

# Life Cycle Greenhouse Gas Emissions of Natural Gas

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A LITERATURE REVIEW OF KEY STUDIES COMPARING EMISSIONS  
FROM NATURAL GAS AND COAL



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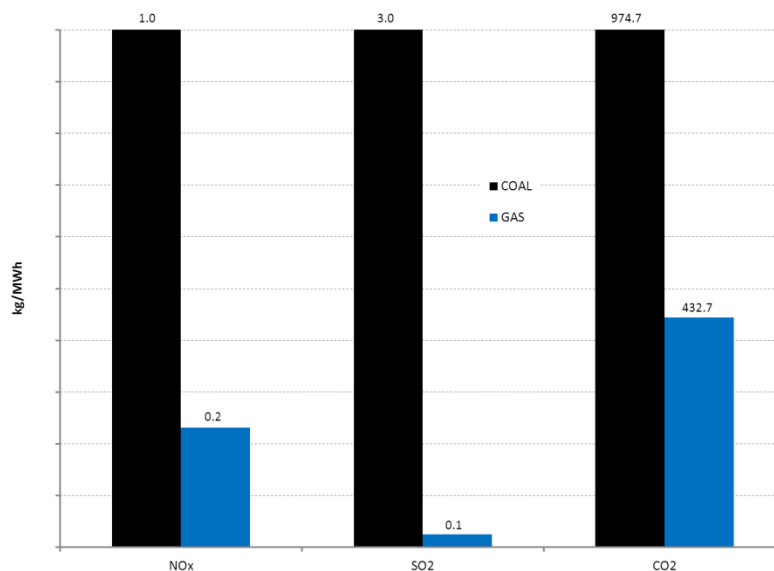
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## Introduction

The rapid increase in production of shale gas in North America in recent years has focused attention on the increased role that low-priced, abundant natural gas can play throughout the economy. The low emissions from natural gas use have been recognized as an additional benefit of this potential increased role. Natural gas has the lowest carbon content of any fossil fuel and hence the lowest carbon dioxide (CO<sub>2</sub>) emissions when burned. It also has lower sulfur than coal or most grades of petroleum, resulting in lower sulfur (SO<sub>2</sub>) and particulate (PM) emissions. The ability to very effectively control the combustion of natural gas allows for the minimization of nitrogen oxides (NO<sub>x</sub>) and PM emissions relative to other fuels. Figure 1 shows how these characteristics result in significantly lower emissions for gas-fired electricity generation relative to coal.

**Figure 1. Coal vs Gas Emissions for Power Generation - 2009 (kg/MWh)**



Source: U.S. EPA Data/eGRID

Although natural gas is a very clean-burning fuel, when it is released into the atmosphere as uncombusted methane, it is a potent greenhouse gas (GHG). The warming effect of GHGs is measured by their global warming potential (GWP), which is the ratio of each GHG's warming effect relative to CO<sub>2</sub>. Methane has a GWP of 25<sup>i</sup>, meaning that one tonne of methane has the warming effect of 25

<sup>i</sup> The GWP is calculated over a specific time-period in order to show the relative impact of greenhouse gases over different time periods since each greenhouse gas has a distinct life. The Intergovernmental Panel on Climate Change (IPCC) uses 20, 100 and 500 year time horizons. Our baseline GWP for methane is the 100-year time horizon factor of 25, which is the IPCC standard.

tonnes of CO<sub>2</sub>. Because of the release of methane at various points in the natural gas production and delivery chain and its high GWP, the total GHG effect of natural gas use must include the emissions throughout the chain, known as a life-cycle analysis (LCA). Lifecycle GHG emissions are the aggregate quantity of GHGs related to the full fuel cycle, including all stages of fuel and feedstock production and distribution, from feedstock extraction through distribution and delivery and use of the finished fuel.

LCA comparisons of natural gas and other fuels have been done for many years. In early 2011, Howarth et al. of Cornell University published a paper<sup>1</sup> stating that the life-cycle GHG emissions of shale gas are higher than those of coal due to the fugitive and vented emissions of methane during the production and transportation processes, especially the venting of methane during the well completion flowback process. This was widely reported and created a lot of popular debate about whether natural gas from shale is really a better fuel source than coal when it comes to combating climate change.

This paper reviews the recent scientific literature on life-cycle GHG emissions from coal and conventional and shale gas production and their use for electricity generation. All of the research other than the Howarth study finds that lifecycle GHGs are less from gas than from coal and that there is relatively little difference between conventional and shale gas in life-cycle GHG emissions.

