Reducing the Green House Gas Emissions from the Transportation Sector

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ABSTRACT

In the United States, two thirds of the carbon monoxide and about one third of carbon dioxide emissions come from the transportation sector. Ways to reduce these emissions in the future include replacing gasoline and diesel by biofuels, or by blend of biofuels with conventional gasoline and diesel, or by compressed natural gas (CNG), or by replacing internal combustion engines by electric motors powered by hydrogen fuel cells or battery-powered electric vehicles recharged from the electric grid. This presentation will review these technologies the fuel production pathways, when they are likely to be available, and by what fraction transportation sector green house gas emissions could be reduced by each.

A well-to-wheels (WTW) analysis is performed on each vehicle/ fuel technology using the GREET model and the total energy use, the CO_2 emissions, NO_x emissions, SO_x emissions for the life cycle of the vehicle technologies are calculated. Prospects for reducing foreign oil dependence as well as mitigating green house gases emission from the transportation sector will be considered in the analysis.

Keywords: Green House Gas, Transportation, Reducing Emission and Life Cycle.

INTRODUCTION

In the United States, the transportation sector is responsible for more than half of the carbon monoxide (CO) and nitrogen oxide (NO_x) emissions and most of these emissions are contributed by light duty vehicles (LDV). In 2007, the transportation sector's share of U.S. emissions for CO was 68.4% while that for NO_x was 57.1% [1]. Ways of reducing transportation sector emission include behavioral change (i.e. less traveling), technological advancement through alternative fuels, more energy efficient drive trains and increased fuel economy.

Reducing vehicle miles travelled (VMT) is one of the effective ways of reducing emission. The amount of VMT increased from pre 1970 to November 2007 after which it has been decreasing till this present day [2]. Although, there has been improvements in reducing U.S. air pollution since the Clean Air Act was passed. However, newer and tougher regulations might prove impossible to attain by conventional gasoline and diesel that have dominated the transportation sector for long. Several alternative fuels such as compressed natural gas (CNG), Fisher-Tropsch diesel (FTD), dimethyl ether (DME), methanol, ethanol, liquefied petroleum gas (LPG), biodiesel to mention a few have been suggested as possible replacements to conventional gasoline and diesel because they have good fuel properties like high octane number, high cetane number, good lubricity and they also emit lesser GHGs. While some of these alternative fuels might generate lower tailpipe emissions, they have a lower energy density, tend to be more expensive, require new infrastructures for transportation, storage and dispensing, and some of these alternatives generate more well to pump (WTP) GHGs emissions compared to conventional gasoline. Technological advancement has led to more efficient drive trains such as plug-in hybrid electric vehicles, electric vehicles and fuel cell vehicles with higher fuel efficiency (miles per gallon) compared to spark ignition or compression ignition drive trains.

The objective of this study is to perform a detailed life cycle analysis (LCA) or well to wheel (WTW) analysis on various fuel and vehicle/ fuel technologies using the GREET model and propose concepts to reduce transportation GHG emissions. The alternative fuels and fuel/vehicle technology studied are subjected to various scenarios.

METHODS

To begin the GREET simulation, we first choose the year and the type of vehicle to be simulated, in this case we selected the year 2020 and passenger cars respectively. Year 2020 was used for this study because we expect the fuels selected to be commercially available by then. Also, we used passenger vehicles because it accounts for more than half of the GHGs emission in the transportation sector. The fuel pathway that is expected to be available by the year 2020 is then selected from the fuel pathway groups which consist of petroleum, natural gas/biomass/coal, bio-ethanol, hydrogen, biodiesel and electricity.

For the simulated year, the petroleum fuel types expected to be available in commercial quantities are gasoline, diesel and liquefied petroleum gas (LPG). Compressed natural gas (CNG), liquefied natural gas (LNG), Fischer-Tropsch diesel (FTD), methanol and LPG are the natural gas types expected to be in commercial quantities by year 2020. Ethanol fuel types and blends expected to be available are low level ethanol blend, which is a 5-15% by volume ethanol with gasoline or diesel mixture, a high level ethanol blend, which is a 50-90% by volume ethanol with gasoline mixture and 100% ethanol for fuel cell vehicles (FCV).

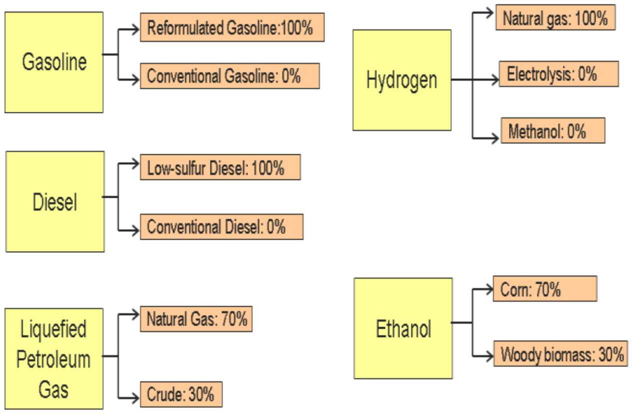

Figure 1: Fuel production pathways

The other fuel types and pathways that are selected in this study are gaseous hydrogen, biodiesel and electricity. Figure 1 shows the fuel production pathways used in this study. The expected market share for gasoline fuel in the year 2020 is 100% reformulated gasoline (RFG) and 0% conventional gasoline (CG). RFG has the same component with CG however, RFG is further processed to make it less evaporative, have fewer toxic components and contain oxygenates that improve combustion. Non attainment areas that did not meet up with the one hour ozone standard clean air act amendment of 1990 were required to use RFG. It first came into use in 1995 and had 28% of the market share [3].

