NATURAL GAS USE IN THE TRANSPORTATION SECTOR

Discussion Questions:

1. What element(s) of our transportation system offers the greatest potential for natural gas usage from a cost and climate perspective?

2. How could natural gas vehicles conversions today encourage ultimate decarbonization of the transportation sector?

3. How and should we incentivize a transition to natural gas use in transportation at the local, state and or national level?

4. Will volatility and range in natural gas prices impact the transportation sector just as for petroleum-based fuels?

5. How would the development of GTL refineries in this country impact the deployment of other natural gas vehicles?

6. Can the nation’s natural gas infrastructure support the significantly greater use that a large adoption in transportation would entail?

7. Should U.S. vehicle emission standards be modified to recognize and encourage the transition to natural gas as a transportation fuel?

HIGHLIGHTS

- The transportation sector uses natural gas in a variety of forms including: as compressed natural gas, as liquefied natural gas, through gas-to-liquids technologies, in fuel cells, or as a generation fuel for electricity.
- Depending on the type of natural gas vehicle, greenhouse gas reductions can be between 28 and 55 percent as compared to gasoline- and diesel-powered engines.
- Greater replacement of petroleum-based fuels with natural gas could contribute to reduced petroleum imports and increased national energy independence.
- Natural gas vehicles currently offer lower fuel costs; however, there are higher up-front vehicle and infrastructure costs.

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INTRODUCTION

Natural gas is the most flexible of the three primary fossil fuels (coal, petroleum, natural gas) used in the United States and accounted for 25 percent of the total energy consumed nationwide in 2009. In spite of the major roles that natural gas plays in electricity generation as well as in the residential, commercial, and industrial sectors, it is not commonly used for transportation. In total, as illustrated in Figure 1, the U.S. transportation sector used 27.51 quadrillion British thermal units (Btus) of energy in 2010, of which 25.65 quadrillion Btus came from petroleum and just 0.68 quadrillion Btus came from natural gas (93 percent and 3 percent of the sector, respectively). A variety of vehicle technologies available today allow natural gas to be used in light-, medium-, and heavy-duty vehicles. Most commonly, natural gas is used in a highly pressurized form as compressed natural gas (CNG) or as liquefied natural gas (LNG). While CNG and LNG are ultimately combusted in the vehicle, it can also power vehicles in other ways. It can be converted into liquid fuel that can be used in conventional vehicles, power fuel cell vehicles, or be used in the production of electricity for electric vehicles. Despite the existence of these technologies, only about 117,000 of the more than 250 million vehicles on the road in 2010 (about .05%), were powered directly by natural gas (not including electric vehicles). Of these, the majority of natural gas vehicles are buses and trucks. The recent relative cost differential between natural gas and oil as a fuel source, however, has increased interest in expanding the use of natural gas beyond just buses and trucks thus representing a much broader market opportunity.

A VARIETY OF NATURAL GAS TRANSPORTATION TECHNOLOGIES ARE AVAILABLE

Of all natural gas powered vehicles, CNG is the most common form of natural gas used in transportation today. There were 114,270 CNG vehicles on U.S. roads in 2009 using 875 CNG fueling sites. Although Honda offers a CNG passenger vehicle, only 4,000 vehicles are scheduled for production in 2012, and sales figures are not available. CNG vehicles are most commonly found in larger transportation fleets, at present. Public transit buses, for example, are the largest users of natural gas in the transportation sector, with about one fifth of buses running on CNG or LNG. Other fleets also use natural gas trucks, including thousands of trucks at Waste Management, FedEx, UPS and AT&T.

CNG is natural gas compressed to less than 1 percent of its standard atmospheric pressure volume. As a consequence of its highly pressurized state, CNG requires special handling and storage. In vehicles, CNG requires cylindrical storage tanks, which are significantly larger than conventional fuel and keep the fuel at pressures of up to 3,600 pounds per square inch. Given the size requirement of these tanks, their placement in passenger vehicles, can take up valuable passenger or trunk space.
Like CNG, but to a lesser extent, LNG vehicles (mainly heavy-duty trucks) are also used on U.S. roads and a budding fueling infrastructure has begun to develop. Approximately 3,176 LNG vehicles were in use in the United States in 2009 using 40 public and private refueling sites, 32 of which were in California. Liquefied natural gas is created by chilling it to -260 degrees Fahrenheit at normal pressures, at which point it condenses into a liquid 0.0017 percent the volume of the gaseous form. The conversion of natural gas to LNG removes compounds such as water, CO₂ and sulfur compounds from the raw material leaving a purer methane product, whose combustion results in fewer air emissions. The stable, non-corrosive form also makes LNG more easily transportable such that it can be moved by ocean tankers or trucks. Today, LNG is mainly used as direct replacement for diesel in heavy-duty trucks because they are able to accommodate this hefty storage system and use LNG fueling infrastructure currently limited to trucking routes.

