Natural Gas in Transportation

Sustainable Transportation Energy Pathways (STEPS)

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Repeating Boom and Bust Cycles Characterize Oil Oil

- High oil prices usher in demand destruction through conservation, efficiency gains, and substitution
- High oil prices stimulate drilling innovations, which over time can lead to supply bubbles.

Source: Medlock, K.B., Amy Jaffe, “The price of crude oil: deja vu all over again?” (2013), EIA
Breakevens for US shale oil and gas are lower than many other regions.

Unconventionals are not at the top of the scale for breakeven costs. Arctic and Mega-LNG projects could be most under pressure as global gas prices ease.

<table>
<thead>
<tr>
<th>Field</th>
<th>Breakeven</th>
<th>OPEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marcellus (gas)</td>
<td>$2.50</td>
<td>$1.00</td>
</tr>
<tr>
<td>Barnett (gas)</td>
<td>$3.80</td>
<td>$1.80</td>
</tr>
<tr>
<td>Haynesville (gas)</td>
<td>$3.60</td>
<td>$1.80</td>
</tr>
<tr>
<td>Eagle Ford (oil)</td>
<td>$37</td>
<td>$7-$8</td>
</tr>
<tr>
<td>Permian (oil)</td>
<td>$49</td>
<td>$10-$12</td>
</tr>
<tr>
<td>Bakken (oil)</td>
<td>$37</td>
<td>$7-$8</td>
</tr>
<tr>
<td>Mississippian</td>
<td>$43</td>
<td>$7-$8</td>
</tr>
</tbody>
</table>

Source: Citi Research
U.S. shale gas is prolific and supply abundance will be sustainable

Shale’s diverse geographic location enhances security of supply
Natural Gas In Transportation

• The wide spread between natural gas prices and oil prices offered the promise of fuel savings and led to forecasts of extensive fuel switching in the freight sector.
• Excitement emerged surrounding America’s natural gas highway.

We sought to quantify both the temporal and spatial market response to the price incentives that might promote fuel switching in the U.S. Class 8 heavy duty trucking fleet
• We created an optimization model to determine the optimal LNG refueling network and supply chain for long haul trucks and test scenarios including station subsidies and high diesel prices.
Optimistic forecasts look at history and assume that low natural gas prices will eventually drive shift to natural gas for heavy trucks, after a slow start.

But is the S Curve for diesel fuel really indicative of what will happen in US for natural gas in trucking?

Estimated NGVs as % new HDV sales in the US

Diesel’s share of new Class 8 trucks sales in US, 1950-2010

Source: Citi Research
Modeling Insight: Network development more sensitive to travel intensity of trucking corridors and relative diesel price levels rather than proximity to or surplus of available natural gas supply.

Highest Traveled U.S. Trucking Corridors:
I-5 in California; Milwaukee to Chicago; upstate NY; NYC-New Jersey; Dayton, OH to Cincinatti, OH; Kansas City region; Chicago to Indiana; Dallas to Houston; and Orlando to Tampa

Higher U.S. Diesel Prices:
NY and PA about 10% over national average
OH, MI & New England about 5% over national average
CA, DE, & MD about 2% over national average
ITS Davis modeling finds that natural gas fuel cost advantage is not sufficient to launch a national network.
The fuel cost discount of natural gas compared to diesel is not large enough to compensate for the large capital costs for new natural gas fueling infrastructure.

The delivered cost of an LNG gallon involves infrastructure and capital costs not required in the incumbent diesel refueling network. The success of LNG as an economical alternative to diesel fuel is largely dependent on economies of scale at the liquefaction site and refueling station. Station with larger annual flows will see smaller per-LNG gallon expenses for their fixed costs.
While U.S. national network is hard to launch, California has unique aspects that make NGV fueling more commercially viable. California’s freight route is highly concentrated and heavily traveled.
Over time, a California NGV trucking network would connect to an expanded system as demand is able to accrue and spread out and system costs fall. Policy makers view system potentially enabling for biogas.
The majority of emissions come from vehicle operations.
Carbon Intensity under different methane leakage

Only most efficient engine offers substantial advantages

![Graph showing methane leakage (%) vs. gCO₂e/mi for different fuel types: DIESEL CI, CNG SI, LNG SI, and LNG HPDI. The graph illustrates how methane leakage affects carbon intensity.](image-url)
Research Team/Acknowledgments

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Concluding summary

• Alternative fuel cost discount compared to incumbent fuel is an important element to commerciality but not the only driver to a successful transition. Level of costs of new infrastructure also significant variable to developing new networks.

• Traffic volume more important element to freight market infrastructure success than natural gas supply surplus.

• Concentrated regional focus in key markets for early investment can be a better strategy than broader initial investment in national coverage.

• New natural gas modular technologies like LNG in a box still too expensive to wide-spread adoption without government intervention.

• Technologies exist to improve environmental performance of natural gas in vehicles but may require government regulation to stimulate wider adoption.