## Analysis

Over the last two years there have been several natural gas LCA studies based on U.S. data. The key studies include:

Howarth et al. (Cornell)<sup>1</sup> – This study from Cornell University was the first peer-reviewed study to specifically focus on the life-cycle emissions from shale gas production. The study gained a lot of attention due to its conclusion that shale gas has higher life-cycle GHG emissions than coal, due largely to methane emissions during the extraction process.

Hultman et al. (University of Maryland)<sup>2</sup> – This peer-reviewed study from the University of Maryland compared the life-cycle emissions of conventional gas, shale gas and coal for electricity generation. It found that the GHG impacts of shale gas are 11% higher than those of conventional gas, and 44% lower than for coal.

Jiang et al. (Carnegie Mellon)<sup>3</sup> – This peer-reviewed study updates several earlier LCAs done at Carnegie Mellon University to specifically address the life-cycle emissions of shale gas produced through hydraulic fracturing. It found that the life-cycle GHG emissions of shale gas are approximately 5% higher than the base case conventional gas case and the life-cycle emissions from gas-fired electricity generation are about 42% lower than for conventional coal generation.

Burnham et al. (Argonne National Laboratory)<sup>4</sup> – This peer-reviewed study by researchers at the Argonne National Laboratory used a variety of detailed data sources and the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) LCA model to develop life-cycle GHG emissions estimates for conventional gas, shale gas and coal-based electricity generation. Unlike other studies, this one found that the emissions from conventional gas production were slightly higher than for shale gas production, due primarily to fugitive methane emissions from liquid unloading in conventional gas production<sup>ii</sup>. Overall, it found that life-cycle GHG emissions from gas-fired electricity production were 36% lower than for coal-fired electricity production.

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<sup>ii</sup> Liquid unloading is the process of removing liquids that would otherwise impede gas production from a conventional vertical well. One method of liquid unloading is to vent the well to the atmosphere. This results in high methane emissions. Alternative methods of liquid unloading that do not result in high emissions are also in use.

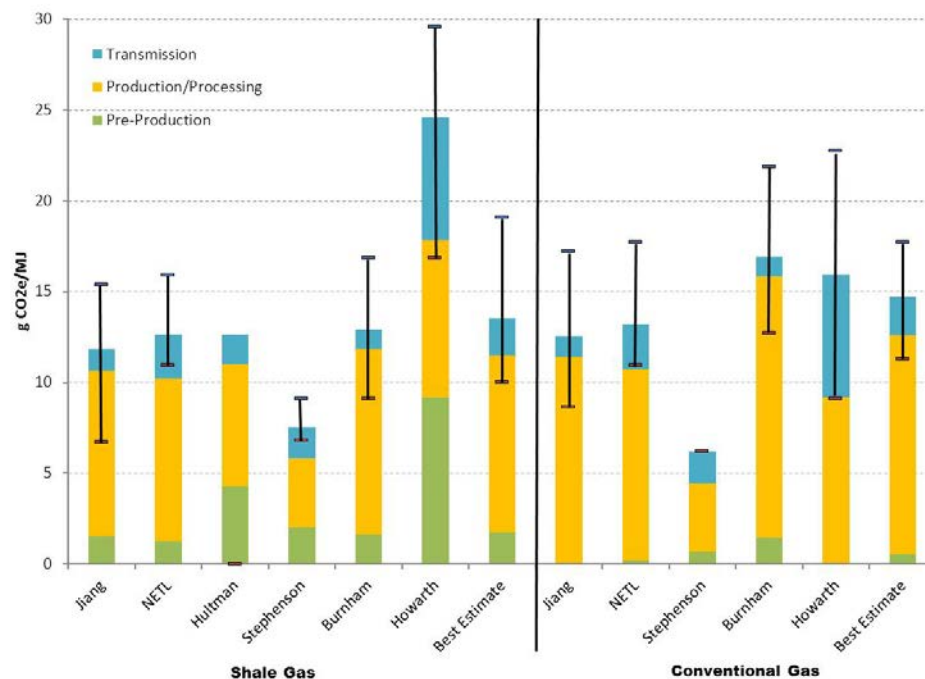
Stephenson et al. (Shell Global Solutions)<sup>5</sup> – This peer-reviewed study estimated that shale gas has life-cycle GHG emissions about 1.8–2.4% higher than conventional gas, arising mainly from higher methane releases in well completion. In all cases considered, the life-cycle emissions of electricity generation from gas were significantly lower than those of coal.

