Life-Cycle Greenhouse Gas Emissions of Shale Gas, Natural Gas, Gasoline, and Diesel as Transportation Fuels

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Life-Cycle Greenhouse Gas Emissions of Shale Gas, Natural Gas, Coal, and Petroleum

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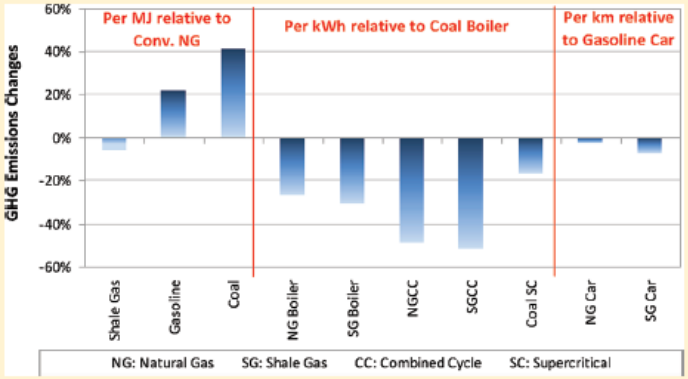
Supporting Information

ABSTRACT: The technologies and practices that have enabled the recent boom in shale gas production have also brought attention to the environmental impacts of its use. It has been debated whether the fugitive methane emissions during natural gas production and transmission outweigh the lower carbon dioxide emissions during combustion when compared to coal and petroleum. Using the current state of knowledge of methane emissions from shale gas, conventional natural gas, coal, and petroleum, we estimated up-to-date life-cycle greenhouse gas emissions. In addition, we developed distribution functions for key parameters in each pathway to examine uncertainty and identify data gaps such as methane emissions from shale gas well completions and conventional natural gas liquid unloadings that need to be further addressed. Our base case results show that shale gas life-cycle emissions are 6% lower than conventional natural gas, 23% lower than gasoline, and 33% lower than coal. However, the range in values for shale and conventional gas overlap, so there is a statistical uncertainty whether shale gas emissions are indeed lower than conventional gas. Moreover, this life-cycle analysis, among other work in this area, provides insight on critical stages that the natural gas industry and government agencies can work together on to reduce the greenhouse gas footprint of natural gas.



