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FAQ About the Heavy Duty Vehicle Methane Emissions Report

1. What is radiative forcing?

Radiative forcing is a concept widely used to describe and quantify the contribution of greenhouse gases (GHGs) to global temperatures. It is the primary index used to track climate change. In effect, increased GHGs in the atmosphere “force” changes in the Earth’s temperature by modifying the balance between incoming and outgoing heat energy, formally called thermal radiation. Because GHGs absorb some of the Earth’s outgoing radiation and prevent it from being released back into space, they produce a net warming effect. Radiative forcing can thus be used as a measure of how much a given activity that produces GHGs affects the climate; it is measured in units of Watts per square meter (W m-2). A more detailed, yet accessible explanation of radiative forcing is provided in Chapter 1 of the National Academy of Sciences’ 2005 report “Radiative Forcing of Climate Change.”

2. What is Global Warming Potential (GWP)?

GWP is used to compare the cumulative radiative forcing of different greenhouse gases (GHGs), relative to CO2, over a specific time period (usually 20 or 100 years). GWPs account for differing attributes of GHGs: capacity to absorb heat energy, atmospheric lifetime and any indirect effects on other radiatively active molecules or compounds (like methane’s contribution to tropospheric ozone and stratospheric water). The larger the GWP, the larger the influence of a unit emission of a GHG on global temperatures. The GWPs for methane are 28 and 84 for 100-year and 20-year time horizons, respectively.

3. What advantages do Technology Warming Potentials (TWPs) have relative to GWPs?

TWPs were proposed by Alvarez et al. in their 2012 paper on methane leakage in the Proceedings of the National Academy of Science as an alternative to conventional GWP analyses to better explain the time-dependent radiative forcing (or climate influence) of different fuel-technology options. While GWPs have been a valuable tool to compare the radiative forcing of individual gases over set time horizons, they are not sufficient when thinking about common fuel switching scenarios that involve multiple GHGs with distinct atmospheric lifetimes. For example, the methane lost during the production and delivery of natural gas diminishes the CO2 benefits of using natural gas as a fuel.

A second limitation of GWP-based comparisons is that they only consider the radiative forcing of single emission pulses, which do not reflect the climatic consequences of real-world investment and policy decisions: these are better simulated as emission streams over multiple years. For example, while an emission pulse can reasonably represent the effect of renting a natural gas car for one day; converting a corporate fleet of trucks from diesel to compressed natural gas (CNG) is better represented by a multi-year stream of emissions.

TWPs use the well-established science of radiative forcing used to calculate GWP, but they package the results in a more transparent way. TWPs plot the relative radiative forcing between two options as a function of time to reveal time-dependent climate benefits or damages of policy choices and/or investment decisions. They also allow us to calculate the number of years required before a fuel technology choice begins to produce benefits for the climate, an approach that can be used to define the conditions under which a policy choice produces climate benefits on all time frames.

4. How are CO_2 and methane different for global climate?

CO2 is the principal GHG and must be significantly reduced to achieve climate stabilization goals. However, methane (CH4) is an important gas because of its potency and the opportunity it affords for short-term mitigation of climate impacts. Each pound of methane emitted initially produces around 120 times more radiative forcing than CO2, but methane is removed much more rapidly from the atmosphere than CO2. The GWPs for methane are 28 and 84 for 100-year and 20-year time horizons, respectively. The larger value for 20 years reflects the shorter timeframe during which methane emissions remain in the atmosphere. Methane emissions also contribute to global background levels of tropospheric ozone, which is a GHG and harmful to human health and ecosystems.

5. If methane's effective lifetime is only 12 years, why is it common to use a 100-year time horizon for its GWP?

First, the lifetime does not mean the time after which all of the methane is gone; the lifetime is the time constant of an exponential decay after which 63% of the initial amount is removed. Second, the GWP is a measure of cumulative radiative forcing; even though 98% of a pulse of methane is gone after four lifetimes (50 years), the accumulated radiative forcing in the early years is still contributing to the cumulative total.

6. Your paper emphasizes the importance of timeframes. What timeframe is most important when talking about climate change?

