

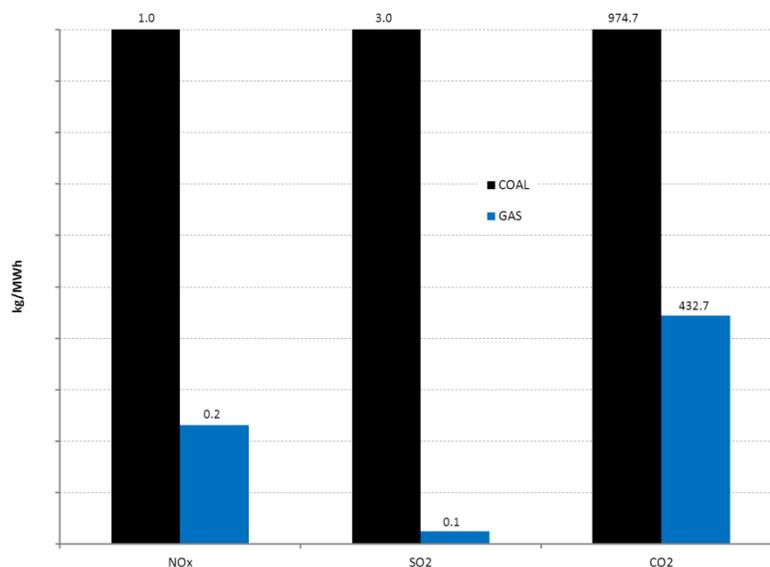
Life Cycle Greenhouse Gas Emissions of Natural Gas

A literature review of key studies comparing emissions from natural gas and coal

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 (CO₂) emissions when burned. It also has lower sulfur than coal or most grades of petroleum, resulting in lower sulfur (SO₂) and particulate (PM) emissions. The ability to very effectively control the combustion of natural gas allows for the minimization of nitrogen oxides (NO_x) 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 CO₂. Methane has a GWP of 25ⁱ, meaning that one tonne of methane has the warming effect of 25

ⁱ 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 CO₂. 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 paper¹ 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)¹ – 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)² – 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)³ – 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)⁴ – 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 productionⁱⁱ. Overall, it found that life-cycle GHG emissions from gas-fired electricity production were 36% lower than for coal-fired electricity production.

ⁱⁱ 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.

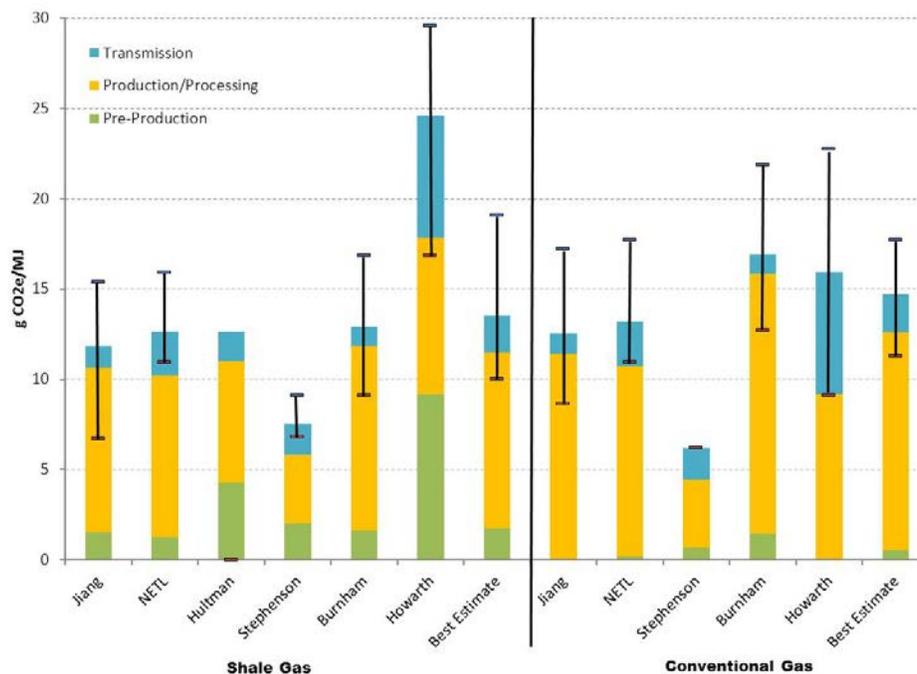
Stephenson et al. (Shell Global Solutions)⁵ – This peer-reviewed study estimated that shale gas has life-cycle GHG emissions about 1.8–2.4% higher than conventional gas, arising mainly from higher methane releases in well completion. In all cases considered, the life-cycle emissions of electricity generation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

National Energy Technology Laboratory (NETL)⁶ – 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 analysis⁷, 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)⁸ – 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 CO₂e/MJ)ⁱⁱⁱ for upstream emissions and the highest variability for shale gas. The Stephenson study has the lowest value (7.6 g CO₂e/MJ) and the other four studies are very close in their final results (11.8 to 12.9 g CO₂e/MJ). The Best Estimate value is 13.5 g CO₂e/MJ.

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



Source: Weber and Clavin

ⁱⁱⁱ The Weber and Clavin article uses g CO₂/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 CO₂e/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 CO₂ emissions from the end use combustion of the gas. The upstream CO₂ emissions from drilling engines, process equipment, pipeline compressors, other equipment and CO₂ 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 CO₂ released during the actual combustion of the fuel – 56.3 g CO₂e/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.⁹ 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.

