Box S-1 | **Key Findings from the Working Paper**

1. Fugitive methane emissions from natural gas systems represent a significant source of global warming pollution in the U.S. Reductions in methane emissions are urgently needed as part of the broader effort to slow the rate of global temperature rise.

2. Cutting methane leakage rates from natural gas systems to less than 1 percent of total production would ensure that the climate impacts of natural gas are lower than coal or diesel fuel over any time horizon. This goal can be achieved by reducing emissions by one-half to two-thirds below current levels through the widespread use of proven, cost-effective technologies.

3. Fugitive methane emissions occur at every stage of the natural gas life cycle; however, the total amount of leakage is unclear. More comprehensive and current direct emissions measurements are needed from this regionally diverse and rapidly expanding energy sector.

4. Recent standards from the Environmental Protection Agency (EPA) will substantially reduce leakage from natural gas systems, but to help slow the rate of global warming and improve air quality, further action by states and EPA should directly address fugitive methane from new and existing wells and equipment.

5. Federal rules building on existing Clean Air Act (CAA) authorities could provide an appropriate framework for reducing upstream methane emissions. This approach accounts for input by affected industries, while allowing flexibility for states to implement rules according to unique local circumstances.

While a shift in electric generation to natural gas from coal has played a significant role in recent reductions in U.S. carbon dioxide ($CO_2$) emissions, more will need to be done for the U.S. to meet its goal of reducing GHG emissions by 17 percent below 2005 levels by 2020. A related WRI report found that cost-effective cuts in methane leakage from natural gas systems are among the most important steps the U.S. can take toward meeting that goal.[1] To achieve climate stabilization in the longer term, policies are needed to address combustion emissions through carbon capture and storage or by other means.

In addition to methane emissions, natural gas sector operations and infrastructure represent a significant source of $CO_2$; volatile organic compounds (VOCs), which are chemicals that contribute to ground-level ozone and smog; and hazardous air pollutants (HAPs). In 2012, EPA finalized air pollution standards for VOCs and HAPs from the oil and natural gas sector. These rules will improve air quality and have the co-benefit of reducing methane emissions. As discussed below, these standards can be complemented by additional actions to further reduce methane emissions, which will help to slow the rate of global temperature rise in the coming decades.

Fortunately, most strategies for reducing venting and leaks from U.S. natural gas systems are cost-effective, with payback periods of three years or less. The case for policy action is particularly strong considering that recent research shows that climate change is happening faster than expected. In addition, the projected expansion in domestic oil and natural gas production increases the risk of higher emissions if proper protections are not in place.

Box S-2 | **The Scope of this Study**

This study focuses primarily on evaluating and reducing upstream methane emissions in the natural gas sector. This has two important implications. First, this paper in no way aims to diminish the urgent need to achieve GHG emissions reductions from other segments of the economy. For example, significant cost-effective opportunities also exist to reduce carbon dioxide emissions from both upstream and downstream stages of the natural gas life cycle, and to reduce methane emissions from coal mines, landfills, and other sources. Longer term, addressing combustion emissions will be increasingly important, whether through carbon capture and storage or by other means. Second, this paper does not address other aspects of natural gas development that pose significant risks for public health and the environment, including potential effects on drinking water and other community impacts. We focus on actions to reduce methane emissions, and generally do not consider additional policies that may be necessary to protect the public interest from these other risks. The one exception is that toxic and VOC emissions are frequently discussed—because the technologies and practices that effectively reduce those emissions typically also achieve reductions in methane emissions.

