Well-to-Wheel Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems

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In evaluation of energy use and greenhouse gas emissions from future vehicles technology and fuel options, it is important to consider the entire fuel cycle from resource recovery to vehicle operation. To evaluate future conventional, hybrid electric, and fuel cell vehicle operation, General Motors sponsored a study of Well-to-Wheel energy use and greenhouse gases. The study considered North America in the timeframe for the study was 2005-2010. The fuel production portion of the study, called Well-to-Tank was conducted by Argonne National Laboratory using the GREET model. Three energy companies—BP, ExxonMobil, and Shell—participated in the study by providing input and reviewing Argonne's results. The Tank-to-Wheel portion of the study was conducted by General Motors using its proprietary Hybrid Powertrain Simulation Program (HPSP). All pathways included a range of values for all estimates of data input, and probability distribution of results using Monte Carlo analyses.

In the Well-to-Tank portion, 75 different fuel pathways were analyzed for energy use and greenhouse gas emissions. These included three petroleum-based fuels: gasoline, diesel, and naptha. Natural gas-based fuels were: compressed natural gas, methanol, Fischer-Tropsch diesel, Fischer-Tropsch naptha, and gaseous and liquid hydrogen. Hydrogen production by electrolysis of water was also included for various electricity sources. Ethanol production from corn, woody cellulose, and herbaceous cellulose were included as well.

The Well-to-Tank analysis concluded that for the same amount of energy delivered to the tank for each fuel pathway, petroleum-based fuels and CNG have the lowest energy losses. Methanol, Fischer Tropsch liquids, compressed hydrogen from natural gas and corn-based ethanol have moderate energy losses. Liquid hydrogen from natural gas, electrolysis hydrogen, and cellulosic ethanol are subject to the largest Well-to-Tank energy losses. Greenhouse gas emissions were highest for production of hydrogen from via electrolysis using the U.S. electricity mix and production of liquid hydrogen from natural gas. Lowest greenhouse gas emissions were for production of ethanol from cellulose because of the absorption of CO_2 by plants.

Tank-to-Wheel modeling was performed for 15 combinations of fuels and vehicle architecture. These included conventional vehicles, hybrid electrics, reformer fuel cells and hydrogen fuel cells. A key objective of the vehicle study was to consider equal vehicle size and vehicle performance among all of the vehicle/fuel options. The vehicle modeled was a Chevrolet Silverado pickup truck. The truck was selected because with its high sales volume vehicle and relatively high fuel consumption, the impact of fuel savings can be very large. Emissions standards assumed were Tier II Bin 5 for all vehicles except the reformer fuel cell (Tier II Bin 2) and hydrogen fuel cell (Tier II Bin 1). The intent of the modeling was for the customer to sustain no performance degradation for the hybrid electrics or for the fuel cell vehicles. For example, all propulsion systems had to be able to sustain 55 mph on a 6% grade for 20 minutes.

The results of the Tank-to-Wheel analysis were expressed as miles per gallon of gasoline energy equivalent. The baseline truck with gasoline achieved 20 miles per gallon. Energy equivalent fuel economy improved 18% for diesel compared to gasoline. Hybrid electrics gave roughly 20% higher fuel economy than the non-hybrid counterparts due to regenerative braking and engine-off idles. This is somewhat smaller than have been shown for hybrids in other studies, and results from the requirements that customers not suffer performance degradation with hybrids. The hybrid gasoline reformer fuel cell truck gave about the same energy equivalent fuel economy to that of the diesel internal combustion engine hybrid—both were about 50% higher than the conventional spark ignition engine truck on gasoline. The methanol reformer hybrid vehicle had about 70% higher energy economy than for conventional gasoline spark ignition. Highest fuel economy was the hydrogen fuel cell hybrid—energy equivalent fuel economy was almost 2.5 times that of the conventional gasoline engine vehicle.

The fuel production and vehicle results were combined into total Well-to-Wheel results expressed as BTU/mile for energy consumption and grams CO_2 equivalent per mile for greenhouse gas emissions for 25 complete pathways. The lowest energy consumption was achieved with the diesel hybrid, gasoline reformer fuel cell hybrid, and the hybrid fuel cell fueled with gaseous hydrogen from natural gas. Although vehicle fuel economy was highest for the hydrogen fuel cell hybrid, production of hydrogen used more energy than production of gasoline or diesel fuel, resulting in nearly equal Well-to-Wheel energy consumption among these options. The full cycle energy consumption for the methanol reformer fuel cell was no better than that for gasoline reformer fuel cell vehicles. The ethanol vehicle options had higher total energy consumption than the petroleum and natural gas-based fuels, but this was primarily renewable energy. The fuel cell vehicle operating on hydrogen produced via electrolysis had the highest total energy consumption of all pathways examined.

Well-to-wheel greenhouse gas emissions were lowest for the vehicles fueled with ethanol from cellulose. The next lowest greenhouse gas emissions were for the fuel cell hybrid vehicles operating on hydrogen from natural gas (about 45% lower than conventional gasoline). The gasoline reformer fuel cell vehicle had greenhouse gas emissions 32% below those for conventional gasoline and the diesel hybrid engine vehicle had greenhouse gases about 27% below those for conventional gasoline.