Both CNG and LNG are less dense forms of energy than conventional diesel fuel, which requires vehicles using these fuels to have larger fuel tanks to store the same amount of energy, as seen in Figure 3. The energy density of CNG is so low that CNG vehicles with ranges of greater than 300 miles are unlikely to be produced due to space and weight limitations. CNG is often thought about as primarily suitable for fleet passenger vehicles, municipal buses, and other vehicles where travel distances are shorter. The greater energy density of LNG, however, makes it more practical for long-haul tractor-trailers that can accommodate larger fuel tanks. Despite these lower energy densities, both CNG and LNG can be an attractive fuel source for certain applications from an economic and environmental perspective.

While CNG and LNG are today the most common forms of natural gas fuels in vehicles, other technologies are available that could increase the use of natural gas in the broader transportation system. One such technology converts natural gas into diesel or gasoline, which can be both used in the existing vehicle fleet and moved through existing infrastructure. Gas-to-liquids (GTL) technology transforms natural gas hydrocarbons into gasoline or diesel hydrocarbons and the resulting products have similar energy density as traditionally-produced diesel properties that allow for better engine performance and potentially.

Conversion technologies typically require 10 million cubic feet (mcf) of gas to produce one barrel of oil-equivalent product output, which may include diesel, naphtha, and other petrochemical products. At $4 per mcf of natural gas, that is equivalent to $40 per barrel of oil equivalent. GTLs have been produced at facilities around the world, and the development of new facilities in the United States is underway. Several companies are said to be in various stages of analysis for GTL facilities on...
the Gulf Coast because of natural gas supplies and current domestic prices.²⁴

Natural gas also plays a role in supplying fuel cell vehicles. Fuel cells produce electricity through an electrochemical process, rather than through combustion, resulting in heat and water and far fewer GHGs or other pollutants. Fuel cells are fueled by hydrogen, and the most common source of that today is natural gas. Hydrogen can be extracted on board the vehicle using a reformer, or it can be externally extracted and subsequently added to the vehicles as fuel.²⁵ Today, no light-duty fuel cell vehicles are commercially available in the United States, although there are certain test vehicles on the road as well as rudimentary hydrogen fueling infrastructure in California.²⁶ Several companies have concept cars that are powered by fuel cells, while 14 companies are working to introduce commercially-available fuel cell vehicles and infrastructure in Japan.²⁷ Hyundai plans to build 1,000 fuel cell vehicles for distribution in 2013²⁸ and Toyota has suggested that production costs are decreasing such that it should be able to sell fuel cell vehicles for $50,000 by 2015. Several other companies plan to offer fuel cell vehicles by 2015 as well.²⁹

Electric vehicles are another type of vehicle becoming more common on U.S. roads, and these vehicles use electricity from the U.S. electrical grid, which is increasingly powered by natural gas as a fuel source. As of April 2012, Americans had purchased over 25,000 plug-in electric vehicles, including Chevrolet Volts, Nissan LEAFs, and Toyota Plug-in Priuses.³⁰ PEVs are also now available from BMW, Ford, Mitsubishi, and Daimler. By the end of 2012, other models will be offered by automotive startups Coda and Tesla.³¹ When fueled by a combined cycle natural gas power plant, such “natural gas-powered electric vehicles” offer significant efficiency and GHG emission benefits over conventional diesel- or gasoline-powered vehicles.³²

INCREASED CNG USE IN HEAVY DUTY VEHICLE FLEETS

While fuel pricing differentials clearly provide a market opportunity for natural gas in the transport sector, significant expansion barriers exist for CNG and LNG vehicles. CNG and LNG trucks currently offer less range, refueling options and resale value than traditional diesel-powered trucks. A diesel truck with a 150-gallon tank and a 6 to 7 mpg fuel economy can travel about 1,000 miles on one tank, which is significantly more than its natural gas counterparts. Depending on the mounting of the cylindrical tanks, CNG trucks can travel 150 miles or 400 miles between fueling. LNG trucks can travel 400 miles.³³ The limited availability of fueling infrastructure also hampers deployment of natural gas trucks, and better infrastructure is a requirement for greater use.³⁴ However, fleet owners are often not faced with the same constraints that passenger vehicles owners are. Range requirements may not be as significant an issue, as fleet vehicles travel regular and known paths. Refueling can also take place at a centralized facility or along a set route.³⁵

