Natural Gas Use in Transportation

1. FCEV vs. NGV

What is the best use of natural gas for transportation? Is it better to burn that natural gas in an internal combustion engine (ICE) natural gas vehicle (NGV), or is it better to reform that natural gas to make hydrogen for a fuel cell electric vehicle? Converting NG to hydrogen is the clear winner for two reasons: less natural gas will be required to travel a given distance, and hydrogen in a FCEV will create less well-to-wheels greenhouse gases (GHG) than burning the NG in an NGV.

First consider efficiency. The steam reforming process to convert natural gas to hydrogen is approximately 75% efficient on a lower heating value basis, meaning that 25% of the energy is wasted in converting NG to hydrogen.

But a FCEV is up to 3 times more energy-efficient than an internal combustion engine. For example, the Toyota Highlander SUV that was converted to a FCEV has been certified by the DOE National Laboratory Engineers[1] to have an on-the-road fuel economy of 68.3 miles per kg of hydrogen consumed. This is equivalent to 69.1 mpg of gasoline on an energy equivalent basis[2]. The conventional Toyota Highlander is rated at approximately 22 mpg, so the FCEV version is 3.1 times more efficient.

So even after accounting for the 25% loss in making hydrogen, the net system efficiency of the FCEV using hydrogen from natural gas is:

3.1 x .75 = 2.325 times more efficient.

Thus the FCEV will travel 2.325 times farther on a given quantity of natural gas than a NGV, assuming that the ICE has the same efficiency running on natural gas as running on gasoline.

For example, suppose someone has 1 MBTU of natural gas. That natural gas can be converted to 0.75 MBTU or 6.6 kg of hydrogen. This is enough hydrogen to propel a FCEV for 68.3 miles/kg x 6.6 = 450.9 miles.

Assuming that the Highlander achieves the same fuel economy on natural gas as on gasoline or 22 mpg or gasoline, this is equivalent to 191.3 miles/MBTU. Therefore 1 MBTU of natural gas would propel the NG SUV for 191.3 miles.

However, the EPA lists the Honda Civic GX NGV at 29.39 mpg combined cycle (24 mpg city and 36 mpg highway) but 24.8 mpgge (21 mpg city and 29 mpg highway)

[1] See Keith Wipke (NREL), Donald Anton (Savannah River National Laboratory) and Sam Sprik (NREL), " Evaluation of Range Estimates for Toyota FCHV-adv Under Open Road Driving Conditions", Report # SRNL-STl-2009-00446, August 10, 2009, available at http://www.nrel.gov/hydrogen/pdfs/toyota_fchv-adv_range_verification.pdf

[2] Hydrogen has a LHV of 0.1136 MBTU/kg and gasoline has a LHV of 0.115 MBTU/gallon, so 68.3 miles/kg is equivalent to 68.3 x .115/.1136 = 69.1 mpgge.

for the gasoline Civic[3], or a 1.187 times improvement in fuel economy running on natural gas. If we apply this same improvement factor to the NG SUV, the 191.3 miles range on 1 MBTU of natural gas becomes 227 miles.

Bottom line on fuel economy: the FCEV could travel 450.9/227 =1.99 times farther than an NGV of the same size, assuming that the NGV ICE has 1.187 times better fuel economy than a gasoline ICE.

Near-Term GHG Emissions

In the next decade or so, the GHG emissions predicted by the Argonne National Laboratory GREET 1.8d model is summarized in this table:

	GHGs in grams of CO2-equivalent			
Fuel	ICV	FCEV	ICE HEV	PHEV-40 (Volt)*
Gasoline	405	N/A	290	310
Natural Gas	316	N/A	233	278
Hydrogen from NG	404	197	304	262
*Hydrogen PHEV is fuel cell electric vehicle		Car GHG and criteria pollutants.XLS; WS 'GHG' E92 5/25/2011		
(US ave grid mix; circa 2020)				

Making hydrogen from natural gas to use in a FCEV will cut GHGs 1.6 times more than burning that NG in a NGV, and 2.3 times more than burning the NG in a PHEV-40 such as the Chevy Volt.

Long-Term GHG Emissions

In the long-term, the hydrogen-powered FCEV will have even greater advantages over the NGV in terms of cutting GHGs, since hydrogen can be made from many low-carbon sources such as biomass, or electrolysis of water using renewable or nuclear electricity, or electrolysis using coal-based electricity with carbon capture and storage (CCS). As shown below, FCEVs could achieve society's goal of cutting GHGs by 80% below 1990 levels, while natural gas powered vehicles, even when hybridized could at best achieve a 47% reduction assuming that the natural gas was used to power a plug-in hybrid electric vehicle (PHEV) with a near-zero carbon electrical grid.