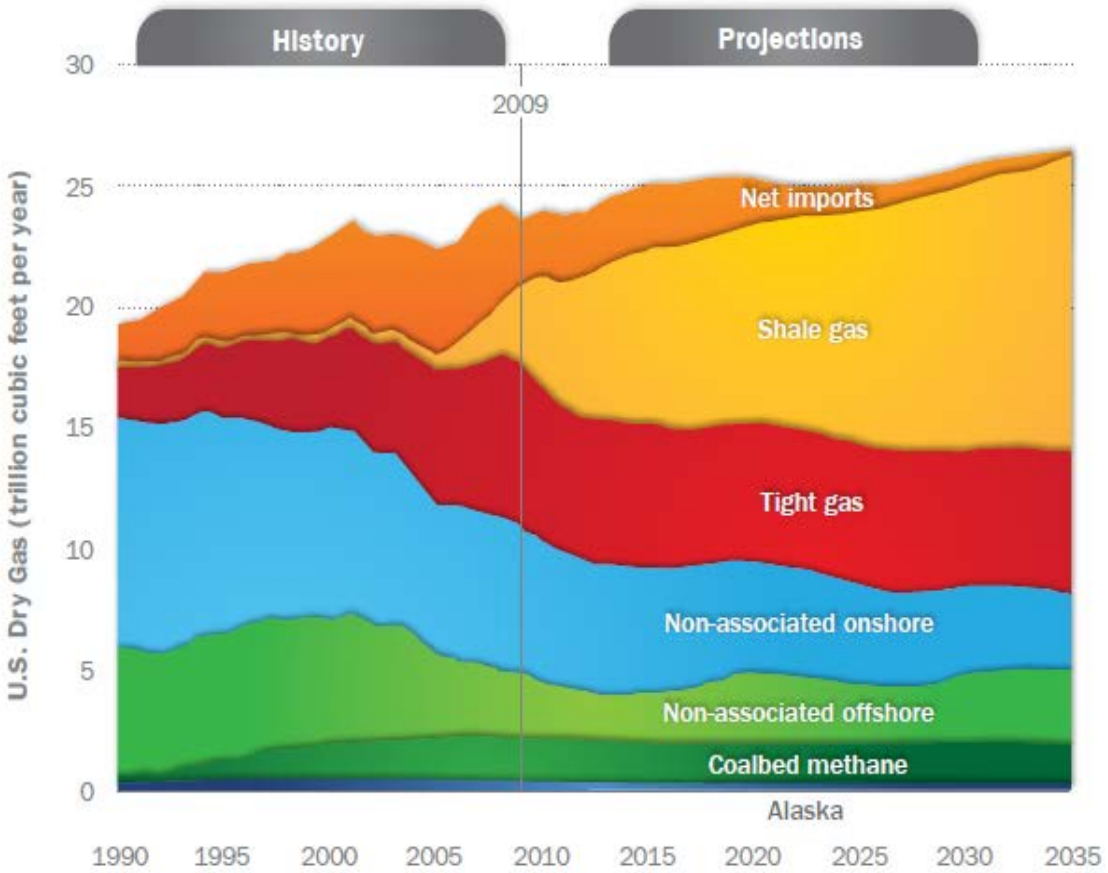
From the Department of Energy's Perspective Transportation Sector: Dual Challenges, Dual Approaches

- Challenges
  - Petroleum consumption (energy security)
  - Greenhouse gas emissions (climate change)

- Approaches
  - Vehicle efficiency (and transportation system efficiency)
  - New transportation fuels

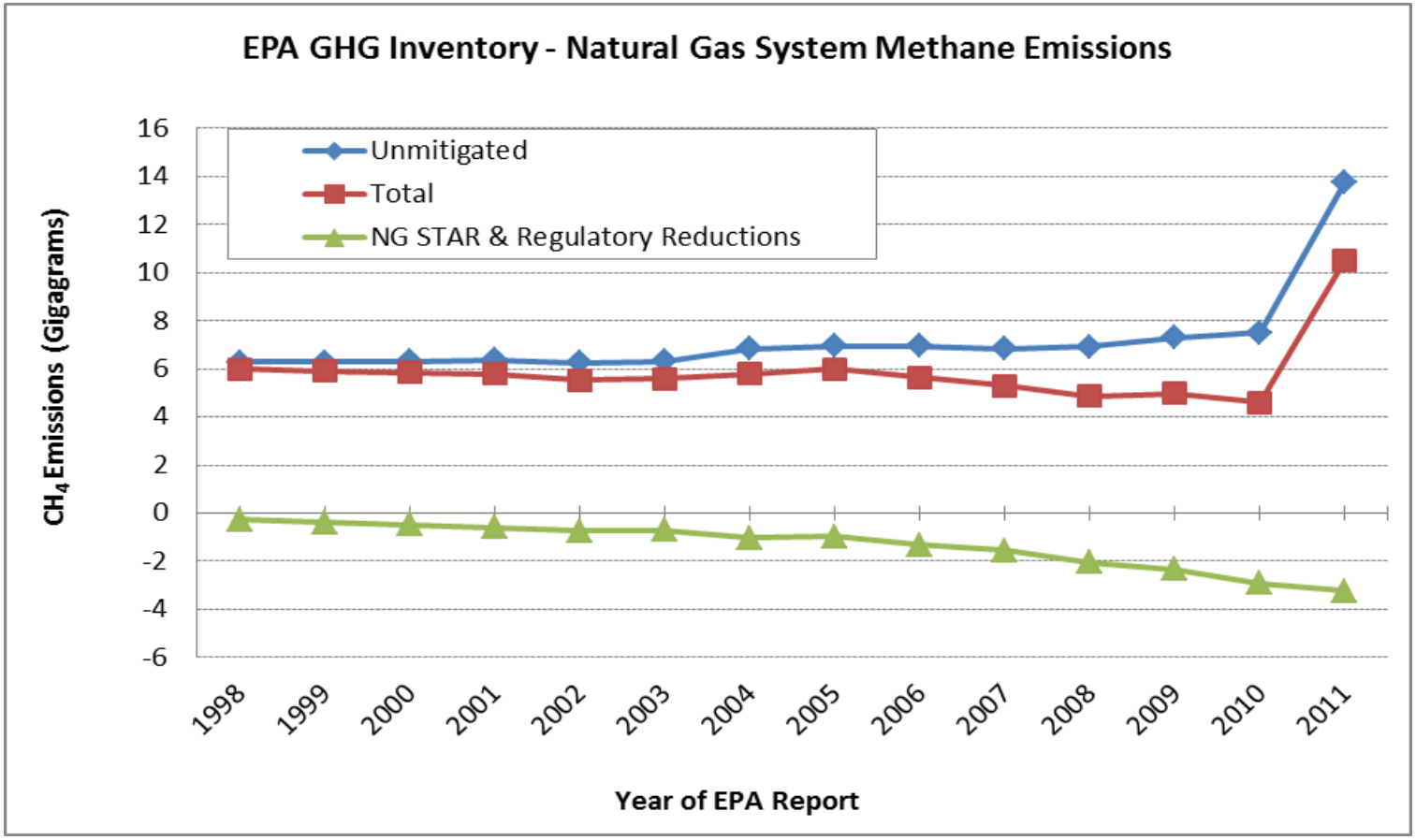
Shale Gas Described as a "Game Changer"

