Life Cycle Greenhouse Gas (GHG) Emissions from Natural Gas Pathways for On-Road Vehicles

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STEPS Workshop: Technological, Economics and Environmental Potential of Natural Gas as a Sustainable Transportation Fuel in the United States
A Transition to Natural Gas Pathways?

• Research Gaps
  • Previous studies do not account for recent developments in natural gas (e.g. methane leakage) extractions and current vehicle technologies.
  • Findings from previous studies on life cycle GHG emissions of natural gas developments and heavy-duty vehicles are mixed and contradictory.

• Research Questions
  • Which natural gas pathways or which vehicle segments provide GHG emissions reductions compared to petroleum fuels?
  • How sensitive are the results to methane leakage rates and other factors?
Bottom-up Attributional Life Cycle Assessment (LCA)

- **Emission Sources**
  - Resource extraction: natural gas and oil (baseline).
  - Fuel production, transport, distribution.
  - Vehicle operation (tailpipe).
  - Vehicle manufacturing emissions (esp., battery and fuel cells).
  - Emissions from infrastructure construction.
  - Emissions from end-of-life disposal or treatment.

- **GHGs**
  - \( \text{CO}_2, \text{CH}_4, \text{N}_2\text{O} \)
  - Global warming potential (GWP)
  - IPCC AR5 values.
  - Uncertainty in GWPs.

- **Functional Unit**
  - Vehicle distance (kilometer)
  - Freight distance (metric ton-km)
Modified from Tong et al. (2015a, 2015b).
Not All Transportation Fuels Can be Used to Fuel Every Vehicle Type

- More fuel options for light-duty vehicles; less fuel options for heavy-duty trucks.
- CNG is the only fuel that spans over all vehicle classes.

<table>
<thead>
<tr>
<th>Unit of fuel economy+</th>
<th>Class 1 Passenger vehicle</th>
<th>Class 1 Sports utility vehicle (SUV)</th>
<th>Class 2b Pick-up truck/van</th>
<th>Class 4 Parcel delivery van</th>
<th>Class 6 Box truck</th>
<th>Class 8 Transit bus</th>
<th>Class 8 Refuse truck</th>
<th>Class 8 Tractor trailer</th>
<th>Class 8 Tractor trailer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MPG (gasoline gallon)</td>
<td>MPG (diesel gallon)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasoline (SI-ICEV)</td>
<td>33.0</td>
<td>25.0</td>
<td>14.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Diesel (CI-ICEV)</td>
<td>32.3</td>
<td>26.2</td>
<td>16.1</td>
<td>11.5</td>
<td>7.0</td>
<td>4.0</td>
<td>3.3</td>
<td>4.3</td>
<td>6.5</td>
</tr>
<tr>
<td>Gasoline-HEV(SI-ICEV)</td>
<td>45.0</td>
<td>33.0</td>
<td>16.8</td>
<td>10.9</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Diesel-HEV (CI-ICEV)</td>
<td>-</td>
<td>-</td>
<td>19.3</td>
<td>14.4</td>
<td>9.3</td>
<td>4.8</td>
<td>3.6</td>
<td>5.2</td>
<td>7.2</td>
</tr>
<tr>
<td>CNG (SI-ICEV)</td>
<td>31.0</td>
<td>-</td>
<td>14.0</td>
<td>10.8</td>
<td>6.6</td>
<td>3.6</td>
<td>2.9</td>
<td>3.9</td>
<td>5.9</td>
</tr>
<tr>
<td>LNG (SI-ICEV)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3.6</td>
<td>2.9</td>
<td>3.9</td>
<td>5.9</td>
</tr>
<tr>
<td>LNG (CI-ICEV)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4.2</td>
<td>6.4</td>
</tr>
<tr>
<td>M85 (SI-ICEV)</td>
<td>35.3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>-</td>
</tr>
<tr>
<td>E85 (SI-ICEV)</td>
<td>31.6</td>
<td>24.7</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Propane (SI-ICEV)</td>
<td>-</td>
<td>-</td>
<td>14.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>BEV</td>
<td>110.0</td>
<td>76.0</td>
<td>42.0</td>
<td>34.5</td>
<td>21.0</td>
<td>16.8/14.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>H₂-FCEV</td>
<td>61.0</td>
<td>49.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>7.6/30.9</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Modified from Tong et al. (2015a, 2015b).
Sample Results - Natural Gas Pathways Are Worse.

