LIFECYCLE GREENHOUSE GAS EMISSIONS FROM SHALE GAS COMPARED TO COAL: AN ANALYSIS OF TWO CONFLICTING STUDIES

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Over the past decade he has researched, published, and lectured widely on global energy and sustainability issues in North America and internationally. He is a board member of the Association for the Study of Peak Oil and Gas–Canada and is a Fellow of the Post Carbon Institute. He recently contributed to Carbon Shift, an anthology edited by Thomas Homer-Dixon on the twin issues of peak energy and climate change, and his work has been featured in Canadian Business, Walrus, and other magazines, as well as through the popular press, radio, television, and the Internet. He is currently president of a consultancy dedicated to research on energy and sustainability issues.

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Abstract

Two studies with conflicting conclusions have recently been produced on full-cycle greenhouse gas (GHG) emissions from shale gas production, one from scientists at Cornell University and another from a scientist at the National Energy Technology Laboratory (NETL). The Cornell study, published in a peer-reviewed journal, suggests that lifecycle GHG emissions from shale gas are 20%-100% higher than coal on a 20-year timeframe basis, especially considering that 70% of natural gas consumption is not used for electricity generation. The NETL study, presented in a talk at Cornell University and later posted on the NETL website, suggests, on an electricity-generation comparison basis, that natural gas base load has 48% lower GHG emissions than coal on a 20-year timeframe basis. The NETL comparison, however, does not single out shale gas, which is projected by the U.S. Energy Information Administration (EIA) to be the major source of natural gas supply growth going forward, nor does it consider the overall emissions from natural gas-fired electricity generation, focusing instead on the more efficient base load combined cycle component.

When the assumptions of the NETL study are examined in detail and compared to the U.S. Environmental Protection Agency (EPA) 2009 emissions inventory for natural gas, as well as to the likely ultimate production from shale gas wells, the resulting conclusions are not significantly different than the Cornell study. Shale gas full-cycle GHG emissions are higher than those of coal when comparing both the existing electricity generating fleets and best-in-class electricity generation technologies for both fuels over a 20-year timeframe basis, but are lower than those of coal on a 100-year timeframe basis. This has significant policy implications for utilizing natural gas as a “transition” fuel to a low carbon future in mitigating near-term GHG emissions.
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Introduction

On April 14, 2011, Cornell scientists Robert Howarth, Renee Santoro and Anthony Ingraffea published a peer-reviewed paper entitled “Methane and the greenhouse-gas footprint of natural gas from shale formations”\(^1\) which concluded, among other things, that:

“The [greenhouse gas] footprint for shale gas is greater than that for conventional gas or oil when viewed on any time horizon, but particularly so over 20 years. Compared to coal, the footprint of shale gas is at least 20% greater and perhaps more than twice as great on the 20-year horizon and is comparable when compared over 100 years.”

This proved to be a very controversial conclusion, particularly among proponents of natural gas as a “transition” fuel from oil and coal.

On May 12, 2011, NETL scientist Timothy Skone presented a lecture at Cornell entitled “Life Cycle Greenhouse Gas Analysis of Natural Gas Extraction & Delivery in the United States.”\(^2\) Skone later modified several input parameters and posted an update on the National Energy Technology Laboratory (NETL) website.\(^3\) Although Skone did not mention the recently published paper of Howarth et al. on life cycle analysis of greenhouse gas (GHG) emissions from gas and coal\(^4\) directly, others have suggested Skone’s presentation is a direct rebuttal of the conclusions of Howarth et al. Michael Levi, at the Council of Foreign Relations, for example, states\(^5\):

“Using a 100-year global warming potential and assuming an average power plant, unconventional gas results in 54% less lifecycle greenhouse gas emissions than coal does. Even using a 20-year global warming potential, as Howarth controversially argues one should, the savings from substituting unconventional gas for coal are almost 50%.”

