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Greenhouse Gas Emissions Associated with Marcellus Shale

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About this document

This commentary was prepared to provide an independent analysis and explanation of recent studies of the relative impacts of natural gas produced by shale, especially compared to coal. Our goal is to improve public understanding and create a more informed discussion on the issue. Our target audience includes all stakeholders associated with Marcellus shale development, including industry, residents, and government – especially in Northeastern Pennsylvania. Thus, we have minimized technical language as much as possible.

Summary

The use of natural gas and the other fossil fuels for energy contributes greenhouse gases, especially carbon dioxide, into the atmosphere. Those gasses are thought to increase global temperatures. Studies conducted between 2000 and 2007 suggested that natural gas produces fewer greenhouse gases than coal, especially when used to generate electricity. A study by a team of researchers at Cornell University published in April 2011 found that extracting natural gas from shale released large quantities of methane – a far more potent greenhouse gas than carbon dioxide. They concluded that when the full life-cycle of energy extraction, delivery, and use is considered, shale gas produces up to twice the greenhouse gas emissions compared to burning coal or oil – especially when viewed over a 20-year time-span. However, seven analyses released in the summer and fall of 2011 came to a different conclusion than the Cornell study. All seven found that natural gas produces 20-60% lower greenhouse gas emissions, especially when used for electrical generation and when viewed over a 100-year time span. The discrepancies between the Cornell and subsequent studies appear to result primarily from the different time-frames used (20 vs. 100 year). One modeling analysis predicted that switching from coal to natural gas would reduce global temperatures by less than 0.4˚C, and would take decades to be observed. All of the analyses were based on data obtained from the U.S. Environmental Protection Agency (EPA) and other sources, some of which had high levels of uncertainty. Additional field research is needed to more accurately understand methane emissions from well sites and pipelines. Reducing methane loss during drilling and distribution by using best practices would give shale-derived natural gas a decidedly lower greenhouse gas footprint than coal.

Introduction

Extracting and burning fossil fuels such as coal, oil, and natural gas releases carbon dioxide and methane into the atmosphere. Since the late 1980s, scientists have become increasingly concerned that growing concentrations of these gases, called greenhouse gases, are causing more of the sun's energy to be trapped near the earth's surface. That increase in energy is widely believed to cause an observed increase in worldwide temperatures – a phenomenon called global warming (IPCC 2007). There are other important greenhouse gases, including water vapor, nitrous oxide, and several man-made compounds, but methane and carbon dioxide are the most important when fossil fuels are considered.

While all fossil fuels contribute to the rise in atmospheric carbon, the amount of carbon released varies greatly between the three energy sources. Coal and oil are made up of molecules composed of at least six carbon atoms. When we burn those fuels, each carbon forms its own carbon dioxide molecule. Natural gas is composed mostly of methane, which has only one atom of carbon per molecule (see http://energy.wilkes.edu/pages/148.asp for more information about natural gas). Thanks to its simpler molecular structure, natural gas has the lowest carbon

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content of any of the commonly used fuels in the United States. Compared to coal, natural gas contains approximately 56% of the amount of carbon per unit of energy produced (EPA 2010). This means that if all the carbon in both fuels was burned to produce carbon dioxide (CO_2), natural gas would have 56% fewer emissions of CO_2. Natural gas also contains 85% of the carbon content of liquefied petroleum gas (LPG), 74% of the content of gasoline, and 71% of the carbon content of crude oil. Thus, using natural gas instead of other fossil fuels can reduce greenhouse gas emissions. That advantage is discussed in the peer-reviewed literature (Hayhoe et al. 2002; Jaramillo et al. 2007), and is often touted by proponents of the gas industry.

That comparison is complicated by the fact that methane is a much more potent greenhouse gas than carbon dioxide. According to the most recent assessment by the International Panel for Climate Change (2007), each molecule of methane has a 25 times greater global warming potential (GWP) than a molecule of carbon dioxide when viewed on a 100-year time basis. The impact is even higher (72 times) when viewed on a 20-year basis. An analysis by Shindell et al. (2009) assigns even higher values: 33 and 105 times, respectively.