National Energy Technology Laboratory (NETL)<sup>6</sup> – This is a very detailed, bottom-up study of life-cycle emissions from electricity generated from conventional and shale gas from various sources compared to the life-cycle emissions from coal-fired electricity production. It is part of a series of studies on life-cycle emissions from various energy sources. The study found that life-cycle emissions of GHGs from natural gas-fired electricity generation are 39% less than from coal-fired electricity generation. It also found that electricity generation using unconventional gas, including shale gas, had life-cycle emissions only slightly higher than from conventional gas resources. (In a recent update of the analysis<sup>7</sup>, NETL finds that the upstream GHG emissions from shale gas are 20% lower than in the original study. This yields total life-cycle emissions for shale gas that are 3.5% lower than the original study including combustion emissions.)

Weber and Clavin (Institute for Defense Analyses)<sup>8</sup> – This peer-reviewed study examined the six recent LCA studies of conventional and shale gas listed above. The study normalized all of the studies to consistent boundary conditions and assumptions. It then used a Monte-Carlo simulation of the most significant variables to develop a “Best Estimate” value.

This results of the Weber study (Figure 2) show that the Howarth study has the highest value (24.6 g CO<sub>2</sub>e/MJ)<sup>iii</sup> for upstream emissions and the highest variability for shale gas. The Stephenson study has the lowest value (7.6 g CO<sub>2</sub>e/MJ) and the other four studies are very close in their final results (11.8 to 12.9 g CO<sub>2</sub>e/MJ). The Best Estimate value is 13.5 g CO<sub>2</sub>e/MJ.

**Figure 2. Normalized Comparison of Recent U.S. Gas LCA Studies**



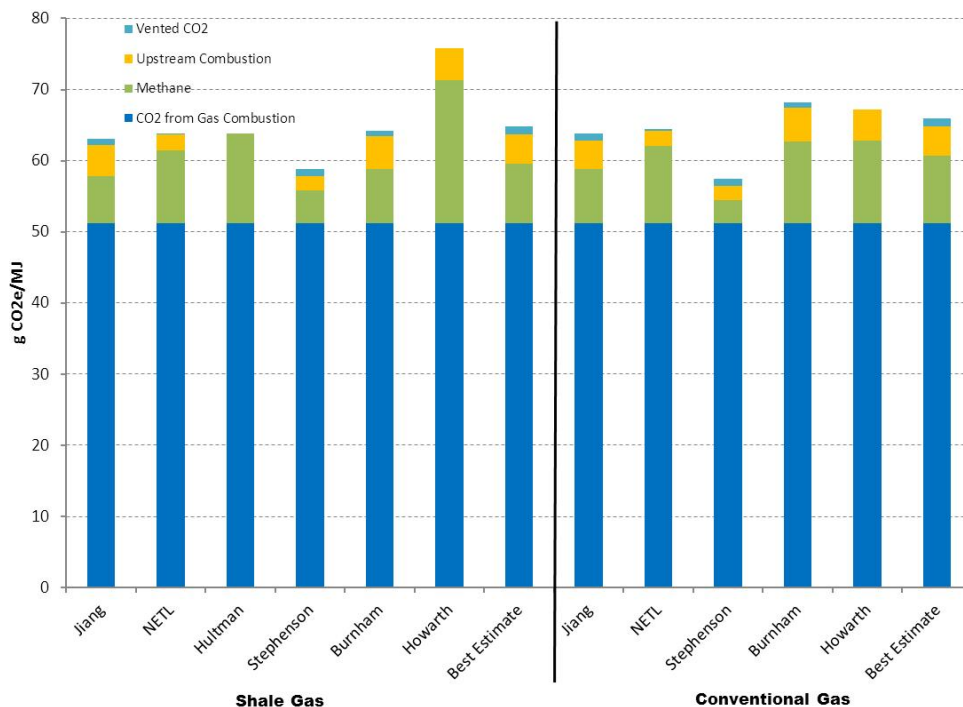
Source: Weber and Clavin

<sup>iii</sup> The Weber and Clavin article uses g CO<sub>2</sub>/MJ lower heating value (LHV) but the values are adjusted to higher heating value (HHV) here to be consistent with other studies.

For conventional gas, there is less variability of upstream emissions on the high side but the Stephenson study is still the low value. The Best Estimate is 14.7 g CO<sub>2</sub>e/MJ, slightly higher than for shale gas but well within the uncertainty range. Based on these studies, the life-cycle GHG emissions from conventional gas production are slightly higher than from shale gas, primarily due to the emissions associated with liquids unloading for conventional gas wells.