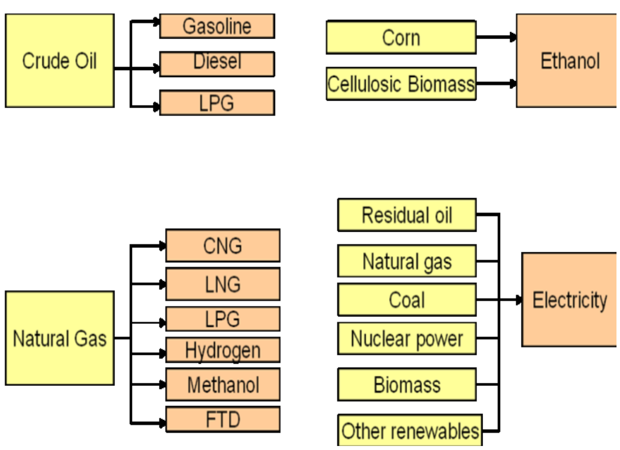

Figure 2: Assumed market share for GREET simulation

On road diesel vehicle were required to have much reduced sulfur level starting in 2006. This low sulfur diesel is expected to significantly reduce the NO_x emission in diesel engines. The assumed market share for the fuel used in this study is shown in figure 2.

For corn ethanol, the share of ethanol plant type is 90% dry milling plant (DMP) and 10% wet milling plant (WMP). The difference between the DMP and the WMP is the initial way the corn is processed and the value of its co-products. DMP has a lower capital and operating cost, it is more efficient and easier to operate while WMP produces a great variety of valuable co-products. 80% of the process fuel for the DMP is NG while 20% is coal. For the WMP, 60% of the process fuel is NG while 40% is coal. The vehicle technology used for ethanol are FCV for 100% ethanol, flexible fuel vehicle spark ignition (FFV SI) engine for high-level blend with gasoline, SI engine for low-level blend with gasoline and CIDI engine for low-level blend with diesel. The biomass ethanol pathway used is fermentation.

The vehicle technologies used for this study are the spark-ignition (SI) vehicles, the compressed-ignition direct-injection (CIDI) vehicle, the hybrid electric vehicle (HEV), the plug-in hybrid electric vehicle (PHEV), the fuel cell vehicle (FCV) and the electric vehicle (EV). Figure 3 shows the various vehicle/fuel technologies used in the study.

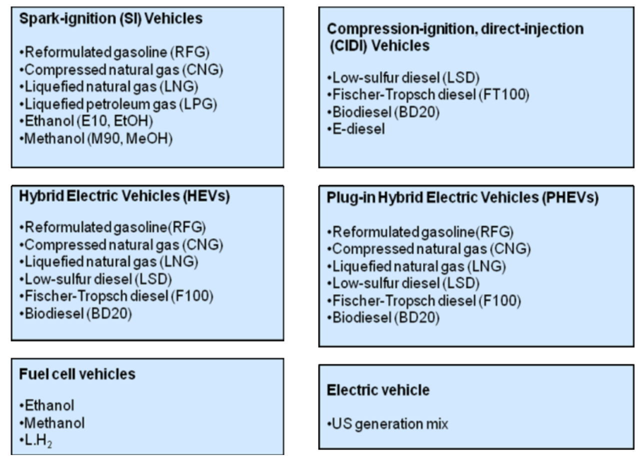

Figure 3: Vehicle/ fuel systems used in GREET simulation

An important part of the inputs required in the GREETGUI are the energy efficiency assumptions such as crude recovery efficiency, crude refining efficiency, natural gas processing efficiency etc. Due to lack of data in the literature, the fuel production assumptions used are the GREET default.

The well to wheel (WTW) analysis is split up into two LCA, the WTP which covers the feedstock and fuel production stages and the PTW which covers the vehicle operation stages. When regulations are made on vehicle emissions the emphasis is on the vehicle operation stage or the PTW analysis. Figure 4 illustrates the methods and steps used by GREET to estimate the energy and GHGs emission.

RESULTS

The output from the GREET simulation consists of the well to pump (WTP) result, the relative change results and the well to wheel (WTW) results. In the WTW result sheet, separate energy uses such as fossil fuels energy use, petroleum energy use and total energy (renewable and non-renewable energy) use are calculated.