Given the importance of understanding the true significance of full-cycle greenhouse gas (GHG) emissions, particularly from shale gas, which is projected to be the major source of growth in U.S. gas supply through 2035,\(^6\) it is important to examine the substance of the Skone (NETL) presentation and the veracity of the claims it makes relative to the conclusions of Howarth et al. The most critical grounds for comparison include:

- Veracity of the input parameters.
- Assumptions of the magnitude of fugitive methane emissions, which are the largest contributor to GHG emissions from shale gas before the burner tip.
- Assumptions of the global warming potential of methane and the time period over which it is assessed.
- Assumptions made on the comparison of gas-fired- to coal-fired-electricity generation.
Veracity of Input Parameters

The veracity of the input parameters is crucial, for, depending on input assumptions, one can get any answer one wants out of the analytical process.

The sources of the input parameters used, and assumptions made, by Howarth et al. are laid out in their peer-reviewed paper, although the authors acknowledge that these data are much less than perfect. The U.S. Environmental Protection Agency (EPA) has acknowledged the need for more comprehensive data on fugitive methane emissions and has implemented a series of new regulations, with first reporting due in March 2012.7

The Skone analysis, which is a slide deck (i.e., a PowerPoint presentation) that has not been peer-reviewed, includes many input parameters of conventional and unconventional gas (slides 21-23); yet the sources of the values assigned are mostly not cited in the presentation. In an email, however, Skone states:

“The NETL study utilizes the February 2011 EPA emission factors applied to the GHG Inventory for the natural gas sector (not the EPA inventory results for extraction and processing - the NETL model develops the results on a life cycle basis (30-year temporal period) using the emission factors) combined with other emission factors to develop a representative life cycle GHG profile for natural gas.”8

Notwithstanding this statement, there is no reference cited in the presentation to “February 2011 EPA emission factors.” The document cited in the presentation as the source of these values is presumably the EPA’s "Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources, AP-42"9, yet an examination of this document reveals none of the many input parameters Skone lists in the presentation (slides 21-23). Revised emission factors for conventional and unconventional well completions and well workovers listed by the EPA10 were presumably used, however this is not explicitly stated. Moreover, in the case of unconventional gas, the EPA emission factors are an average of coalbed methane, tight gas, and shale gas across the industry. Methane emissions from horizontal, hydraulically-fractured shale gas wells are typically much higher than those from coalbed methane or vertical tight gas wells, hence using an average underestimates the actual contribution of shale gas.

As will be shown below, the estimated ultimate recovery or total lifetime production (EUR) of shale gas wells is also a very important factor in determining the percentage of total fugitive methane emissions, and there is a wide difference between the value Skone uses for his average Barnett Shale gas well and that used by Howarth et al.
Assumptions of the Magnitude of Fugitive Methane Emissions

Notwithstanding the issues with the veracity of the input parameters, one might ask how the Skone estimates of fugitive methane emissions compare with the latest EPA inventory data for 2009. Skone assumes that a certain percentage of fugitive methane emissions are flared, which reduces GHG impact given the much higher global warming potential (GWP) of vented methane over short timeframes. Table 1 illustrates the main parameters Skone uses for fugitive methane emissions, discounted for the percentage flared, using his assumptions for an average Barnett Shale gas well.

The principal method used by Howarth et al. to determine the magnitude of fugitive methane emissions per unit of heat generated was by determining a percentage range of fugitive methane emissions. For shale gas, Howarth et al. estimated that between 3.6% and 7.9% of total production was lost as fugitive methane. This includes cumulative losses from extraction, processing, transmission, storage, and distribution.