All timeframes are important. Even though the permanent, long-term solution to climate change involves stabilizing CO2 emissions, the shorter time frames affected by methane emissions are also important because they increase the risk of undesirable climate outcomes in the near future. For example, accelerated rates of warming mean ecosystems and humans have less time to adapt to climate change. Given the dire need for concerted global action on climate change, current energy policy should, at a minimum, abide by a “Do No Harm” policy: no policy should contribute to increased radiative forcing on any time frame.

7. Why are the Technology Warming Potential (TWP) curves shaped the way they are?

The shape of the TWP curves results from the counterbalancing effects of methane’s (CH4) large radiative forcing and its short atmospheric lifetime relative to carbon dioxide (CO2). In early years, the influence of the well-to-wheels CH4 emissions in the natural gas fuel cycle outweighs the lower CO2 from natural gas fuel use. Over longer time frames, the effect of fresh CH4 emissions is outweighed by the forcing due to accumulated CO2 from prior years (because atmospheric CH4 concentrations from continued fleet operation reach a steady state, whereas CO2 concentrations continue to accumulate in a roughly linear fashion). The TWP approach was proposed to draw attention to this time-dependent behavior.

8. How do emissions occur in the natural gas industry?

Leaks and routine venting during the extraction, processing, and transportation of natural gas result in emissions of greenhouse gases and, depending on the local composition of unprocessed gas, other pollutants that contribute to locally- and regionally-elevated air pollution that can threaten public health. There are numerous individual components used throughout natural gas systems that are prone to leaks. These components include pumps, flanges, valves, gauges, pipe connectors, compressors, and tanks among others.

Moreover, routine wear, rust and corrosion, improper installation or maintenance, or overpressure of the gases or liquids in the piping can cause leaks. In addition to unintentional leaks, a number of sources intentionally vent gas. Gas is often vented during well completions or when liquids are unloaded from wells, by design from pneumatic valves, and from oil and condensate storage tanks. Pneumatic valves, which are used throughout natural gas systems, operate on pressurized natural gas and can bleed small quantities of natural gas during normal operation. Emissions also occur in various ways from vehicles: as unburned fuel in tailpipe exhaust, from the engine, and from the fuel tank and other fuel system components.

9. What are “well-to-pump”, “in-use”, and “well-to-wheels”? Why is this important?

“Well-to-wheels” refers to the entire fuel cycle for a transportation fuel. It includes all of the activities that take place before the fuel is used in a vehicle, such as producing, processing and transporting the fuel to the end user (“well-to-pump”), plus any emissions that occur from refueling and from the use of the fuel at the vehicle level (“in-use” or “pump-to-wheels”). These distinctions are important in the case of natural gas because there is very little data about the amount of methane emissions from in-use vehicles, and what little does exist suggests that it adds a measurable amount.

As part of the series of 16 methane field studies currently underway to update estimates of emissions across the U.S. natural gas system, West Virginia University is leading the “Pump-to-Wheels” study which aims to gather precisely this sort of data: methane emissions associated with natural gas vehicles and fueling stations.

10. What data sources did you rely on?

We examined multiple data sources, but relied heavily on the following in particular: first, we use the U.S. Department of Energy Argonne National Laboratory’s Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) vehicle fuel cycle model (version GREET 1 2013) to generate most of our emissions factors. Second, we used the U.S. Environmental Protection Agency’s Greenhouse Gas Inventory (2014) and engine certification database (2012 and 2014) for data on current loss rates and fuel efficiency respectively. Other sources include the U.S. Department of Energy’s Energy Information Administration and multiple peer-reviewed articles.

11. What are the natural gas engine types you examined and why did you choose those?

We evaluate two engine types commonly used in the heavy-duty trucking sector: the spark ignition (SI) engine and the high pressure direct injection (HPDI) engine. More specifically, we examine an 11.9 Liter SI running on both compressed natural gas (CNG) and liquefied natural gas (LNG) fuel and a 15 Liter HPDI which runs on LNG – all compared to their respective diesel counterparts. We also examine an 8.9 Liter SI engine (both CNG and LNG) in our Supporting Information. These engines have varying levels of fuel efficiency and emissions associated with their use – we wanted to include a range of types of engines in order to provide a more complete picture of the potential climate impacts of a switch towards natural gas across the trucking sector, including for current technology as well as what the industry standard might be in the future.