While gas companies capture most of the methane leaving gas wells, some methane is released when new wells are drilled and gas is shipped. Since natural gas consists largely of methane, any leakage of natural gas during production and shipping will reduce the benefits resulting from its low carbon content. Rates of estimated leakage during production and shipping of natural gas – called *fugitive gas emissions* – have not been precisely measured, but have been estimated to be 1.4% (Skone 2011), 2% (Jiang et al. 2011); and 3.6-7.9% (Howarth et al. 2011) of lifetime well production.

Thanks to the suspected impact of fugitive methane emissions on global warming, any analysis that focuses only on burning a fossil fuel provides only part of the picture of its impact on climate. A more complete understanding of the fuel's full impact must include the amounts of greenhouse gas that are released in operations associated with extracting natural gas, processing it, and getting it to the consumer. Those releases are termed *life-cycle emissions*. Scientists account for the differences in GWP of the various greenhouse gases by expressing gas production in terms of "carbon dioxide equivalents" (CO_2e)" during analyses of life-cycle emissions. Scientists who estimate life-cycle emissions must make various assumptions, including the GWP value (20 vs. 100 year time horizon; IPCC estimates vs. Shindell et al.) and lifetime well production of methane. In addition, some analyses combine all sources of natural gas, while others report individual sources – such as shale, coal-bed methane, and conventional.

Greenhouse Gas Footprint: Coal vs. Natural Gas

Life-cycle analyses of natural gas emissions became important in the early and mid-2000s, as attention turned to the relative merits of using natural gas versus. coal in energy production. The early analyses conducted by Hayhoe et al. (2002) and Jaramillo et al. (2007) pooled all sources of natural gas, and found them to have a lower greenhouse footprint than coal.

In April 2011, a team of researchers from Cornell University (Howarth et al. 2011) published a peer-reviewed report in which they examined the greenhouse gas footprint for natural gas extracted from deeply buried shale using a process called hydrofracking. Using data from the Environmental Protection Agency and other sources, the Cornell team found that hydrofracking and other aspects of gas well development causes the release of large amounts of methane. Coupled with transport losses, Howarth et al. (2011) estimated that 3.6 – 7.9% of all well production is lost as fugitive methane. When the total impact of combustion, leakage, and extraction is considered, GHG emissions from gas produced from deep-lying shales may be as much as double the emissions due to combustion alone (Figure 1). They concluded that burning natural gas from shale could produce up to twice the greenhouse gas emissions compared to burning coal or oil. The disadvantage of using shale gas is especially significant when one uses the 20-year basis for assessing greenhouse gases.

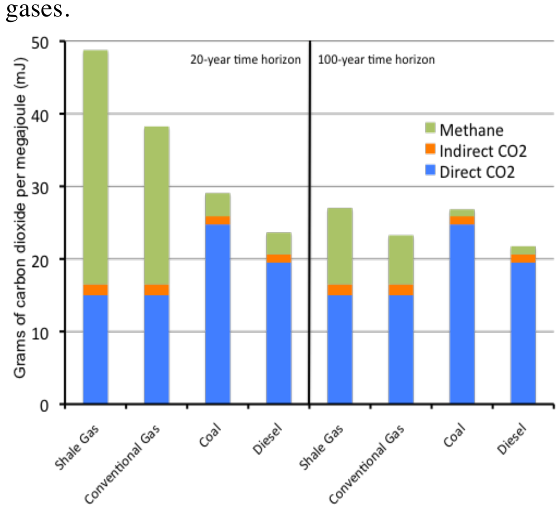

Figure 1. Comparison of greenhouse gas footprints of gas, coal, and diesel oil under 20-year and 100-year time horizons. Modified from Howarth et al. (2011).

Alternative Views to Howarth's Conclusions

Seven life-cycle analyses released during the summer and fall of 2011 arrived at different conclusions than those stated by Howarth. These studies focused on comparing the emissions of shale to coal when the two fuels are used for generating electricity. The authors of each of those studies believe that since most coal is burned to generate electricity, focusing on that use makes for a fairer comparison.

Each of the studies recognized that electric generators that burn natural gas are more efficient than those that burn coal. For example existing gas-fired turbines generate electricity with a 39-42% efficiency level, while coal-fired units operate at a 33-34% level (Hughes 2011; Hultman 2011). New generating technology makes the advantage even greater. The efficiency of new combined cycle gas turbines is 50%, while the best coal units are 39-43% (Hughes 2011; Hultman 2011; Jiang 2011).