## LIFE CYCLE ASSESSMENTS

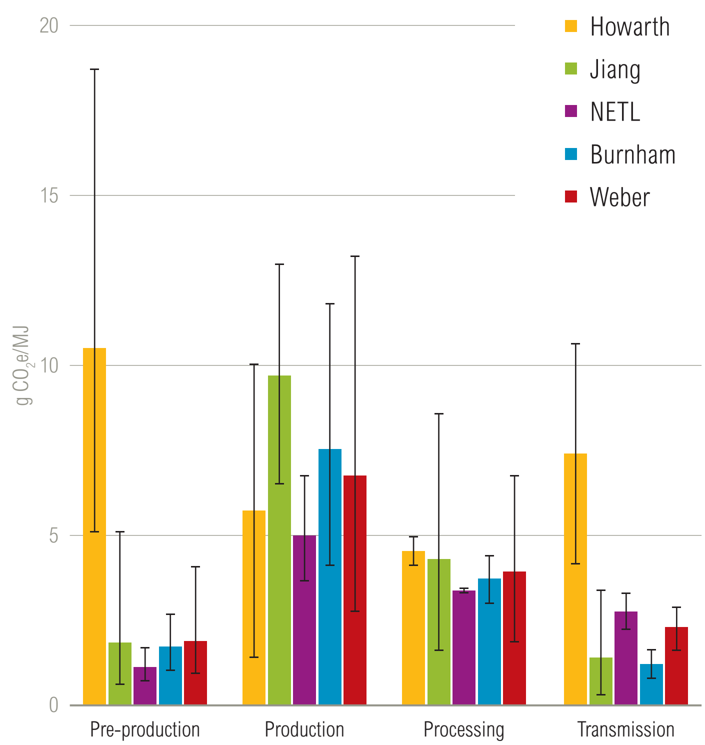
While natural gas emits about half as much carbon dioxide as coal at the point of combustion, the picture is more complicated from a life cycle perspective. There is considerable uncertainty about the scale of upstream methane emissions from natural gas systems due to variations between production basins and a scarcity of recent, direct emissions measurements from several key processes. Ultimately, the question of whether or not gas has a lower climate impact than coal depends on the life cycle methane leakage rates, plus other factors that include subjective policy considerations. Section 2 includes more extensive discussion of this and related questions.

Most life cycle studies agree, based primarily on data from EPA's U.S. GHG Inventory, that carbon dioxide ($CO_2$) emissions from end-use combustion of natural gas represents roughly 70 to 80 percent of total life cycle GHG emissions.[2] Most studies also agree that upstream GHG emissions associated with shale gas and conventional gas production are roughly comparable to one another, within the margin of error. EPA's GHG inventory data imply a methane leakage rate of less than 3 percent of total natural gas production.[3] At this leakage rate, natural gas produces fewer GHG emissions than coal over any time horizon and regardless of how the fuels are used. Additionally, according to a 2012 study published in the Proceedings of the National Academy of Sciences, reducing the methane leakage rate to below 1 percent would ensure that heavy-duty vehicles, like buses and long-haul trucks, fueled by natural gas would have an immediate climate benefit over similar vehicles fueled by diesel. Thus, reducing total methane leakage to less than 1 percent of natural gas production is a sensible performance goal for the sector to achieve.

Accurate life cycle emissions estimates from the natural gas sector require reliable data for a broad range of industry activities and emissions factors associated with those activities. Regarding the quality of available data, there are uncertainties at all life cycle stages. With the exception of one study published by researchers at Cornell University, findings from life cycle assessments of methane emissions from unconventional wells have varied the most on production stage emissions (see Figure S-1). This is because of differing assumptions regarding how frequently the average well requires hydraulic fracturing and liquids unloading[4], and the extent to which control technologies are used when these activities are performed. Hydraulic fracturing is often an emissions-intensive process used to initiate production at both conventional and unconventional wells (i.e., "well completions"; Figure S-2). It may be repeated to re-stimulate production multiple times over a well's estimated 20-to-30-year lifetime (during "workovers"; Figure S-2). Liquids unloading is a practice used to clean up all types of onshore wells, removing liquids to increase the flow of gas, and potentially causing significant emissions.