Table 2 illustrates the fugitive methane emissions assumed by Skone for all of the natural gas supply sources utilizing the parameters listed in Table 1. The Skone presentation indicates that fugitive methane emissions from all natural gas sources ranges from .51% to 2.3% of lifetime production, with a weighted average from all sources of 1.52%, exclusive of distribution emissions. This compares to 2.19%, exclusive of distribution emissions, for the whole U.S. gas production system estimated in the 2009 EPA inventory of GHG emissions from natural gas (see Table 3). Although Skone recognized that fugitive methane emissions from shale gas (as represented in his analysis by the Barnett Shale) are far higher than conventional gas, at 2.3%, his estimates for overall fugitive methane emissions from all sources, at 1.52%, are nearly 31% lower than the EPA inventory data.
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated Ultimate Recovery (EUR) (billion cubic feet)</td>
<td>3.0</td>
</tr>
<tr>
<td>Flaring rate</td>
<td>15%</td>
</tr>
<tr>
<td>Emissions per Workover (mcf)</td>
<td>11,643</td>
</tr>
<tr>
<td>Number of Workovers per well</td>
<td>3.5</td>
</tr>
<tr>
<td>Total emissions from workovers (mcf)</td>
<td>40,751</td>
</tr>
<tr>
<td>Well Completion emissions (mcf)</td>
<td>11,643</td>
</tr>
<tr>
<td>Total emissions from completion and workovers (mcf)</td>
<td>52,394</td>
</tr>
<tr>
<td>Workovers and completions vented (85%) (mcf)</td>
<td>44,534</td>
</tr>
<tr>
<td>Liquids unloading (not considered)</td>
<td>?</td>
</tr>
<tr>
<td>Extraction Pneumatic devices fugitive (mcf)</td>
<td>7,383</td>
</tr>
<tr>
<td>Extraction Other sources fugitive (mcf)</td>
<td>2,886</td>
</tr>
<tr>
<td>Processing Pneumatic devices fugitive (mcf)</td>
<td>20</td>
</tr>
<tr>
<td>Processing Other sources fugitive (mcf)</td>
<td>2,013</td>
</tr>
<tr>
<td>Transmission per 604 miles fugitive (mcf)</td>
<td>12,081</td>
</tr>
<tr>
<td>Total fugitive methane emissions (mcf)</td>
<td>68,917</td>
</tr>
</tbody>
</table>

Table 1. Fugitive methane emissions for the average Barnett Shale gas well from Skone’s presentation (all fugitive emissions expressed in pounds methane per thousand cubic feet have been converted to thousand cubic feet (mcf) over the total well life production assuming methane weighs 44.7 pounds per mcf at standard temperature and pressure).
<table>
<thead>
<tr>
<th>Offshore Conventional</th>
<th>Onshore Associated</th>
<th>Coalbed Methane</th>
<th>Onshore Conventional</th>
<th>Tight Sand</th>
<th>Barnett Shale</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of total U.S. Production</td>
<td>13</td>
<td>7</td>
<td>9</td>
<td>23</td>
<td>32</td>
</tr>
<tr>
<td>Total production per well (bcf)</td>
<td>67.7</td>
<td>4.4</td>
<td>0.2</td>
<td>8.6</td>
<td>1.2</td>
</tr>
<tr>
<td>Average production over 30 years (mcf/day)</td>
<td>6,179</td>
<td>399</td>
<td>20</td>
<td>782</td>
<td>110</td>
</tr>
<tr>
<td>Well completion and workovers (mcf over lifetime)</td>
<td>25</td>
<td>3</td>
<td>139</td>
<td>25</td>
<td>17,813</td>
</tr>
<tr>
<td>Liquids unloading (mcf over lifetime)</td>
<td>10,709</td>
<td>?</td>
<td>?</td>
<td>10,709</td>
<td>?</td>
</tr>
<tr>
<td>Extraction: Pneumatic devices fugitive (mcf over lifetime)</td>
<td>151</td>
<td>10,828</td>
<td>492</td>
<td>21,163</td>
<td>2,953</td>
</tr>
<tr>
<td>Extraction: Other sources fugitive (mcf over lifetime)</td>
<td>15,145</td>
<td>4,233</td>
<td>192</td>
<td>8,273</td>
<td>1,154</td>
</tr>
<tr>
<td>Processing: Pneumatic devices fugitive (mcf over lifetime)</td>
<td>454</td>
<td>30</td>
<td>1</td>
<td>58</td>
<td>8</td>
</tr>
<tr>
<td>Processing: Other sources fugitive (mcf over lifetime)</td>
<td>45,436</td>
<td>2,953</td>
<td>134</td>
<td>5,772</td>
<td>805</td>
</tr>
<tr>
<td>Transmission per 604 miles (mcf over lifetime)</td>
<td>272,617</td>
<td>17,718</td>
<td>805</td>
<td>34,631</td>
<td>4,832</td>
</tr>
<tr>
<td>Total fugitive methane emissions (mcf over lifetime)</td>
<td>344,539</td>
<td>35,764</td>
<td>1,764</td>
<td>80,630</td>
<td>27,566</td>
</tr>
<tr>
<td>Fugitive methane emissions as percentage of total production</td>
<td>0.51</td>
<td>0.81</td>
<td>0.88</td>
<td>0.94</td>
<td>2.30</td>
</tr>
</tbody>
</table>