Figure 3 shows the same results by GHG and with the CO<sub>2</sub> emissions from the end use combustion of the gas. The upstream CO<sub>2</sub> emissions from drilling engines, process equipment, pipeline compressors, other equipment and CO<sub>2</sub> removed from the gas during gas processing are the smaller component, while the upstream methane emissions are the larger share due to the higher GWP of the methane. In all cases, the largest component of the life-cycle natural gas emissions is the CO<sub>2</sub> released during the actual combustion of the fuel – 56.3 g CO<sub>2</sub>e/MJ. The upstream emissions are less than 25% of the end use combustion emissions in all cases except for the Howarth analysis.

**Figure 3. Life-Cycle Emissions by GHG for Natural Gas**



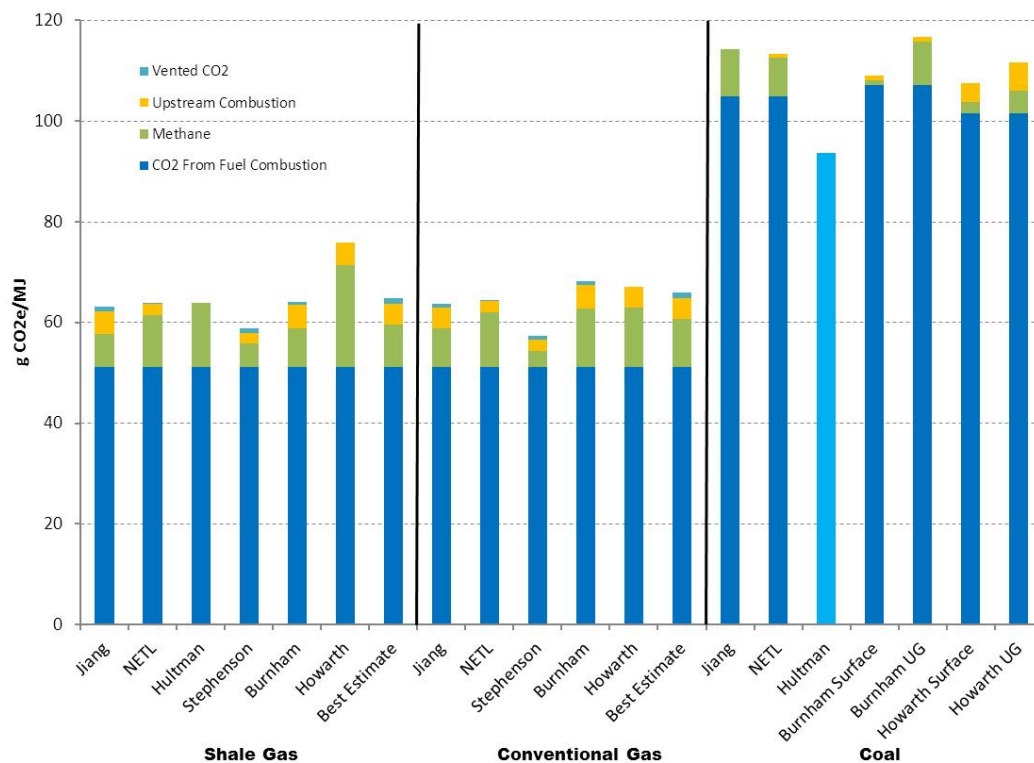
**Data source:** Weber and Clavin

In this normalized representation, the upstream emissions for shale gas in the Howarth study are roughly twice as high as most of the other studies and the Best Estimate. The original Howarth study had values two to nearly five times as high as other studies, almost entirely due to the estimates of upstream methane emissions. One reason for this difference is that Howarth used a different global warming potential (GWP) for methane. The other studies used the standard IPCC 100-year GWP of 25. Howarth used a 20-year GWP and did not use the IPCC value of 72, but a value of 105 proposed by Shindell, et al.<sup>9</sup> This value is based on newer research and is still being evaluated by the international scientific community but has not been accepted as the standard at this time. This choice alone explains much of the difference between the Howarth study and the other recent studies. The other major drivers for the higher values were Howarth’s use of very high estimates for methane emissions from shale gas well completions and fugitive emissions from natural gas pipelines. These estimates were derived from a variety of alternative sources that have been criticized as less reliable by some of the other studies.