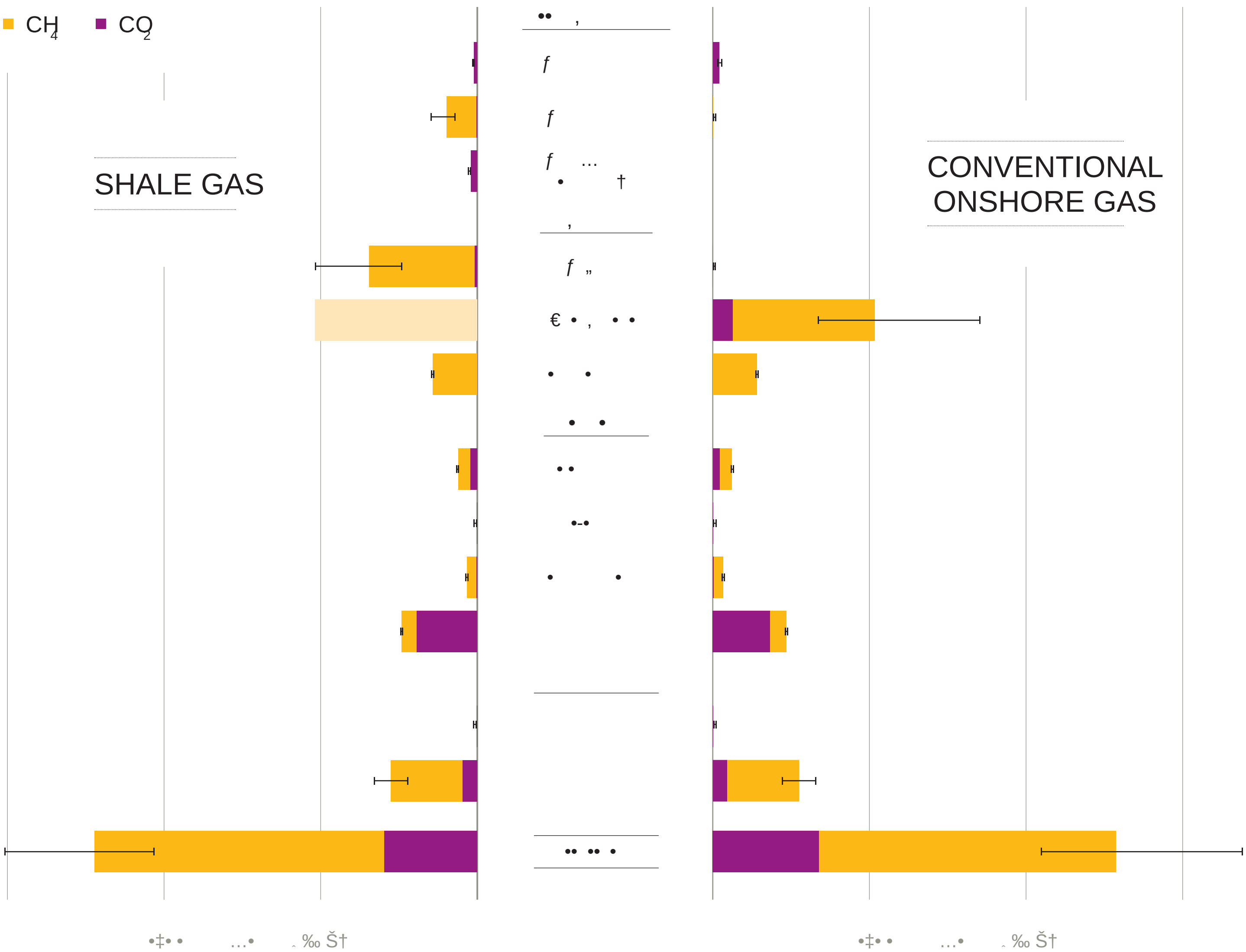
Since 2009, EPA's annual GHG inventory has dramatically adjusted their emissions factors associated with these production-stage activities. In EPA's draft 2013 GHG inventory, there is a 90 percent reduction in their estimates of emissions associated with liquids unloading in response to self-reported industry data showing that unloading events are less emissions-intensive than previously thought; that is, industry reported more frequent use of control technologies than EPA had assumed in earlier inventories.

Figure S-1 | **Upstream GHG Emissions from Shale Gas, by Life Cycle Stage**




*Sources:* All data presented in this figure are derived from the referenced studies, with only unit conversions and minor adjustments for heating rates. See Figure 4 for complete study references and more detailed discussion.

Figure S-2 | Comparing Detailed Estimates of Life Cycle GHG Emissions from Shale Gas and Conventional Onshore Natural Gas Sources




* Data available from Marcellus only
** “Other Production” and “Other Processing” each include point source and fugitive emissions (mostly from valves)
*** Includes all combustion and fugitive emissions throughout the entire transmission system (mostly from compressor stations)

*Notes:* Recent evidence suggests that liquids unloading is a common practice for both shale and onshore conventional gas wells (Shires and Lev-On 2012). Therefore, contrary to data published by NETL, showing zero emissions, liquids unloading during shale gas development result in GHG emissions that are comparable to those associated with conventional onshore gas development. GWP for methane is 25 over a 100-year time frame.
*Source:* National Energy Technology Laboratory.

Meanwhile, recent research based on field measurements of ambient air near natural gas well-fields in Colorado and Utah suggest that more than 4 percent of well production may be leaking into the atmosphere at some production-stage operations.[5] With hundreds of thousands of wells and thousands of natural gas producers operating in the U.S., this will likely remain an active debate, even as forthcoming data from EPA and other sources aims to clarify these questions in the coming months. For example, independent researchers at the University of Texas at Austin are teaming up with the Environmental Defense Fund and several industry partners to directly measure methane emissions from several key sources. When results are published in 2013 and 2014, these data will provide valuable points of reference to help inform this important discussion.