Table 2. Fugitive methane emissions by source for each of the supply sources listed in the Skone (NETL) presentation.
<table>
<thead>
<tr>
<th>Process</th>
<th>CH₄ mass (Gg)</th>
<th>CH₄ volume @ STP (bcf)</th>
<th>As % of total U.S. production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field Production</td>
<td>6,205</td>
<td>306</td>
<td>1.49</td>
</tr>
<tr>
<td>Processing</td>
<td>834</td>
<td>41</td>
<td>0.20</td>
</tr>
<tr>
<td>Transmission and Storage</td>
<td>2,115</td>
<td>104</td>
<td>0.51</td>
</tr>
<tr>
<td>Distribution</td>
<td>1,381</td>
<td>68</td>
<td>0.33</td>
</tr>
<tr>
<td>Total</td>
<td>10,535</td>
<td>519</td>
<td>2.52</td>
</tr>
</tbody>
</table>

Table 3. Fugitive methane emissions (2009) for U.S. natural gas production, processing, transmission, storage, and distribution U.S.¹³ Total U.S. dry production of natural gas in 2009 was 20,580 bcf.
Figure 1 illustrates the comparison of the various components of fugitive methane emissions for each supply source in Skone’s presentation compared to the EPA inventory data for 2009, which is an average of fugitive methane from all U.S. natural gas supply sources. This raises a very significant question: Why should Skone’s estimates of fugitive methane emissions be so much lower than those in the EPA inventory? It should also be noted that the Government Accounting Office (GAO) estimate of fugitive emissions is still higher at 4.2% per annum for the years 2006-2008 from all sources.\textsuperscript{14}

If Skone’s fugitive emissions estimates were adjusted so that overall average emissions matched the EPA emissions inventory data, the percentage contribution would be as illustrated in Figure 2. This still places shale gas emissions from the Barnett Shale below the lower end of the Howarth et al. shale gas estimate – 3.31% versus 3.6% for Howarth et al.
A further consideration in assessing the percentage of overall production emitted as fugitive methane is the estimated ultimate recovery (EUR) of the shale gas wells. In the case of shale gas from the Barnett Shale, Skone has assumed an average EUR of 3 billion cubic feet (bcf). This is higher than the 2.8 bcf estimated by operators\(^\text{17}\) and much higher than estimated by the U.S. Energy Information Administration (EIA). The EIA suggests that the average EUR of the Barnett Shale is 1.42 bcf and the average EUR for all U.S. shale gas plays is 1.02 bcf\(^\text{18}\). Analyst Arthur Berman suggests the average EUR of the Barnett Shale may be lower still. He states:\(^\text{19}\)

“In 2007, I projected EUR for almost 2,000 horizontal wells in the Barnett Shale (World Oil, November 2007). At that time, these were the only horizontal wells with enough production history to evaluate. Now, with two additional years of production, I revised the decline curves for the same control set of 1,977 horizontal wells. The overall EUR decreased 30% from my previous estimate, and the average per-well EUR fell from 1.24 Bcf to 0.84 Bcf.”
The assumed total production of shale gas wells (EUR) is critical in determining vented methane as a percentage of total production. Table 4 illustrates Barnett Shale fugitive methane emissions and their percentage of total production as a function of EUR based on the Skone estimates of fugitive methane emissions. Figure 3 illustrates the percentage of total fugitive methane as a function of EUR for the Skone estimates as presented for the Barnett Shale and as adjusted to match the EPA overall emissions data. At an EUR of 1.24 bcf/well the Skone estimates for the average Barnett Shale well amount to 4.4% of total production and, when the overall Skone analysis is adjusted to match the 2009 EPA inventory data, amount to 6.35%. If an average EUR of 0.84 bcf/well is used, Skone’s estimates for the average Barnett Shale well would amount to 6.1% and 8.8% respectively. This is comparable to the estimates of Howarth et al., which assumed an EUR of 1.24 bcf for an average Barnett Shale well and overall fugitive methane emissions from shale gas of 3.6% to 7.9% (including distribution emissions which were not considered by Skone).

