reports both 20 and 100-year GWPs, as does the recent NETL comparison of life cycle GHG emissions from pipeline gas, LNG and coal.
29. Shoemaker et. al. (2013). What Role for Short-Lived Climate Pollutants in Mitigation Policy? Science (Volume 343).
30. The National Inventory Report, produced by Environment Canada, also reports greenhouse gas emissions from BC's natural gas sector. The data is not as detailed as the BC facility level inventory, but it does track emissions back to 1990.
31. BC Ministry of Environment, "Facility Green House Gas Emissions Reports Questions and Answers," September 19, 2013. <http://www.env.gov.bc.ca/cas/mitigation/ggrcta/reporting-regulation/emissions-reports-qa.html>
32. BC Ministry of Environment, Information bulletin on Pneumatic Devices: <http://www.newsroom.gov.bc.ca/2013/12/study-results-in-improved-reporting-of-ghg-emissions.html>. The adjustment was based on a report from the Prasino Group, "Final Report For Determining Bleed Rates for Pneumatic Devices in British Columbia", that was prepared for BC Climate Action Secretariat, Ministry of Natural Gas Development and Canadian Association of Petroleum Producers (2013). http://env.gov.bc.ca/cas/mitigation/ggrcta/reporting-regulation/pdf/Prasino_Pneumatic_GHG_EF_Final_Report.pdf
33. Government of British Columbia (2014). British Columbia Greenhouse Gas Inventory Report 2012.



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