Howarth also assumed that there is no mitigation of the well completion emissions. The completion emissions can be mitigated either by flaring or by reduced emission completions (REC). Under REC, the gas that would be vented is captured, cleaned and put into pipelines for sale. Two states, Wyoming and Colorado, require that completion emissions be captured or flared; other states are considering such regulations. In 2012, the EPA finalized revised New Source Performance Standards for the oil and natural gas industry that will require REC or flaring for most gas wells nationally.<sup>10</sup> The State of New York has also proposed regulations for shale gas production that would require REC or flaring for most shale gas wells.<sup>11</sup> The Canadian province of Alberta also has extensive regulations prohibiting venting, and requiring and regulating flaring of gas during clean-up operations.<sup>12</sup> The assumption in the Howarth Study that there is no mitigation of completion emissions is another primary source of the difference between that study and the other studies and also seems to indicate an overestimate of methane emissions.

Figure 4 compares the LCA for GHG emissions from gas and coal. The coal combustion emissions are higher than for gas whereas the upstream coal emissions are slightly lower. All of the total values are significantly lower for gas than for coal, 35% lower on average. The upstream coal emissions are smaller but, like gas, dominated by the methane emissions from mining.

**Figure 4. Natural Gas and Coal LCA Comparison**

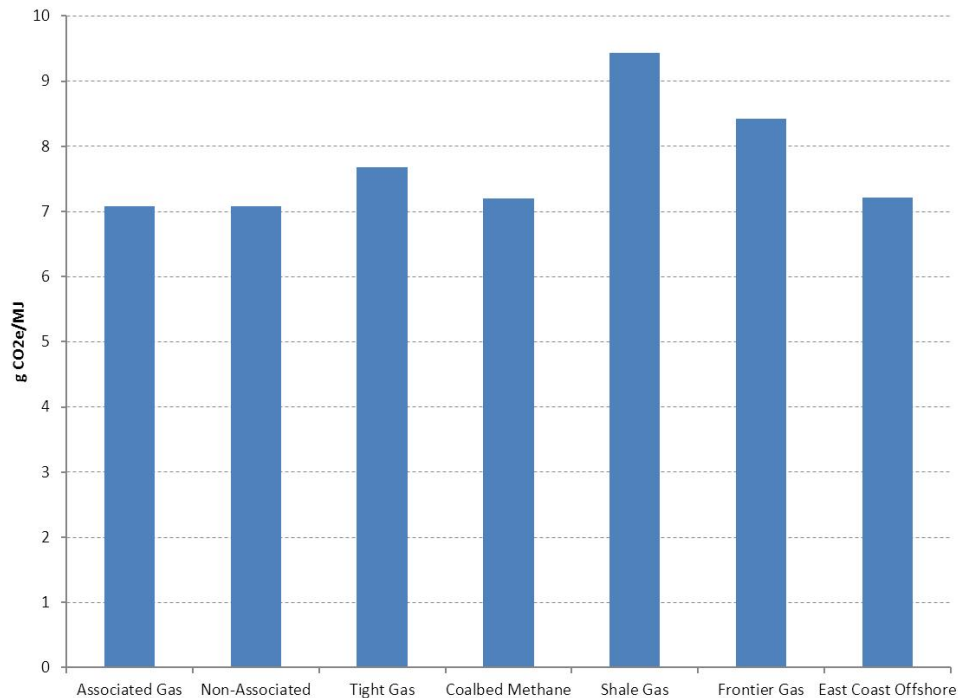


**Data source:** Cited Studies, Weber and Clavin, ICF Analysis

In addition to the U.S. studies, there is one Canadian study, prepared for Natural Resources Canada.<sup>13</sup> This analysis uses the GHGenius model, which NRCAN has been using for more than ten years. The model was updated for this study to address shale gas production. Figure 5 summarizes the results of the study. The weighted average GHG emissions are 7.2 g/CO<sub>2</sub>e/MJ, which is significantly lower than the Best Estimate of 13.5 to 14.7 g/CO<sub>2</sub>e/MJ in the U.S. studies. There are several reasons for these lower values. In particular, the most significant sources of methane in the U.S. analysis are the well completion emissions for shale gas and well liquids unloading for conventional gas production. The Canadian study did not include emissions estimates for these operations because they are not believed to be applicable for Canadian production. The study states that well completion emissions are flared in Canadian shale

gas operations and venting for liquids unloading is not used in conventional gas production operations. The upstream GHG emissions for shale gas production are higher than for conventional production largely due to higher CO<sub>2</sub> content in the gas from the particular region studied (Horn River) and to a lesser extent due to increased energy for drilling and fracturing. Gas from other regions with lower CO<sub>2</sub> content would have lower life-cycle emissions. Even at this higher level, the total life-cycle emissions from shale gas, including combustion emissions, are less than 4% higher than conventional gas and are lower than nearly all of the U.S. studies.