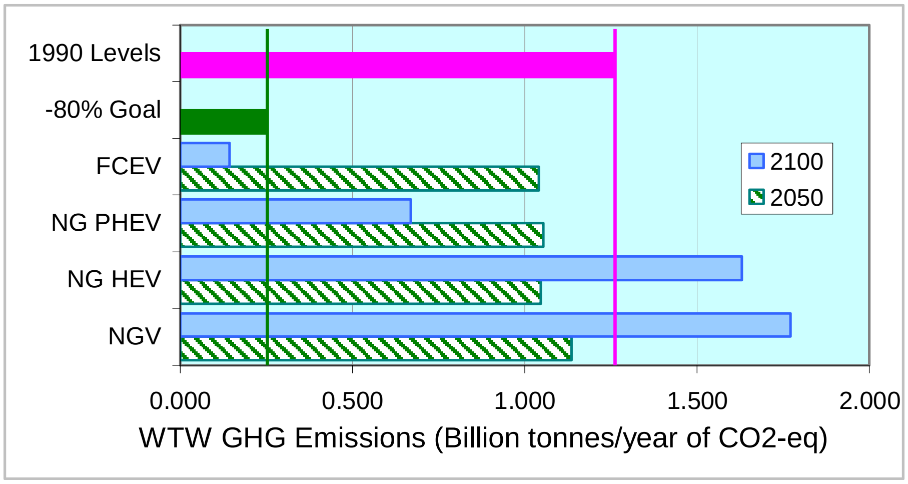
From a long-range perspective, using natural gas for transportation is a dead-end street. It still leaves us dependent on a non-renewable fossil fuel, and it has no prospect of achieving the deep reductions in GHGs needed to avert substantial climate change. In other words, natural gas is not sustainable, so converting to NGVs would be a wasted effort, since other approaches such as FCEVs and hydrogen will be required in the future to put us on a sustainable transportation energy path.

We have calculated the well-to-wheels GHG emission over the 21st century using the Naitonal Hydrogen Association's "Energy Evolution" model[4], comparing FCEVs

[3] See http://www.fueleconomy.gov/FEG/bifueltech.shtml

[4] See http://www.ttcorp.com/evolution/evolutionReport.pdf and, for more details on the simulation, http://cleancaroptions.com

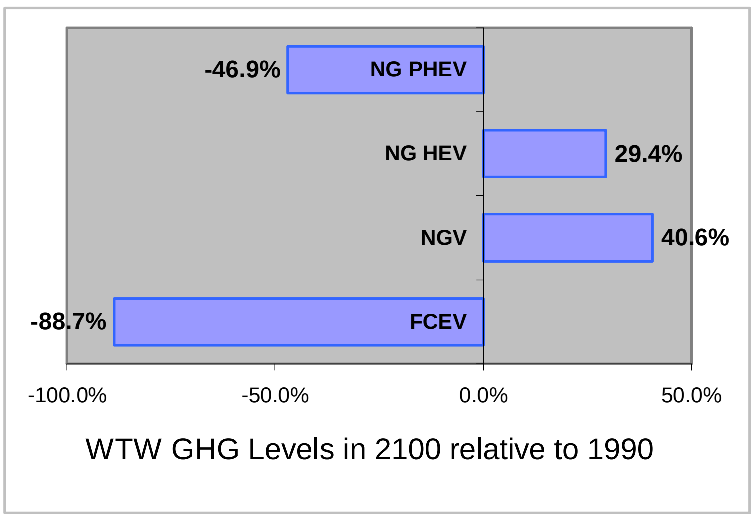
with NGVs, NG HEVs, and NG PHEVs. The GHG results are summarized in figure 1 for two years in the simulation; 2050 and 2100, showing that only hydrogen-powered FCEVs will achieve the societal goal of cutting GHG emissions by 80% below 1990 levels in the US.



NGV f.e. comparisons.XLS; Tab 'GHG'; D 112 5/3 /2010

Figure 1. Total US greenhouse gas emissions in 2050 and in 2100 for four scenarios: one dominated by hydrogen-powered fuel cell electric vehicles (FCEV); one by natural gas vehicles (NGV); one by natural gas-powered hybrid electric vehicles (NG HEV; and one dominated by natural gas-powered plug-in hybrid electric vehicles (NG PHEV).

The same data for 2100 are plotted in figure 2 in terms of the % reduction in GHG levels relative to 1990, showing that FCEVs can reduce GHG emissions by almost 89%, while NGVs, and even NG HEVs will increase GHGs by 29% to 40.6% over 1990 levels. A NG PHEV could cut 1990 GHGs by 46.9%, assuming a near zero-carbon electrical grid by 2100 which is included in the "Energy Evolution" model.



NGVf.e. comparisons.XLS; Tab 'GHG'; J 131 5/3 /2010

Figure 2. 2100 GHG emissions as a percentage below the 1990 levels for the four scenarios

Natural Gas Fueling Infrastructure Costs

While natural gas is available in most parts of the country, this gas must be pressurized and stored in high pressure tanks at the station to rapidly fill the NGV car tanks. Thus expensive gas compressors, storage tanks, and high pressure dispensers will be required at fueling stations to service NGVs. These three pieces of equipment make up from 70% to 74% of the cost of a hydrogen fueling station. Thus the costs for a natural gas high pressure fueling infrastructure will not be much less than the costs of building a hydrogen infrastructure. So the question for society is whether to invest this money in a temporary, non-sustainable transportation option (the natural gas supply is finite, and NGVs cannot meet our GHG reduction targets.), or should we instead begin building the long-term sustainable solution: hydrogen powered FCEVs?