- Large-scale production made possible by advancements
  - Horizontal drilling
  - Hydraulic fracturing
- Has generated interest in expanding NG use in several sectors
  - Expansion into vehicles would displace petroleum
  - But what are the GHG implications?



Source: EIA - Annual Energy Outlook 2011

EPA Made Substantial Changes to Estimate of CH_4 Emissions from the Natural Gas System



Source: EPA - U.S. GHG Inventory Archive

- Major changes for 2011 included
  - Adding shale gas well completions emissions
  - Updating emission factors for conventional NG liquid unloadings

Scope of Argonne's Natural Gas Life-Cycle Analysis

- Developed shale gas pathway and updated CH_4 leakage estimates for conventional NG, petroleum, and coal pathways for Argonne's GREET Model
  - Quantified material and energy requirements for well infrastructure development
  - Looked at 3 functional units: per MJ (direct combustion); per kWh (electricity generation); per mile (passenger transportation)

- Focused on estimating uncertainties and identifying data gaps to provide insight to NG industry and government
  - Developed distribution functions for key parameters

Key Issues Affecting Natural Gas Life-Cycle Results

- Estimated Ultimate Recovery (EUR)
- Shale Gas Well Completion Emissions
- Conventional Gas Liquid Unloading Emissions
- Global Warming Potential
- End Use Efficiency

Periodic Well Emissions Must be Allocated Over Lifetime NG Production

- Several key activities are estimated on a per-well basis
  - Lower the EUR, larger the impact
- Shale gas EURs are highly uncertain as industry is in its infancy
  - Wide range for several plays
- Conventional NG productivity is declining
  - Lower EUR than key shale plays

	Low EUR Estimate (Bcf)	High EUR Estimate (Bcf)
Barnett	1.4	3.0
Marcellus	1.4	5.2
Fayetteville	1.7	2.6
Haynesville	3.5	6.5
Shale Per-Well Weighted Avg.	**1.6**	**5.3**
Conventional Avg.	**0.8**	**1.2**

