Fugitive Methane and Greenhouse Warming

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Natural gas has some very bad greenhouse gas properties and some very good ones. Which dominate depends on the numbers, so let's look at them.

Methane is bad

The dominant component in natural gas is methane, CH_4, typically 85% of the gas. Methane is a potent greenhouse gas: pound for pound it traps about 85 times more heat radiation than does carbon dioxide.[1] In the jargon of the field, we say methane's global warming potential GWP is 85. This dramatic effect is offset, however, by the relatively short lifetime of methane in the atmosphere. Whereas carbon dioxide remains in the atmosphere for many decades, until finally dissolved into the oceans or absorbed into soil and rock, methane is destroyed by solar radiation, resulting in a lifetime of about 12 years.[2] That means that only the recently released methane is important in global warming calculations. When this is taken into account the net effect is that methane is about 30 times more potent than is carbon dioxide in producing long-term greenhouse warming, that is, its long-term GWP is 30. This number is still not certain; the EPA[3] recently used the value of 21.

Methane is good

Despite this high greenhouse potential, methane has a natural advantage over coal. When burned to produce electricity, it produces only one third to one half as much carbon dioxide compared to that produced burning coal. This reduction is responsible for much of the decrease in the U.S. greenhouse gas emissions that have taken place in recent years.

The lower greenhouse gas emission of natural gas compared to coal comes from two effects. When methane burns, $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$, about half of the energy comes from the burning of the hydrogen,[4] and that produces no CO_2. (Even though H_2O is also a greenhouse gas, the produced water does not contribute to greenhouse warming.[5]) The second effect comes from the nature of modern electrical generator technology. The most efficient combined cycle natural gas power plants can turn about 60% of the produced thermal energy into electricity; the most efficient supercritical combustion coal plants operate at 43% efficiency.[6] So for the same thermal energy, the natural gas plant produces 60/43 = 1.40 times as much electricity. Include the factor of 2 from the heating values, and the net result is that for the same electricity produced, burned carbon produces 2.8 times more carbon dioxide than does burned methane. Actual coal will contain some hydrocarbons, and methane will contain some heavier molecules, so this number can be lower. It can also be higher if an older and inefficient coal plant is replaced by a high-efficiency natural gas one. We will call this number E and use the value E = 2.8 in many of our calculation, but we will leave it as a parameter in the formulas we give so you can use whatever value you wish.

Fugitive Methane Greenhouse Effect

"Fugitive methane" is the colorful word adopted by the energy community for methane that escapes, some at the wellhead (particularly if vented rather than flared), some in the pipeline, some when it is used. Several recent papers have suggested that 6% to 8% of the methane produced in natural gas wells is fugitive, but those numbers are now being hotly debated. A recent EPA report concludes that only 1.7% of the methane escapes. [7]

The high global warming potential of methane, 30, leads many people to conclude (incorrectly[8]) that if even if only 1/30 = 3% of the methane leaks, the net effect of using methane for a fuel will negate its value over coal. If more leaks, then it is worse than coal. In fact, these incorrect conclusions are based on a simple mistake. The break-even number turns out to be 14%. How can that be?

The mistake is in using the wrong version of the GWP. The standard value is given in units of kilograms – but one kilogram of methane with burned (combined with oxygen) does not produce one kilogram of carbon dioxide; it produces 2.75 kilogram of CO_2. That's because the added oxygen is heavy.[9]

Burn a kilogram of methane and you get 2.75 kg of CO_2.
Release a kilogram of methane and you get 1 kg of methane.
The global warming effect of 2.75 kg of CO2, in the GWP scale, is 2.75.
The global warming effect of 1 kg of CH_4, in the GWP scale, is 30.
So releasing the methane is 30/2.75 = 11 times worse than burning it, from a global warming point of view.

Pound per pound, methane is 30 times worse. Molecule per molecule, it is 11 times worse. You must use the right value; confusing them leads to ridiculous results, just as if you were confusing Fahrenheit and Celsius.

Now let's talk about leaked methane. If one molecule leaks, it is not burned. Its effect in greenhouse warming is 11 times worse than if it burned. The important result is that it is not 30 times worse, but 11 times worse.

We can now calculate how much methane has to leak (not be burned) for the net process to have a greenhouse effect equal to that of coal (for the same energy produced). The formula derived in the footnote[10] is

$$f_C = \frac{E-1}{E-1+G/2.75}$$

where f_C is the fraction of methane that must leak for the use of methane to have no benefit compared to coal, E is the energy efficiency of a methane power plant compared to that of coal, and G is the greenhouse potential of methane per unit weight. If we take E = 2.8, G = 30, we get f_L = 14%. Thus, for the standard parameters we discussed above, if less than 14% of the methane leaks, the burning of methane produces less of a greenhouse gas than does coal.