Each of the subsequent studies recalculated EPA data to determine the number of units of greenhouse gas produced (usually as grams of CO_2 equivalent) per unit of electricity (usually as kilowatt hours). Each study had slightly different assumptions, but generally came to the same conclusions.

One such study, performed by researchers at Carnegie Mellon University (Jiang et. al. 2011), was published in the peer-reviewed journal *Environmental Research Letters*. The CMU study was conducted independently of the Cornell team. The authors found that shale-derived gas had an 11% higher greenhouse gas footprint than natural gas produced by other sources. But when the shale gas is used to produce electricity, life-cycle GHG emissions of greenhouse gases from Marcellus shale production were 20-50% lower than those of coal (Figure 2).

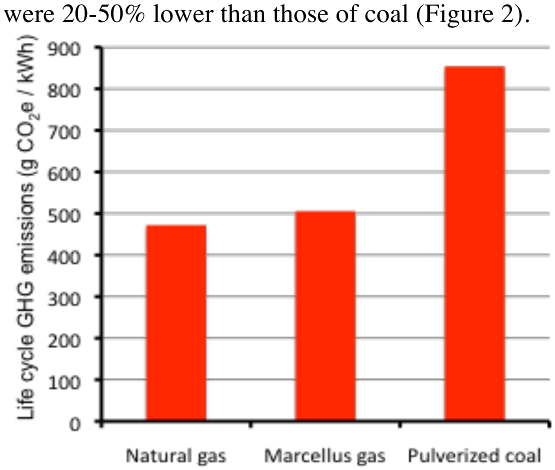

Figure 2. Life-cycle greenhouse gas footprints of gas and coal based on electric generation. Modified from Jiang et al. (2011).

Six other analyses that were performed after the release of the Cornell team's study explicitly sought to evaluate the Cornell conclusions. The follow-up work was performed by researchers at the Clear Skies Foundation (Staple and Swisher 2011), Department of Energy's National Energy Technology Laboratory (Skone 2011), Deutsche Bank Group (Fulton et al. 2011), the University of Maryland (Hultman et al. 2011), Argonne National Laboratories (Burnham et al. 2011), and from a second research team at Cornell University (Cathles et al. 2011). Like the CMU study, all of the teams compared the greenhouse gas emissions of natural gas to coal for electricity generation. They also used the 100-year time horizon for methane as calculated by the IPCC.

All of the follow-up studies found natural gas to produce a lower greenhouse gas footprint, when compared to coal. For existing technology, generating electricity by using natural gas typically produced 500-730 g of CO_2 equivalent per kilowatt-hour, compared to 900-1050 g for existing coal. When using new technology, the emission rate reduces to 430-660 g for gas and 800-900 g for coal.

Each study found that natural gas produced lower greenhouse gas emissions than coal. Reported values included 33% (Burnham et al.), 43% (Hultman 2011), 47% (Fulton et al. 2011), 55% (Skone 2011), 50-67% (Cathles et al.), and 51-63% (Staple & Swisher 2011)

As Howarth et al. (2011) found, most of the studies found the greenhouse gas footprint of shale to be larger than that of conventional natural gas. However, the differential tended to be much smaller (10-15%) than Howarth's estimate. Interestingly, Burnham et al. (2011) found that shale gas had 6-12% lower emissions than conventional gas, though the difference was not statistically significant.

Most authors criticized Howarth's use of Shindell's estimates for the greenhouse gas footprint of methane, rather than the more widely accepted IPCC values. Both Cathles et al. (2011) and Fulton et al. (2011) asserted that the leakage rates estimated by Howarth would create unsafe conditions at the well, and that the loss of such huge volumes of valuable methane would represent an unacceptable financial loss to the industry.

In an effort to reconcile the differences between one dissenting opinion (Skone) to that of Howarth, J.D. Hughes of the Post-Carbon Institute released a report in July 2011. Using data provided by the EPA and other sources, Hughes found that both authors' conclusions could be correct, depending on the assumptions used. Shale gas has a higher footprint (supporting Howarth's conclusion) if one uses the 20-year greenhouse gas value for methane. Shale has a lower footprint (supporting Skone's conclusion) if one uses the 100-year value for methane (Figure 3), Other authors have accounted for different methane footprints, so Hughes's conclusions may not apply to those studies.