Nevertheless, the profitability of CNG vehicle projects depends on the many variables inherent in fleet vehicle composition and use and refueling infrastructure costs. NREL conducted research into three different types of notional CNG fleets and refueling infrastructures that might be used by municipal governments: transit buses, school buses, and refuse trucks. This segment was targeted by NREL based on “the advantages of CNG, including long-term cost-effectiveness, more-consistent operational costs, increased energy security, reduced greenhouse gas emissions, reduced local air pollution, and reduced noise pollution.”³⁶ NREL’s research led to the creation of a model for fleet profitability that highlighted the importance of fleet size and vehicle miles driven in calculating the cost and benefits of CNG vehicles. It estimated payback periods of between 3 and 10 years that were sensitive to the costs related to refueling stations, vehicle conversion, operations, and maintenance.

This model, like others, includes the cost of building and operating centralized fleet refueling infrastructure and thus avoids the “chicken versus egg” refueling quandary that is challenging to non-fleet applications. If it were not for the lack of a public CNG refueling infrastructure, the decision to convert heavy-duty vehicles would be much more compelling as their high annual miles driven provide a much quicker return on the upfront cost of vehicle conversion than do fleet vehicles. One approach that may help to overcome the vehicle conversion versus refueling infrastructure hurdle is to focus on a subset of the high mileage, heavy-duty, tractor-trailer industry segment, namely, intercity transport as opposed to interstate.
In intercity regions with high tractor-trailer industry usage areas, a very small number of public CNG refueling stations can serve a large number and percentage of the heavy vehicle transportation segment. As illustrated in Figure 4, the United States has eleven “Megaregions” where tractor-trailers travel tens of thousands of miles annually, but never leave the confines of a relatively small geographic area. Natural gas infrastructure can be built out in these Megaregions, such as through the Texas Clean Transportation Triangle strategic plan shown in Figure 5. Nearly 75 percent of Texas intrastate heavy and medium transport occurs within the triangle, making it an excellent candidate for CNG infrastructure. Nominal public CNG vehicle refueling infrastructure in the eleven Megaregions could also prove sufficient to service the interstate CNG tractor-trailer segment for a significant portion of the nation and create enough consumer demand to encourage the installation of CNG refueling capability throughout the nation’s network of commercial truck stops.

**FIGURE 4: Megaregions in the United States**

![Megaregions in the United States](image1)

*Source: Regional Plan Association, 2012*

**FIGURE 5: Texas Clean Transportation Triangle**

![Texas Clean Transportation Triangle](image2)

*Source: Greater Houston Natural Gas Vehicle Alliance, 2010*

**PASSENGER NATURAL GAS VEHICLES**

While there are 159,006 retail gasoline stations in the United States in 2010, more than 65 million U.S. homes currently have natural gas service. Home refueling of a CNG vehicle requires the installation of a wall-mounted electric compressor to deliver the low-pressure gas from the residential system into the high-pressure CNG vehicle tank. The compressors are small and unobtrusive, but require several hours to fill the vehicles tank. Home refueling of CNG private vehicles, in addition to lower fuel prices may persuade some consumers to consider purchasing CNG passenger cars or to convert existing ones over from gasoline. However, other barriers to adoption exist. When compared with conventional gasoline vehicles, CNG vehicles have reduced range because of CNG’s lower energy density (Honda says the maximum range of the Civic GX NG is 248 miles).
higher up-front costs, and a smaller trunk capacity. The lack of a large national CNG refueling infrastructure is also a barrier.45

Electric vehicles are now available nationwide from multiple major automakers and are being marketed at passenger vehicle drivers. Great attention is paid to these vehicles throughout the public and private sectors because of the perceived opportunity they present to issues related to energy security, the environment, and the economy. However, market growth is highly uncertain due to policy, economic, and technical challenges. The C2ES-led An Action Plan to Integrate Plug-in Electric Vehicles with the U.S. Electrical Grid identified challenges and opportunities to PEV deployment including the need for a consistent regulatory framework for PEVs nationwide, the optimization of private and public investments in PEV infrastructure, and consumer education.46 To a great extent, the plan’s actions must be implemented for the electric vehicle market to compete with conventional vehicles without providing unwarranted public support.