Suppose instead of long-term greenhouse warming, we were concerned with the short-term effect over the next few years. Then it would be appropriate to use the long term value G = 85, and we get f_C = 5.5%.

Suppose we use the value used by the EPA, GWP = 21. Then the formula gives f_C = 19%.

The value in these equations is not in their precision but in their simplicity. They do not take into account the fact that natural gas is not pure methane, and coal is not pure carbon. As a result, the energy efficiency of power plants may not be E = 2.8 times better for natural gas than for coal, but only 2.0. Using this value for E and G = 30, gives f_C = 8.4%. If the new methane plant is replacing an old, inefficient plant, then the improvement factor E could be substantially higher than 2.8.

Benefit Calculation

The greenhouse warming benefit of burning methane rather than coal depends on the fugitive fraction f. The formula derived in the footnote[11] gives the benefit B to be

$$B = \frac{E(1-f)}{1-f+fG/2.75}$$

Note that if the fugitive fraction is 0, then B = E.

According to a recent EPA report, methane emissions in the US have been decreasing. When calculated as a ratio of the methane consumed, the leakage rate turns out to be about 1.65%.[12] For this value, with G = 30 and E = 2.8, we get B = 2.4. If we use G = 30 and E = 2.0, we get B = 1.7. If these numbers are correct, then installing a natural gas plant rather than a coal plant can cut the added greenhouse warming by a factor of 1.7. If you are replacing an old coal plant with a new natural gas plant, then the energy factor E can be larger than 2.8, and the benefit greater.

Conclusion

A switch from coal to natural gas, even if substantial amounts of the gas leak (even above 10%), still offers to slow the long-term greenhouse warming by a factor of order 2. Of course, even greater benefit occurs if the leakage is lower.

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[1] In the 2007 report of the Intergovernmental Panel on Climate Change, the value is given as about 70. However, in drafts of the upcoming report (AR5), the value is closer to 85.

[2] This is the value used by the IGPP in AR5; the value used by the EPA can be found at http://epa.gov/climatechange/ghgemissions/gases/ch4.html

[3] Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2011 (2013), report # EPA 430-R-13-001, www.epa.gov/climatechange/emissions/usinventoryreport.html.

[4] The factor of 2 can be calculated as follows: The "lower" heating values (assuming no energy recovered from condensing the water vapor produced) for methane and carbon are respectively 21433 and 14150 Btu/lb. Reference: www.engineeringtoolbox.com/heating-values-fuel-gases-d_823.html. The weight of methane is 16/12 that of carbon. So net ratio is lower heating value per mole $CH_4/C = 21433/14150 \times 16/12 = 2.0$. This number can be made larger by condensing the water vapor.

[5] The water vapor does not significantly increase the greenhouse effect of the atmosphere, since it is negligible compared to the natural water available from rivers and oceans.

[6] www.worldcoal.org/coal-the-environment/coal-use-the-environment/improving-efficiencies/; Rao, Vikram, *Shale Gas, The Promise and the Peril*, p. 52 (RTI Press International, Research Triangle N.C., 2012).

[7] See the memo by Zeke Hausfather and Richard Muller, online at www.BerkeleyEarth.org.

[8] I made this mistake myself, until Zeke Hausfather pointed out my error. Thanks, Zeke.

[9] The atomic weight of methane, CH_4, is 12 + 4 = 16. The atomic weight of CO_2 is 12 + 2x16 = 44. So 16 grams of methane (one mole) when completely burned produces 44 grams of carbon dioxide (one "gram molecular weight" or *mole*).

[10] The net global warming potential from using methane is $(1\text{-}f) + f\,(G/2.75)$, where the first term comes from the burned methane (which produces CO_2) and the second term comes from the escaped methane. For an equal energy produced by carbon, the number of molecules of CO_2 produced is $(1\text{-}f)\,E$. If we set the global warming potentials equal for methane and carbon, we get

$$(1\text{-}f) + \mathrm{f}\,(G/2.75) = (1\text{-}f)\,E$$

Solving for f gives the equation in the text.

[11] Take the global warming potentials for methane and carbon from the previous footnote. The benefit is their ratio: $B = [(1\text{-}f)\,E] \,/\, [\,(1\text{-}f) + \mathrm{f}\,(G/2.75)\,]$.

[12] See the memo by Zeke Hausfather and Richard Muller, online at www.BerkeleyEarth.org.