Modified from Tong et al. (2015a).

Class 8 Line-haul Tractor Trailer

Life cycle GHG emissions (Unit: g CO\textsubscript{2}-eq/km-metric-ton)

- Upstream (100-yr GWP)
- Tailpipe (100-yr GWP)
- Upstream (20-yr GWP)
- Tailpipe (20-yr GWP)

Conv. diesel HEV

Conventional diesel

Modified from Tong et al. (2015a).
Many pathways **do not achieve emissions reduction** yet.

<table>
<thead>
<tr>
<th>Definitely a lot of potentials</th>
<th>Marginally good or bad</th>
<th>Very likely to increase emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity + Battery electric vehicles</td>
<td>CNG</td>
<td>Methanol, Ethanol, and liquid hydrogen, Fischer-Tropsch liquids</td>
</tr>
<tr>
<td>Gaseous Hydrogen + Fuel cell electric vehicles</td>
<td>LNG</td>
<td></td>
</tr>
<tr>
<td>Passenger vehicle, SUVs, and transit buses.</td>
<td>Almost all vehicle applications. Heavy-duty trucks. Light-duty &amp; medium-duty trucks.</td>
<td>Passenger vehicles</td>
</tr>
<tr>
<td>Efficient fuel production, zero tailpipe emissions, &amp; highly efficient vehicle technologies.</td>
<td>Simple fuel production &amp; comparable vehicle technologies.</td>
<td>Complex fuel production (penalty) &amp; comparable vehicle technologies.</td>
</tr>
</tbody>
</table>

- **4 scenarios * 9 vehicle types**
- Baseline/Pessimistic methane emissions estimates.
- 100-year/20-year GWP metrics.

\[
\text{Life Cycle} = \frac{\text{fuel carbon intensity}}{\text{vehicle fuel efficiency}} + \text{tailpipe nonCO}_2
\]
If natural gas vehicles have the same fuel efficiency as diesel vehicles, then it allows up to 3.1% of methane leakage rate to achieve emissions reduction.

Modified from Tong et al. (2015a).
Higher or lower relative vehicle fuel efficiency allows higher or lower methane leakage.

Modified from Tong et al. (2015a).
LNG/CNG vs. Diesel (MHDVs)

Energy economy ratios (EERs) of natural gas vehicles

Break-even methane leakage rate

- LNG, 100-year GWP
- LNG, 20-year GWP
- CNG, 100-year GWP
- CNG, 20-year GWP

Modified from Tong et al. (2015a).
Natural Gas Pathways vs. Gasoline (LDVs)

Break-even methane leakage rate vs. Energy economy ratio (EERs) of natural gas vehicles.

Current CNG vehicle
Current FCEV
GH2 FCEV, 100-yr
Current BEV
GH2 FCEV, 20-yr
BEV, 20-yr
BEV, 100-yr

Modified from Tong et al. (2015b).
Comparison of Life Cycle Greenhouse Gases from Natural Gas Pathways for Medium and Heavy-Duty Vehicles