PRICE PLAYS A PIVOTAL ROLE

A main driver of the discussion these increased uses of natural gas fleets and passenger vehicles is the relative abundance and low price of domestic natural gas, in comparison to oil. On April 30, 2012, the national average diesel fuel price was $4.07 per gallon and gasoline was $3.83,47 while a gasoline gallon equivalent of natural gas was $2.09.48 This price differential primarily results from the differential between the price of petroleum and natural gas, which on the same day were $104.87 per barrel for oil49 and $12 per energy equivalent of natural gas.50 In recent years, oil prices have risen while natural gas prices have decreased, creating an ever widening gulf between the two prices, as seen in Figure 6. This differential makes natural gas vehicles increasingly economical from the perspective of fuel costs.51

FIGURE 6: Oil price as a multiple of natural gas prices

Source: Energy Information Administration, 2012

EMISSIONS IMPLICATIONS OF NATURAL GAS VEHICLES

Depending on the type of natural gas technology used, natural gas vehicles offer a significant potential to reduce GHG emissions when compared to traditional gasoline and diesel vehicles. Figure 7 compares the total carbon intensity of diesel with gasoline LNG, CNG, and hydrogen from natural gas as determined by the California Air Resources Board for the purposes of California’s low carbon fuels standard, showing reductions in carbon intensity – up to 55 percent in the case of fuel cell vehicles.53 While natural gas fuels offer GHG emission reductions when compared to traditional transportation fuels, it is currently difficult to determine the precise carbon intensity of GTL products, as the technologies involved in production are in early stages of development and the emissions factors are not clear. While there are process emissions from GTL production, the CO2 emitted from facilities is pure and as such are a good candidate for carbon, capture, utilization, and sequestration.54
FIGURE 7: Total carbon intensity of selected transportation fuel options

<table>
<thead>
<tr>
<th>FUEL</th>
<th>TOTAL CARBON INTENSITY (GCO2E/MJ)</th>
<th>% CHANGE FROM GASOLINE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>95.85</td>
<td>0%</td>
</tr>
<tr>
<td>Diesel</td>
<td>94.71</td>
<td>-1%</td>
</tr>
<tr>
<td>LNG</td>
<td>83.13</td>
<td>-13%</td>
</tr>
<tr>
<td>CNG</td>
<td>68.00</td>
<td>-29%</td>
</tr>
<tr>
<td>Hydrogen for Fuel Cells</td>
<td>42.74</td>
<td>-55%</td>
</tr>
</tbody>
</table>

Source: California Air Resources Board, 2009

FIGURE 8: Transportation GHG Emissions by Source in 2010

Depending on the source of electricity, electric vehicle operation can be responsible for much lower greenhouse gas emissions than nearly all conventional vehicles available today on a well-to-wheels basis. A discussion of the increasing role of natural gas in the power sector is to be found in the paper “Natural Gas in the Power Sector.” In the near term, the effects of natural gas vehicle use on emissions will depend on the type of vehicles in which it is used, and the relative emissions levels from sources in 2010 is illustrated in Figure 8. Long-haul tractor-trailers account for two-thirds of all fuel consumption for freight trucks (medium- and heavy-duty trucks). In total, freight truck emissions are increasing more rapidly than other transportation sources and will account for a greater percentage of the sector’s GHG emissions over time, as trucking is taking on a greater portion of deliveries for consumer products, using more vehicles for just-in-time shipping, and taking advantage of lower labor costs and changing land use patterns. As such, reducing the carbon intensity from freight trucks will be critical to reducing transportation sector GHG emissions and increased natural gas use is one opportunity. Buses, meanwhile, are a very small share of overall GHGs, only 0.06 percent of on-road vehicle transportation emissions in 2003, despite the more common use of CNG buses.

Reductions of conventional air pollutants from natural gas vehicles are also notable. In a 2001 study conducted by the Department of Energy’s National Renewable Energy Laboratory (NREL) found that natural gas vehicles in the United Parcel Service CNG fleet emitted 95 percent less particulate matter, 75 percent less carbon monoxide, 49 percent less nitrous oxides and 7 percent less volatile organic compounds than their diesel-powered equivalents. This study is encouraging, however, emission reductions vary across vehicle application, age, and type of engine replaced. This complexity also extends to maintenance and operation cost comparisons between CNG-fueled vehicles and their diesel or gasoline equivalents. However, on average, there is little difference in maintenance costs as some applications run slightly higher and others slightly lower.

CONCLUSION

There are several ways in which natural gas use can be expanded in vehicular transportation. Each of them offers potential improvements in some combination of operating cost and reduced emissions, and all of them offset the use of petroleum, resulting in greater reliance on domestic fuel sources and enhanced energy security. There are, however, significant barriers to natural gas vehicles becoming a substantial part of the petroleum-fuels dominated transportation sector.
ENDNOTES


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