12. What is an “efficiency penalty”?

We define efficiency penalty as the difference in fuel efficiency, in miles per gallon of diesel equivalent, between natural gas and diesel engines. Diesel engines achieve higher fuel efficiencies than natural gas engines, which is one of the primary factors contributing to making diesel engines the industry standard in heavy-duty commercial trucking. We examine a range of engine types which we feel encompass the range of efficiency options currently or soon to be available in the market. In our reference case, we find efficiency penalties of 13% for both the CNG and LNG SI 11.9 liter engines and 5.5% for the 15 liter LNG HPDI natural gas engine as compared to their respective diesel counterparts (additionally, in our sensitivity cases we examine the impact of a range of efficiency penalty values between 0 and 20%).

13. Isn’t natural gas a cleaner fuel in terms of local air pollution?

Yes. Natural gas used to fuel power plants and vehicles instead of coal or petroleum-based fuels produces lower exhaust emissions of almost all pollutants; the exception is formaldehyde. Historically, natural gas vehicles (NGVs) have generally emitted lower emissions of smog-forming pollutants and most hazardous air pollutants (other than formaldehyde) in comparison to gasoline and diesel. When compared to diesel vehicles, NGVs also release less soot (black carbon and particulate matter). However, there is little empirical data comparing emissions of NGVs to conventionally fueled vehicles subsequent to the adoption in the last decade of stringent federal tailpipe exhaust standards. These federal standards will have likely diminished the emission benefits of NGVs.

14. How do CNG and LNG compare in terms of emissions across their respective supply chains?

Our analysis relies on assumptions built into the GREET model, with adjustments based on the EPA GHG Inventory (2014), regarding emissions associated with CNG and LNG across the supply chain. These assumptions indicate higher upstream methane emissions in the CNG fuel cycle as compared to LNG due primarily to losses occurring when natural gas travels through hundreds of miles of transmission and distribution pipelines between the well and CNG refueling stations.

Our reference case assumptions for upstream methane loss are 1.65% of natural gas consumed for CNG and 1.2% for LNG. However, there are higher CO2 emissions in the LNG fuel cycle compared to the CNG fuel cycle occurring from liquefaction and transportation of LNG by truck, rail or barge. Figure 2 of the paper provides a sense of how these assumptions compare.

15. What does “critical loss rate” mean and what is a “throughput based loss rate”?

We define “critical loss rate” to be the maximum amount of natural gas loss as a percent of total natural gas consumed at which a natural gas technology always produces lower cumulative radiative forcing than the equivalent diesel technology – in other words, where the Technology Warming Potential (TWP) is less than 1 on all time frames (immediately upon the switch from diesel to natural gas).

The critical loss rates presented in this paper represent a “throughput based loss rate”, defined as the ratio of the volume of natural gas emitted upstream of the point of use relative to the amount of natural gas consumed at the point of use (or the emissions burden associated with each unit of natural gas fuel consumed). The use of a throughput based loss rate in this paper is different than the approach used in Alvarez et al. (2012), which reported loss rates as a percentage of gross production. Defining loss rates based on gross production is problematic when thinking about emissions from individual industry segments in the natural gas system.

For example, if we were interested in the emissions from local distribution systems, it is more useful to think about the loss rate as a share of the amount of gas actually traveling through that particular system, rather than as a share of gross gas production at wellheads. Approximately half of the gross gas produced in the U.S. is consumed or otherwise diverted before entering the local distribution system. Normalizing distribution system emissions relative to gross production is spurious, as there is no relationship between the emissions that occur within the local gas distribution network and the portion of the gas supply that never made into the local gas distribution system.

For purposes of analyses requiring emission intensity per unit fuel consumed, the throughput-based loss rate is more appropriate than a gross production metric; the latter is less problematic as a rough metric of the scale of gas lost across the entire supply chain.