Shale Gas Completions CH_4 Emissions Could Be Large, But Industry Data Says Much is Recovered

- After hydraulic fracturing, a large volume of frac fluid & produced water return to the surface
  - Flowback water contains NG, which can be vented, flared, or captured
- EPA estimates "uncontrolled" CH_4 emissions
  - Data used by EPA to calculate emissions have significant questions
  - Potentially overestimates emissions
    - Applicability of NG STAR program activities to calculate baseline
    - Use of IP rates to estimate flowback emissions
- EPA uses NESHAP regulations and NG STAR reporting to estimate amount of NG flared and captured by industry practices
  - Emissions were reduced by ~40% from 2005-2009
  - Lack of transparency as data is highly aggregated

EPA's Estimates Liquid Unloadings Account for Half of Uncontrolled CH_4 Emissions From NG Production

- Accumulation of fluids in wet NG wells can eventually stop production
  - Assumed to only occur in conventional wells (shale typically dry)
  - Removing liquids can be accomplished by several practices/technologies
    - Largest emissions come from well blowdowns
- EPA updated emission factors because NG STAR savings were larger than the uncontrolled estimates using previous methodology
- Similar to issues with completion emissions, uncertainty arises from
  - Suitability of NG STAR data to calculate uncontrolled emissions
  - Lack of transparency regarding NG STAR reductions
- Our examination found that liquid unloading emissions are potentially more significant than those from shale gas well completions

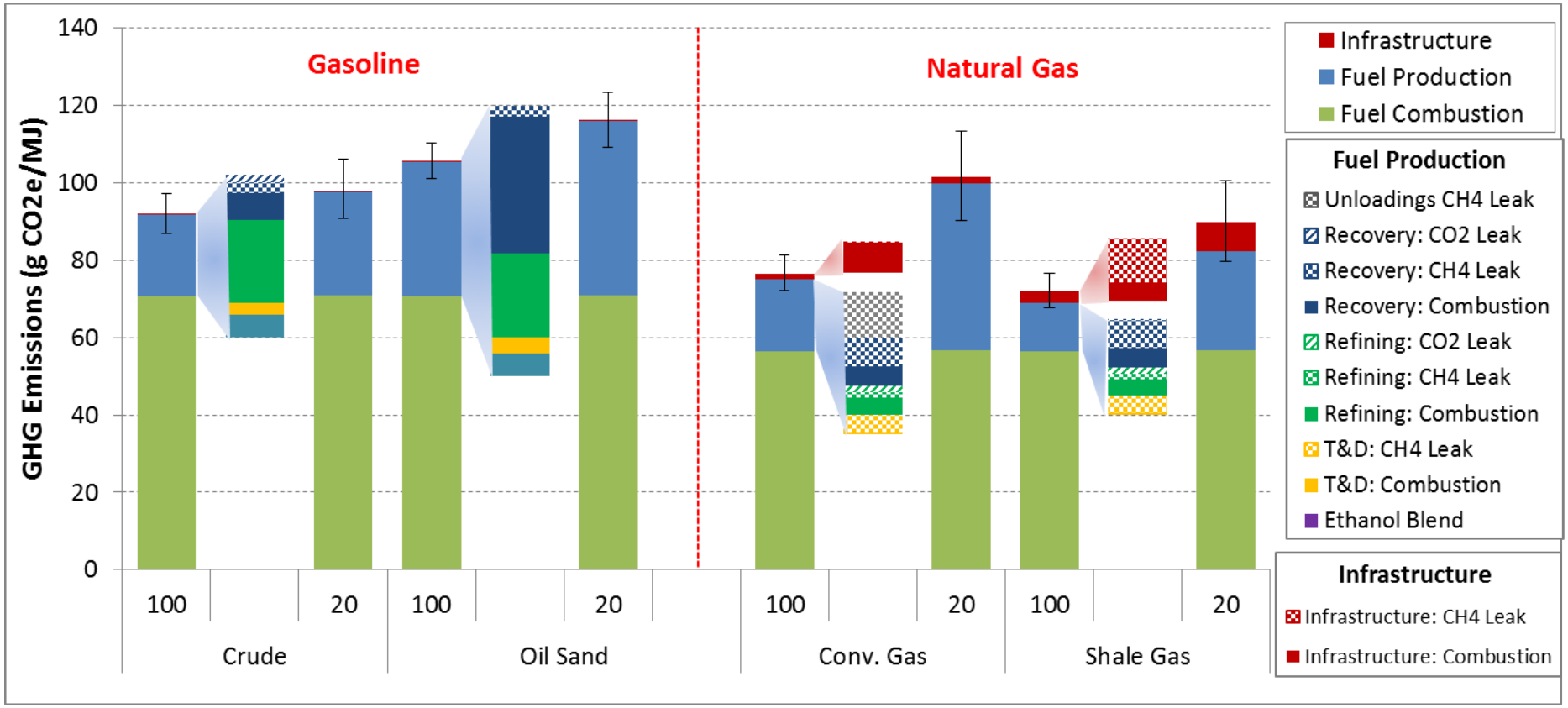
Global Warming Potential is a Simple Measure to Compare Radiative Effects of Different Gases