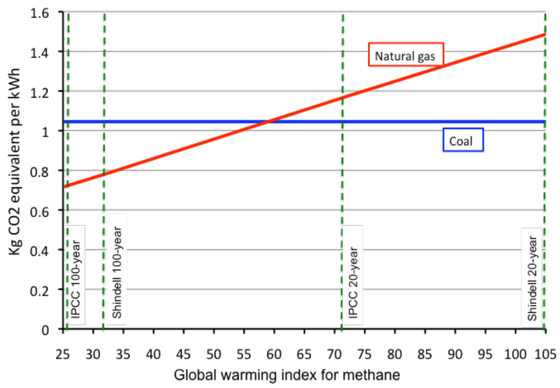

Figure 3. Greenhouse footprint of shale gas and coal based on time horizon selected, according to the analysis of Hughes (2011). Note that gas has a value lower than that of coal for time horizons of less than 60 years, but greater than that of coal for horizons more than 60 years.

Greenhouse gas impacts in transportation fuels

Natural gas is being increasingly touted as a fuel for vehicles such as trucks, busses and fleet cars. It is viewed as being cleaner burning than gasoline or diesel fuel. In addition, natural gas derived from shale gas is perceived as being a domestic fuel, unlike the others that are based on imported oil.

One can ask whether switching from gasoline or diesel to natural gas provides greenhouse gas benefits. Burnham et al. (2011) conducted a life cycle (well to wheel) analysis for transportation fuels.

They found no statistical difference between fuels when viewed on a 100-year time horizon. However, on a 20-year time horizon, natural gas vehicles had a 25-34% higher greenhouse gas impact than those fueled by gasoline or diesel.

Uncertainties in the data

All of the studies conducted to date were based on analyses of data provided by the EPA, the U.S. Energy Information Administration and other sources – some of which were unpublished. None were based on data collected by the authors at Marcellus well sites. Most of the authors admitted that their data had high levels of uncertainty. Burnham et al. (2011) provided an especially detailed analysis of data uncertainty.

A report from the Cambridge Energy Research Associates (Barcella et al. 2011) expressed concern over the EPA data used by all of the studies. The primary issues that they highlighted included estimates that were based on faulty data, and values that did not reflect industry practice, especially regarding capture of methane. The Barcella report also cited additional inaccuracies with the data used by Howarth, such as double-reporting one instance of high methane emissions.

Impacts on Global Temperatures

The claim that natural gas has a smaller greenhouse gas footprint than coal implies that it will lead to a lower risk of global warming in the future. An analysis from National Center for Atmospheric Research tested that idea by examining changes in emissions for carbon dioxide, methane, and sulfur dioxide that would be expected by switching from coal to natural gas (Wigley 2011). The analysis predicted that such a switch would reduce carbon dioxide emissions, leading to less global warming. However, such a switch would lead to more methane leakage, which would cause temperatures to rise. Ironically, the switch would also cause lower sulfur dioxide emissions, which would lead to higher temperatures because that gas acts as an aerosol and would be expected to lower temperatures.

Wigley put together these parameters, and found that – even with no methane leakage – switching from coal to natural gas would cause global temperatures to rise until 2050 due to the loss of sulfur dioxide. However, temperatures would decline afterwards because the cooling effects of lower carbon dioxide emissions would overtake the warming effects of lower sulfur dioxide emissions.

Wigley found that the amount of methane leakage due to shale gas extraction would affect the timing and magnitude of the effect (Figure 4). Holding methane leakage to 2.5% would delay the onset of the cooling effect and would result in less cooling by the end of the next century. The delay and reduction of cooling would be less if higher levels of methane were leaked to the atmosphere.

Significantly, Wigley found that even under the most ideal circumstance of no methane leakage, switching from coal to natural gas would reduce global temperatures by less than 0.4˚C. He argued that such a decline was modest, and that switching from coal to gas should be based on other factors like availability, economics, and environmental considerations other than climate change.