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ABSTRACT: The low-cost and abundant supply of shale gas in the United States has increased the interest in using natural gas for transportation. We compare the life cycle greenhouse gas (GHG) emissions from different natural gas pathways for medium and heavy-duty vehicles (MHDVs). For Class 8 tractor-trailers and refuse trucks, none of the natural gas pathways provide emissions reductions per unit of freight-distance moved compared to diesel trucks. When compared to the petroleum-based fuels currently used in these vehicles, CNG and newly produced LNG increase emissions by 0.3% and 2.13%, respectively, for Class 8 trucks. Battery electric vehicles (BEVs) powered by natural gas-produced electricity are the only fuel-technology combination that achieves emissions reductions for Class 8 transit buses (31% reduction compared to the petroleum-fueled buses). For non-Class 8 trucks (pick-up trucks, parcel delivery trucks, and bus trucks), BEVs reduce emissions significantly (31-40%) compared to their diesel or gasoline counterparts CNG and propose achieve relatively smaller emissions reductions (0-6% and 19%, respectively, compared to the petroleum-based fuels), while other natural gas pathways increase emissions for non-Class 8 MHDVs. While using natural gas for transportation could achieve large emissions reductions for medium-duty trucks, the results suggest there are no great opportunities to achieve large emission reductions for Class 8 trucks through natural gas pathways with current technologies. There are strategies to reduce the carbon footprint of using natural gas for MHDVs, ranging from increasing vehicle fuel efficiency, reducing life cycle methane leakage rates, to achieving the same payload and cargo volumes as conventional diesel trucks.

INTRODUCTION

In recent years, the successful combination of technologies, such as hydraulic fracturing, horizontal drilling, and seismic mapping have led to significant production of unconventional natural gas resources, which in turn has attracted industrial interests in using natural gas as a transportation fuel. While economic considerations have dominated this discussion, environmental impacts of natural gas-based fuels are likely to be of interest to multiple stakeholders. A recent NRC report analyzed the impacts of natural gas to fuel medium- and heavy-duty vehicles (MHDVs) and concluded that "more studies and data are needed to determine the well-to-tank GHG emissions of NG vehicles."

There are several approaches to evaluate the GHG emissions of MHDVs. Both vehicle simulation tools and vehicle test on the field provide estimates of emissions from the use phase. These tests are limited in that they fail to account for emissions sources beyond tailpipe. Thus, vehicle simulations and tests may not be appropriate for making generalized recommendations regarding GHG emissions. Life cycle assessment (LCA) studies overemphasize this shortcoming as they account for use of natural gas for transportation. Low prices and abundant resource open new opportunities for using natural gas, one of which is the production of transportation fuels. In this study, we use a Monte Carlo analysis combined with a life cycle analysis framework to assess the greenhouse gas (GHG) implications of a transition to natural gas-powered vehicles. We consider six different natural gas fuel pathways in two representative light-duty vehicles: a passenger vehicle and a sport utility vehicle. We find that a battery electric vehicle (BEV) powered with natural gas-backed electricity achieves around 40% life cycle emissions reductions when compared to conventional gasoline. Gasoline hybrid fuel cell electric vehicles (FCBEVs) and compressed natural gas (CNG) vehicles have comparable life cycle emissions with conventional gasoline, offering limited reductions with 100-year global warming potential (GWP) yet leading to increases with 20-year GWP. Other liquid fuel pathways (methanol, ethanol, and Fischer-Tropsch liquid) have larger GHG emissions; these pathways are available but limited.

Life cycle GHG emissions of natural gas pathways are sensitive to the vehicle efficiency, to the methane leakage rates of natural gas systems, and to the GWP assumed. With the current vehicle technologies, the break-even methane leakage rates of CNG, gaseous hydrogen (PCD/V), and BEV are 0.06%/2.3%, 1.2%/2.8%, and 4.5%/18.8%/0.5%/20-year GWP/100-year GWP. If the actual methane leakage rate is lower than the break-even rate of a specific natural gas pathway, that natural gas pathway reduces GHG emissions compared to conventional gasoline; otherwise, it leads to an increase in emissions.

REFERENCES

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Comparison of Life Cycle Greenhouse Gases from Natural Gas Pathways for Light-Duty Vehicles

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REFERENCES

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References


Please refer to Tong et al. (2015a, 2015b) for a full list of relevant literature on this topic.
Questions?

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