16. What does “reference case” mean and what is the purpose of the “sensitivity” range of results?

Our “reference case” provides climate impact results using publicly available and peer-reviewed current data. However, since considerable uncertainty remains about the magnitude of upstream and vehicle in-use leakage (data on the latter is particularly scarce), as well as for the potential for these variables as well as vehicle efficiency to change over time, we also present results based on a likely range of assumptions for these key variables – this is our “sensitivity range”.

The goal is to provide a framework for understanding what climate impacts could be given varying assumptions – in this way, we hope to provide a flexible framework for drawing conclusions as we gain better data on the magnitude and distribution of leakage and as both leakage and vehicle efficiency evolve due to policy changes and market dynamics.
Note that significant research is underway to update estimates of methane emissions across the U.S. natural gas system from production through local distribution and natural gas fueling stations and vehicles.

17. How do these results compare to the 2012 PNAS methane leakage paper?

While there are important differences between our analysis and the Alvarez et al. 2012 PNAS paper, the results regarding trucks are aligned in that both indicate that a switch to natural gas in this sector would result in climate damages for several decades based on current and publicly available data and that steps to reduce methane emissions would need to be taken to ensure that a switch produced climate benefits on all time frames.

Our new analysis has reached this conclusion using updated data, a slightly modified TWP methodology that distinguished upstream from in-use emissions, and by examining a range of engine technologies as well as both CNG and LNG fuels. The 2012 PNAS paper examined the

CNG 8.9 liter SI engine only – we include an analysis of this engine in our Supporting Information in order to directly compare results.

18. What is the magnitude of the changes we'd need to achieve climate benefits across all time frames?

Using our reference case assumptions, the critical ***well-to-wheels*** loss rate (the maximum well-to-wheels loss rate that would produce climate benefits on all time frames with a switch to natural gas away from diesel) ranges from approximately 0.9% to 1.5% of throughput across all the vehicle types we examine in both the main paper and in our Supporting Information (see the y-intercept in Figure 4 of the main paper and Figure S3 in the Supporting Information).

This is in comparison to reference case baseline well-to-wheels loss rates ranging from approximately 1.8% to 2.9% (these differ due to varying assumptions regarding upstream and in-use emissions between fuel and engine types). Reductions required to reach these critical loss rates from reference case levels range from 34% (for the more efficient 15 L HPDI engine) to 65% (for the 8.9 L engine; see Supporting Information).

Figure 4 illustrates the critical ***well-to-pump*** loss rates required given a range of assumptions for in-use CH4 emissions and vehicle efficiency. All else equal, higher in-use methane emissions mean that greater reductions must occur upstream to achieve climate benefits. This portion of our analysis emphasizes the important distinction between the different segments of the natural gas value chain, which are affected by different sets of players, regulations, and incentive structures. It is crucial that progress to obtain better data and to reduce emissions is made across the entire value chain.

19. What policy mechanisms are there to help us work towards ensuring these vehicles can achieve climate benefits?

This analysis illustrates that in order to ensure natural gas trucks produce climate benefits on all time frames, significant reductions in both upstream and in-use methane emissions are necessary, as well as improvements in natural gas engine efficiency. There are a number of policy mechanisms already in play that could help move us towards achieving those goals. Recently, in January of this year, President Obama announced plans to develop new regulations to reduce methane emissions from oil and gas production, setting a target of a 45% reduction by 2025. The EPA is set to propose regulations to help achieve this goal this summer, with a final rulemaking in 2016. The EPA and NHTSA are also set to propose regulations this spring extending the greenhouse gas emissions standards and fuel efficiency standards for medium- and heavy-duty engines and vehicles for model years 2018 and beyond.

20. How does this analysis relate to the 16 methane field studies, including the "Pump-to-Wheels" study?

While this analysis is distinct and separate from the series of 16 methane field studies currently underway to update estimates of emissions across the U.S. natural gas system and does not use any data from those studies, it serves complementary purposes. All of these studies emphasize the importance of gathering more and better data on the magnitude of methane emissions across the value chain in order to better understand the life cycle climate impacts of natural gas in comparison to other fossil alternatives. Second, by providing a range of results founded on what we believe encompasses the likely range of assumptions for the key variables, our analysis provides a framework for understanding the climate impacts of a switch in the trucking sector as new data points such as those from the field studies become available.