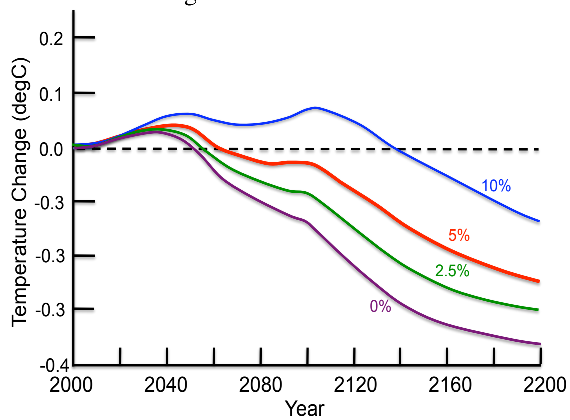

Figure 4. Prediction of future changes in global temperatures resulting from switching from coal to natural gas (after Wigley 2011). Temperatures are predicted to increase before 2060 because the loss of sulfur dioxide emissions (which cools the climate) outweighs the loss of carbon dioxide (which warms the climate). After 2060, the reverse is predicted to occur. Leakage of methane into the atmosphere from gas production will delay and reduce the cooling effect. Even in the best-case scenario, switching from coal to natural gas will lead to a global temperature reduction of less than 4ºC.

Discussion and Conclusions

The assertion – made by Howarth et al. (2011) – that shale gas has a larger greenhouse gas footprint has attracted considerable attention both in the media and by the scientific community. We are aware of seven separate analyses that address life cycle emissions of both fuels. All seven fail to support Howarth's findings, and arrive at relatively consistent results regarding the advantage that shale has over coal in terms of greenhouse gas emissions. We therefore agree that the results of recent studies cast doubt on the conclusions of Howarth et al.

We take note of Wigley's (2011) findings that suggest that switching from coal to natural gas would cause a slight *increase* in temperatures for the next forty years. Any benefits would begin to appear decades from now, and would be relatively modest (less than 0.5˚C. However, his conclusions are based on a modeling analysis with certain assumptions. Additional follow-up work is needed to evaluate his assumptions and determine whether other assumptions might lead to different conclusions.

One obvious shortcoming of all of the studies conducted to date is that they are based on EPA data, which have been called into question, and on poorly documented assumptions regarding release of methane during gas production and distribution. We believe that field research is critically needed to directly evaluate methane release at well sites throughout the areas in which Marcellus gas is being extracted. Those assessments should be based on accepted methods for assessing amounts of methane being released into the air and should last long enough to account for time-related variability that will undoubtedly occur.

Basing the greenhouse gas advantage of natural gas or coal on the selected Global Warming Potential index value of methane (100 vs 20 years, IPCC vs. Shindell) leads to an unproductive debate that should be avoided. However, most authors agree that energy companies can do much to reduce emissions of fugitive methane during production and distribution – thereby clearly shifting the advantage to natural gas. Technologies such as plunger lifts at the wellhead, flash tank separators, and better fittings in pipelines can reduce methane loss to the atmosphere. When methane must be vented, it should be flared – thereby converting it into carbon dioxide. Companies following the recommendations of the EPA's Natural Gas Science to Achieve Results (STAR) program reportedly reduced their methane emissions by 86 billion cubic feet in 2009 (Beckwith 2011).

While important, the greenhouse gas footprint is one of many factors to consider when comparing Marcellus shale gas to other energy sources. Other factors should include other air pollutants (nitrogen oxides, sulfur, and volatile organic compounds), pollution of surface and subsurface waters, impacts to land-based and freshwater ecosystems, security of energy source, and cost to consumer.

Ultimately, the results of the science to date indicate that switching from coal to natural gas will reduce greenhouse gas emissions, especially for electricity generation. The impact on reducing global climate change is less clear. We agree with Hughes (2011) that both fossil fuels will continue to be used for decades to come. However, transitioning from coal to gas whenever possible will have benefits in the long run, especially if industry employs best practices to reduce methane emissions.

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About the IEER

Housed at Wilkes University in Wilkes-Barre, PA, the Institute for Energy and Environmental Research for Northeastern Pennsylvania is a collaborative of Wilkes, King's College, and the Institute for Public Policy and Economic Development. The IEER conducts research and provides community education on issues associated with energy development in northeastern Pennsylvania. The IEER is funded by a contract with the Department of Energy / National Energy Technology Laboratory to support that mission with respect to Marcellus shale gas development. More information about IEER can be found at http://www.IEER-NEP.org.

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