<table>
<thead>
<tr>
<th>EUR – Total lifetime production (bcf)</th>
<th>Methane emissions vented (mcf)</th>
<th>% of total production vented</th>
<th>% of total production vented adjusted to match EPA Emissions Inventory</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>68,917</td>
<td>2.30</td>
<td>3.31</td>
</tr>
<tr>
<td>2.5</td>
<td>64,853</td>
<td>2.59</td>
<td>3.74</td>
</tr>
<tr>
<td>2</td>
<td>60,790</td>
<td>3.04</td>
<td>4.38</td>
</tr>
<tr>
<td>1.5</td>
<td>56,726</td>
<td>3.78</td>
<td>5.45</td>
</tr>
<tr>
<td>1.24</td>
<td>54,613</td>
<td>4.40</td>
<td>6.35</td>
</tr>
<tr>
<td>1</td>
<td>52,662</td>
<td>5.27</td>
<td>7.59</td>
</tr>
<tr>
<td>0.84</td>
<td>51,362</td>
<td>6.11</td>
<td>8.80</td>
</tr>
</tbody>
</table>

Table 4. Fugitive methane emissions for the Barnett Shale using the parameters of Skone as a function of assumed lifetime production (EUR) of his average Barnett Shale well, illustrating the effect of the assumed EUR on the percentage of lifetime production vented as fugitive methane.
Figure 3. Fugitive methane emissions for the Barnett Shale as a function of estimated ultimate recovery (EUR). Represented are the estimates of Skone as presented for various EUR’s and as adjusted to match the EPA inventory of fugitive methane emissions for 2009. The 1.24 EUR estimate was used by Howarth et al. and the 0.84 EUR estimate is the latest determination by Berman for the average Barnett Shale well.\textsuperscript{20}

Thus the Skone presentation, as presented, understates the amount of fugitive methane emissions as a percentage of the total expected production from shale gas wells. When the details of the assumptions used are evaluated, however, and assessed in terms of the realities of what we know about the average EUR’s of Barnett Shale production and the overall methane emissions from gas production as documented by the EPA, the result is not significantly different than the conclusions of Howarth et al. Figure 4 illustrates the comparison of total greenhouse gas emissions between the two studies utilizing a 20-year timeframe with a GWP for methane of 105 times that of carbon dioxide.
Figure 4. Comparison of total shale gas GHG emissions of Howarth et al. to Barnett Shale emissions of Skone after adjustment to an EUR of 1.24 bcf, with and without an adjustment to match the EPA emissions inventory. This assumes a 20-year timeframe with a GWP for methane of 105. Note that the Howarth et al. estimates include distribution losses which the Skone estimates do not.

The Barnett Shale represents just one of many shale gas plays. As mentioned earlier, there is a lot to be desired in terms of good data on fugitive methane emissions, which are highly variable between plays. Skone assigned a uniform value to unconventional well completions and workovers for the Barnett Shale, and considered only the Barnett shale in analyzing shale gas. We know this is unlikely to be the case as the initial productivities of Barnett Shale wells are ten or more times that of the average productivity assumed by Skone, and initial productivities from other shale plays such as the Haynesville are much higher still. Hence emissions from shale gas well completions and early workovers are likely to be far higher than later ones as the bulk of the gas gets produced in the first few years due to steep decline rates. This reflects the need for better data, as the EPA has recognized and is pursuing. The bottom line from this analysis, however, is
that the Howarth et al. estimates of the percentage of fugitive methane emissions from shale gas wells are consistent with the evidence and consistent with the Skone presentation when adjusted for the EPA emissions inventory and corrected to match the likely average EUR of Barnett Shale gas wells.

