



## Assessment of the Greenhouse Gas Footprint of Natural Gas from Shale Formations Obtained by High-Volume, Slick-Water Hydraulic Fracturing

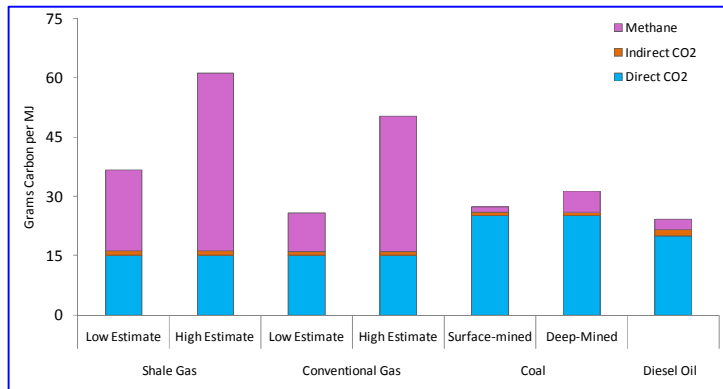
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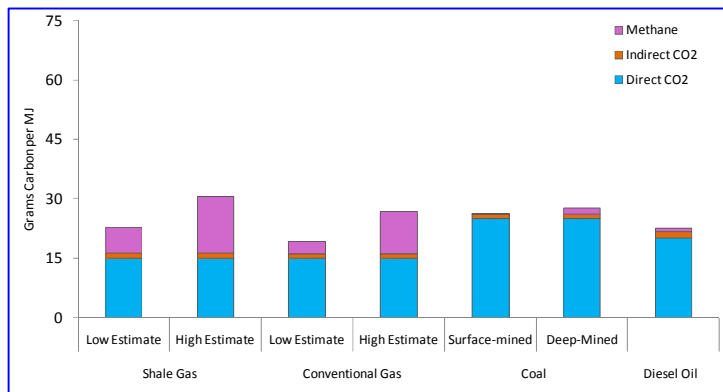
*(Revised January 26, 2011)*

Natural gas is widely advertised and promoted as a clean burning fuel that produces less greenhouse gas emissions than coal when burned. While it is true that less carbon dioxide is emitted from burning natural gas than from burning coal per unit of energy generated, the combustion emissions are only part of story and the comparison is quite misleading. With funding from the Park Foundation, my colleagues Renee

### A. 20-year time frame



### B. 100-year time frame



Top panel is 20-year time frame, and bottom panel is 100-year time frame. Estimates include direct emissions of CO<sub>2</sub> during combustion (blue bars), indirect emissions of CO<sub>2</sub> necessary to develop and use the energy source (red bars), and fugitive emissions of methane, converted to equivalent value of CO<sub>2</sub> for global warming potential (pink bars).

Santoro, Tony Ingraffea, and I have assessed the likely footprint from natural gas in comparison to coal. We submitted a draft of our work to a peer-reviewed journal in November, and now have a revised manuscript under consideration by the journal. The revision is improved with input from reviewers and also uses new information from a November 2010 report from the EPA. The EPA report is the first significant update by the agency on natural gas emission factors since 1996, and concludes that emissions – particularly for shale gas – are larger than previously believed. Our research further supports this conclusion.

A summary figure from our revised submission is shown here. The figure compares shale gas with two estimates of methane emissions to the atmosphere (low and high, two bars to the left), conventional natural gas with two estimates of methane emissions (high and low estimates, next two bars), coal from surface mines (3<sup>rd</sup> bar from right), coal from deep mines (2<sup>nd</sup> bar from right) and diesel oil. Please note this should be treated tentatively, as

further changes or refinements in response to reviewer comments are possible. We nonetheless post the update now due to the tremendous interest in the topic, and its importance in deciding the wisdom of viewing natural gas as a transitional fuel over the coming decades.

Natural gas is composed largely of methane, and 3.6% to 7.9% of the methane from shale-gas production escapes to the atmosphere in venting and leaks. This is 1.3- to 2.1-times greater methane emissions than from conventional gas. The higher emissions from shale gas occur at the time wells are hydraulically fractured -- as methane escapes from flow-back return fluids -- and during drill out following the fracturing. Methane is a powerful greenhouse gas, with a global warming potential that is far greater than that of carbon dioxide, particularly over time periods of a couple of decades following emission. Methane contributes substantially to the greenhouse gas footprint of shale gas on shorter time scales, dominating it on a 20-year time frame. The footprint for shale gas is greater than that for conventional gas or oil when viewed on any time frame, but particularly so over 20 years. Compared to coal, the footprint of shale gas is 1.2- to 2.1-fold greater on the 20-year time frame and is comparable when compared over 100-years.

We urge caution in viewing natural gas as good fuel choice for the future. Note that both the National Academy of Sciences and the Council of Scientific Society Presidents have urged great caution before proceeding with the development of diffuse natural gas from shale formations using unconventional technology. See:

National Research Council (2009). Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use. National Academy of Sciences Press.

Letter to President Obama and senior administration officials, May 4, 2009, from the Council of Scientific Society Presidents.

<http://www.eeb.cornell.edu/howarth/CCSP%20letter%20on%20energy%20&%20environment.pdf>

EPA (2010). Greenhouse Gas Emissions Reporting from the Petroleum and Natural Gas Industry. Background Technical Support Document.

[http://www.epa.gov/climatechange/emissions/downloads10/Subpart-W\\_TSD.pdf](http://www.epa.gov/climatechange/emissions/downloads10/Subpart-W_TSD.pdf)