- Need to choose a time-horizon when comparing emission impacts of different fuels
  - Especially important when comparing contributions of short-lived gases
    - CH_4 has an atmospheric lifetime of ~12 years
- IPCC recommends using a 100-year time-horizon when evaluating climate change mitigation policies
- Other researchers have suggested a 20-year time-horizon should be examined
  - Effects of CH_4 emissions are amplified
- We use the 100-year time-horizon in our analyses
  - Also present 20-year for comparison to other studies

End-use Efficiency is a Key Factor for LCA Results

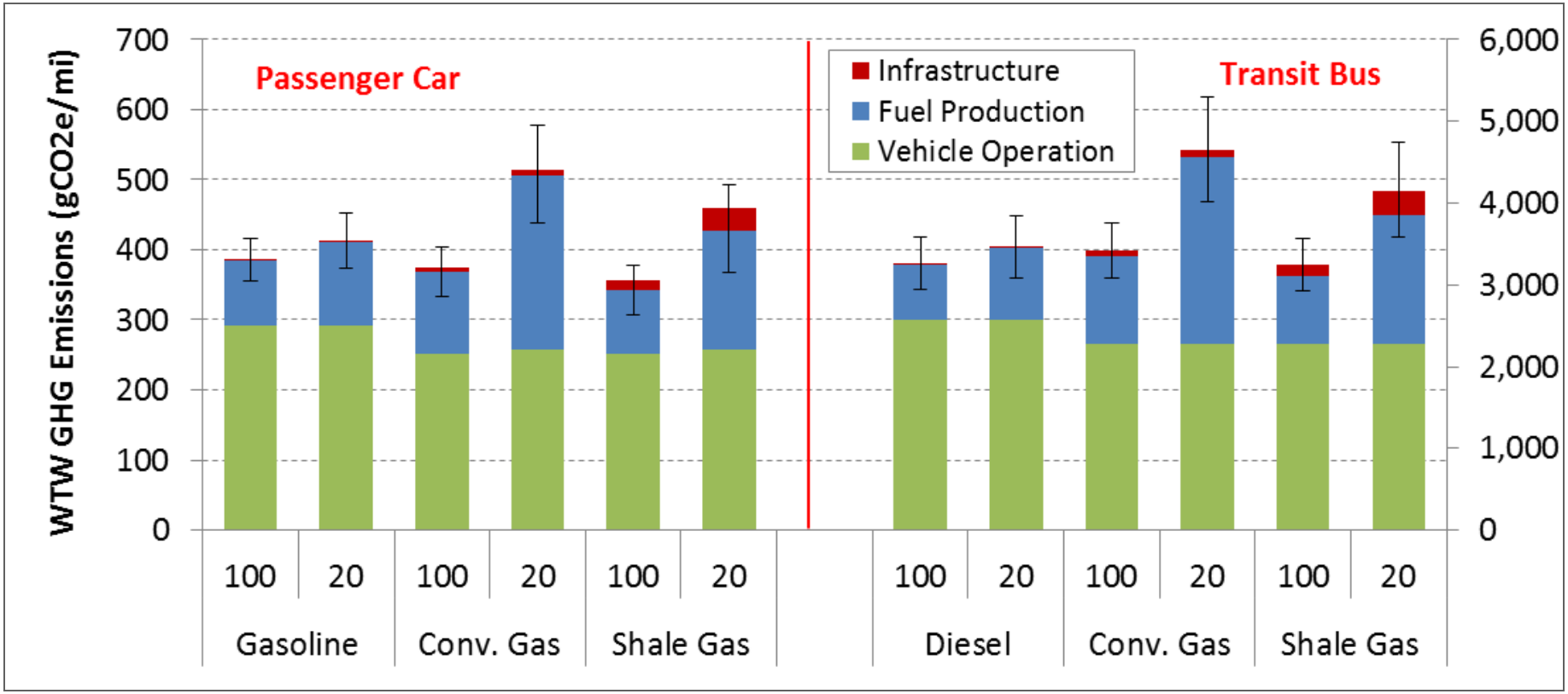
- Compared to gasoline cars, NG cars have slightly lower fuel economy
  - Base case = 5% reduction
    - Weight penalty of CNG storage tanks
    - Power loss due to oxygen displacement
  - Use of direct injection and turbocharging can improve fuel economy and power
- Compared to diesel transit buses, NG buses have moderately lower fuel economy
  - Base case = 15% reduction
    - Spark-ignited engines have low efficiency at low speeds
  - However NG spark-ignited engines have closed the gap on compression-ignition engines
    - Primarily due to emission control strategies implemented for diesels to meet 2010 regulations