**Implications of GWP on the Comparison of Shale Gas to Coal**

Methane is a potent greenhouse gas with a relatively short residency time in the atmosphere compared to carbon dioxide. The global warming potential (GWP) of methane according to the IPCC (2007) is 25 and 72 times that of carbon dioxide over 100- and 20-year timeframes, respectively. These GWP estimates have been recently revised by Shindell et al. (2009) to 33 and 105 times that of carbon dioxide over 100- and 20-year timeframes, respectively. Howarth et al. point out that, as natural gas is being promoted as a low-GHG-impact “transition” fuel by natural gas proponents, including some environmental groups, the short-term impact of conversion to natural gas on GHG emissions is crucial. If short-term emissions from shale gas (the major hope in increasing U.S. supply) in fact make emissions worse over the next two or three decades, a significant increase in shale gas production would be counterproductive to nationwide efforts to reduce GHG emissions.

Figure 5 from Hughes (2011) illustrates the effect of GWP assumptions on the comparison of coal to shale gas and conventional gas using the estimates of Howarth et al. Shale gas estimates of GHG emissions over a 20-year timeframe, whether viewed using either IPCC or Shindell et al. estimates of GWP, exceed those of surface- or underground-mined coal. Over a 100-year timeframe, however, coal exceeds, or, in the case of the highest estimate, roughly equals the emissions from shale gas.

The debate over whether to use a 20- or 100-year timeframe – and which source of GWP factors should be applied to determine the GHG impact of methane – is highly polarized, with natural gas proponents generally denouncing both the use of a 20-year timeframe and the use of the higher GWP values of Shindell et al. Hughes (2011) also makes the point that regardless of the purported GHG benefits (or lack thereof) of shale gas going forward, the major issues are the ability of shale gas to meet the growth hype of natural gas proponents and mitigate the environmental impacts of meeting these exuberant growth forecasts. No one seriously suggests that natural gas will not be an important component of the U.S. energy mix going forward.
Comparison of Coal- and Gas-Fired Electricity Generation Emissions

Another criticism levelled at the Howarth et al. paper is that it did not explicitly compare emissions from coal- and gas-fired electricity generation on a per kilowatt-hour basis. Although only 30% of domestic natural gas consumption was used to generate electricity in 2009, electricity generation accounted for 93% of coal use. At the burner tip, natural gas produces 44% less CO₂ per unit of heat than coal. Furthermore, natural gas-fired generation is more efficient than coal. The existing coal-fired electricity generation fleet in the U.S. has an average heat rate of 10,414 BTU/kWh, which translates to an efficiency of 32.8%, whereas the existing gas-fired electricity generation fleet has an average heat rate of 8,157 BTU/kWh, which translates to an efficiency of 41.8%. Skone used a higher average efficiency of gas-fired electricity generation
of 47.1% by excluding plants with a capacity factor of less than 40%; this excludes a large part of the U.S. natural gas generation fleet including the lower-efficiency combustion turbines, which are commonly used for peaking capacity.

Obviously, if new gas- or coal-fired capacity is built, the most efficient technologies would likely be utilized. For gas this is combined-cycle with a heat rate of 6,800 BTU/kWh, \(^{31}\) which translates to an efficiency of 50.2%, and for coal this is ultrasupercritical pulverized coal with a heat rate of 7,880 BTU/kWh, which translates to an efficiency of 43.3%.\(^{32}\)

Hughes (2011) compared the mean emission estimates of Howarth et al. for shale gas to coal on a per kilowatt-hour basis for both the existing fleets and for the most efficient technologies over a range of GWP factors as illustrated in Figure 6.\(^{33}\) Hughes used the surface-mined coal estimate of Howarth et al. in this comparison as it is the most common fuel source, the low sulphur coal of areas such as the Powder River Basin being preferred to the high sulphur, underground-mined, Illinois coal incorporated in the Skone presentation (which often exceed regulatory sulphur levels and hence cannot be used for thermal power generation).