**Figure 5. Upstream GHG Emissions from the NRCan Natural Gas LCA Study**



Source: Natural Resources Canada

## Conclusions

All of the recent LCA studies reviewed other than the Howarth study, have found that life-cycle GHG emissions from shale gas and conventional gas are significantly lower than that of coal. The Howarth study varied from most other analysis due to several key reasons:

- 1) a higher GWP for methane was used compared to the accepted IPCC value;
- 2) different sources of inventory data were used; and
- 3) the study did not consider the potential for or application of mitigation of methane releases during well completions. The Stephenson study is on the low end of the range and the remaining studies are in a consistent range.

The studies also find that there is little difference between life-cycle GHG emissions for shale gas produced through hydraulic fracturing and conventional gas production. The most significant factors affecting the life-cycle emissions are the mitigation of completion emissions from hydraulic fracturing, which is required in the major gas-producing province in Canada and will soon be required in the U.S., and methane emissions from liquids unloading in conventional gas wells.

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## Endnotes

<sup>1</sup> Howarth, R., Santoro, R., Ingraffea, A. 2011. Methane and the Greenhouse-gas Footprint of Natural Gas from Shale Formations. *Climatic Change Letters*, March 13, 2011

<sup>2</sup> Nathan Hultman, Dylan Rebois, Michael Scholten and Christopher Ramig, “The greenhouse impact of unconventional gas for electricity generation”, *Environ. Res. Lett.* 6 (October-December 2011) 044008.

<sup>3</sup> Jiang, Mohan; W. Michael Griffin, Chris Hendrickson, Pauline Jaramillo, Jeanne VanBriesen, and Aranya Venkatesh. “Life cycle greenhouse gas emissions of Marcellus shale gas.” Carnegie Mellon University and IOP Publishing, 5 August 2011: Pittsburgh.

<sup>4</sup> Andrew Burnham, Jeongwoo Han, Corrie E Clark, Michael Wang, Jennifer B Dunn, and Ignasi Palou Rivera. *Environ. Sci. Technol.*, 22 November 2011.

<sup>5</sup> Trevor Stephenson, Jose Eduardo Valle, and Xavier Riera-Palou “Modeling the Relative GHG Emissions of Conventional and Shale Gas Production”, *Environ Sci Technol.* 2011 December 15; 45(24): 10757–10764.

<sup>6</sup> Skone, T.J., “Life Cycle Greenhouse Gas Inventory of Natural Gas Extraction, Delivery and Electricity Production”, National Energy Technology Laboratory, U.S. Department of Energy, October 23, 2011, DOE/NETL-2011/1522.

<sup>7</sup> Skone, T.J., “Role of Alternative Energy Sources: Natural Gas Technology Assessment”, NETL Office of Strategic Energy Analysis and Planning, June 30, 2012, DOE/NETL-2012/1539

<sup>8</sup> Christopher L. Weber and Christopher Clavin, “Life Cycle Carbon Footprint of Shale Gas: Review of Evidence and Implications”, *Environmental Science & Technology* 2012 46 (11), 5688-5695

<sup>9</sup> Shindell DT, Faluvegi G, Koch DM, Schmidt GA, Unger N, Bauer SE “Improved attribution of climate forcing to emissions.” *Science* 326:716–718 (2009).

<sup>10</sup> U.S. EPA, “Oil and Natural Gas Sector: New Source Performance Standards and National Emission Standards for Hazardous Air Pollutants Reviews”, 76 FR 52738.

<sup>11</sup> New York Department of Environmental Conservation. “High Volume Hydraulic Fracturing Proposed Regulations” New York Department of Environmental Conservation, 2012.  
<http://www.dec.ny.gov/regulations/77353.html>.

<sup>12</sup> <http://www.ercb.ca/directives/Directive060.pdf>

<sup>13</sup> Natural Resources Canada, “Shale Gas Update for GHGenius”, August 2011, Prepared by S&T2 Consultants.



The Canadian Natural Gas Initiative (CNGI) is a partnership represented by the Canadian Association of Petroleum Producers, Canadian Gas Association, Canadian Energy Pipeline Association, Canadian Natural Gas Vehicle Alliance and the Canadian Society for Unconventional Resources.