While CH_4 Leakage is Important, Fuel Combustion Accounts for Largest Portion of NG Life-Cycle Emissions



- Interesting result - base-case shale gas emissions are lower than conv. NG
  - Values overlap so can't say one is actually better than the other
- NG shows benefits for direct combustion but must look at the actual end-use
  - Efficiency of energy conversion to energy service key factor for proper comparison

CNGVs Using Fossil NG May Provide Small GHG Benefit, Improving Vehicle Efficiency is a Key Factor



Shale Gas and Conventional NG Summary

- Estimates of CH_4 leakage from NG have increased significantly
- Shale gas completion emissions could be large in theory
  - However, industry reports that a significant amount is captured
  - Data is extremely limited and there is a lack of transparency
    - Several efforts underway to get better data
- Conventional NG liquid unloadings are potentially a larger source than shale gas completions
  - Causes the greatest amount of uncertainty in our study
- Shale and conventional NG may provide small GHG benefits for passenger cars and transit buses
  - NGV efficiency is a key factor for improvement

Thank you!!!

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Production CH_4 Emissions are Significantly Higher than Previous Estimates

Sector	CH_4 Emissions: Percent of Volumetric NG Produced			
	Harrison et al. (1996)	Previous GREET NG (1999)	New GREET Conv. NG (2011)	New GREET Shale Gas (2011)
Production	0.38	0.35	1.93 (0.62-4.19)	1.19 (0.36-3.95)
Processing	0.16	0.15	0.15 (0.06-0.23)	0.15 (0.06-0.23)
Transmission	0.53	0.27	0.39 (0.20-0.58)	0.39 (0.20-0.58)
Distribution	0.35	0.18	0.28 (0.09-0.47)	0.28 (0.09-0.47)
Total	1.42	0.95	2.75 (0.97-5.47)	2.01 (0.71-5.23)