This analysis indicates that on a 20-year timeframe, the existing U.S. gas fleet emissions exceed the existing U.S. coal fleet emissions by 9% to 27%, depending on whether the IPCC or Shindell et al. estimates of GWP are used. On a 20-year timeframe, the most efficient gas technology emissions exceed the most efficient coal technology emissions by 17% to 34%, depending on whether the IPCC or Shindell et al. estimates of GWP are used.

On a 100-year timeframe basis, however, the existing U.S. coal fleet emissions exceed the existing U.S. gas fleet emissions by 46% to 33%, depending on whether the IPCC or Shindell et al. estimates of GWP are used. On a 100-year timeframe, the most efficient coal technology emissions exceed the most efficient gas technology emissions by 32% to 20%, depending on whether the IPCC or Shindell et al. estimates of GWP are used.

Hughes (2010) also looked at the effect of improving fugitive methane capture by 40% on upstream gas operations, as the Government Accounting Office (GAO) suggests is possible\(^ {34}\). This decreases the comparative emissions of gas versus coal but gas still exceeds or is equivalent to coal, depending on the GWP factor used, on a 20-year timeframe.
Conclusions

An analysis of fugitive methane emissions presented by Skone reveals that they are likely understated, as they are 31% lower than those reported by the EPA inventory of emissions from natural gas for 2009. A further analysis of the impact of the assumed EUR for the Barnett Shale used by Skone on the percentage of fugitive methane emissions over production lifetime reveals that it is likely overstated, at 3 bcf, compared to other recent analyses that suggest the EUR’s are likely to be much lower. This further raises the percentage of fugitive emissions in the Skone presentation. It should be pointed out that it is still early in determining how the EUR’s of many shale plays will turn out, but the Barnett Shale is the most mature play at this point.
Correcting the emissions estimates of Skone to match the EPA Inventory data, and adjusting for the likely average EUR in the Barnett Shale, reveals that they are comparable to the Howarth et al. estimates. On an overall basis, recognizing that 70% of natural gas is currently used for non-electric applications, shale gas has higher emissions than coal on a 20-year basis and equal or lower emissions on a 100-year basis.

On a comparison of coal and gas on an emissions per kilowatt-hour basis, Skone bases his comparison on a gas base load basis only, whereas the U.S. gas-fired fleet is also widely utilized for peak load (typically utilizing lower efficiency combustion turbines which, when included, reduce the average efficiency of the U.S. gas fleet to 41.8% from the 47.1% used by Skone). Skone does not consider the argument that a comparison of future options for both gas- and coal-fired electricity generation should be based on the most efficient technology available for each fuel.

When compared on the basis of the average efficiency of the U.S. gas- and coal-fired electricity generation fleets, and on the basis of most-efficient-technology gas and coal, shale gas clearly has higher emissions over a 20-year timeframe and lower emissions over a 100-year timeframe. Regardless of which GWP is used, coal likely has a lower greenhouse gas impact than shale gas out to 30-40 years for the existing fleet, and 40-50 years comparing the most efficient technologies for coal- and gas-fired generation.

One thing is certain: Both coal and gas will continue, of necessity, to be important contributors to electricity generation in the U.S. Natural gas also has important and irreplaceable uses in the industrial, commercial, and residential sectors that coal does not. From a GHG emissions policy perspective, the comparison of coal to gas over the next two or three decades is important, but it should really be only one of several considerations. The overall issue of gas supply growth, which is forecast by the EIA to come largely from shale gas, comes with other environmental penalties, as does the production and use of coal. A further consideration of these issues can be found in Hughes (2011).37
Endnotes


8 Email from Timothy Skone to Robert W. Howarth dated May 26, 2011.


12 Ibid.


16 Ibid.


20 Ibid.


Intergovernmental Panel on Climate Change, (Cambridge, UK:, Cambridge University Press, 2007) see Chapter 2, page 212.