The GHG emissions CO_2, CH_4 and N_2O and other transportation pollutants such as VOC, CO, PM and NO_x are also calculated. The WTP efficiency is calculated as:

$$Efficiency = \qquad\qquad +$$

Where 1,000,000 = 1 mmBtu of a given fuel available in vehicle tanks [4].

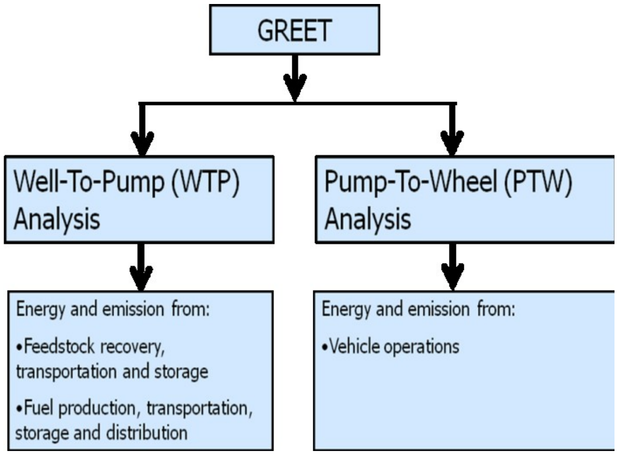

Figure 4: Methods and steps used to estimate green house gases emission

The relative change result tab shows the percentage WTW energy and emissions change of various vehicle technologies, and passenger cars relative to gasoline vehicle fueled with CG. The WTW results are separated into 3 stages: feedstock, fuel and vehicle operation. The feedstock and fuel stages covers the WTP calculations while the vehicle operation covers the PTW calculations. The feedstock stage includes feedstock recovery, storage and transportation while the fuel stage includes fuel production, transportation, storage and distribution. The vehicle operation stage calculates the fuel economy and emission rates of baseline gasoline and diesel vehicles, alternative fuel vehicles and advanced vehicle technologies.

The total energy use by various vehicle/fuel technologies comprises of all energy sources, fossil and non fossil. The fossil energy consists of coal, natural gas and petroleum. Figure 5 shows the total energy used by passenger cars in the year 2020. The best and worst cases for the different fuel types have been selected for better comparison.

It can be seen from figure 5 that the flexible fuel vehicle using Ethanol 85 (E85) uses the most energy while the hydrogen fuel cell vehicle uses the least energy. For gasoline vehicles, E85 uses a lot of energy due to the amount of energy required to gather, process and transport corn ethanol and also due to the low energy density of ethanol compared to conventional gasoline. It should be noticed however that more than half of the total energy used by E85 is renewable. The spark ignition – hybrid electric vehicle (SI-HEV) using reformulated gasoline (RFG) uses the least energy life cycle for the gasoline vehicles studied. This is due to the better vehicle efficiency of the SI-HEV compared to a regular SI vehicle. For diesel vehicles, Fischer-Tropsch diesel (FT100) uses the most amount of energy per mile due to the vast amount of energy required to process and transport coal from its source to the point where it is needed. Liquefied natural gas (LNG) uses the most energy per mile out of the natural gas vehicles most likely due to the energy required to liquefy natural gas. Among the plug-in hybrid electric vehicles (PHEVs) and electric vehicles (EVs), FT100 PHEV uses the most energy per mile due to its feedstock being coal as explained earlier. An ethanol fuel cell vehicle uses the most energy per mile out of the FCVs studied. However, most of the energy used is renewable.

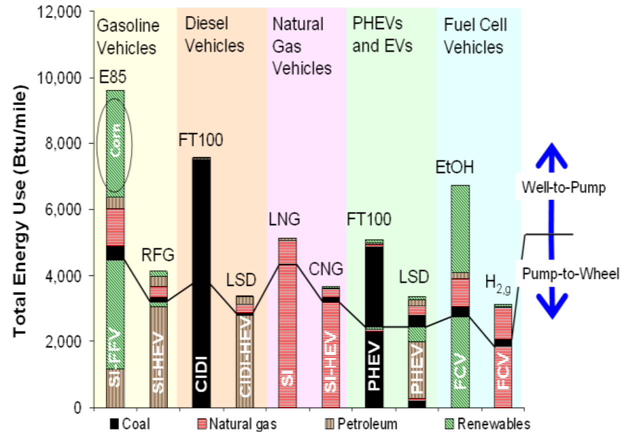

Figure 5: Total energy use by passenger cars

The fuel type that uses the least energy for gasoline, diesel and natural gas vehicles are RFG SI-HEV, LSD CIDI-HEV and CNG SI-HEV respectively. One thing that is common among these vehicles is that they are all hybrid electric vehicles (HEVs) and they are more efficient than either the spark ignition (SI) or compression ignition direct injection (CIDI) vehicle trains. The low sulfur diesel (LSD) PHEV uses the least energy per mile out of the PHEVs and EVs because diesel is more energy efficient than gasoline or natural gas and the US electric mix used to power the EV contains about 48% of coal which uses a lot of energy to produce electricity. The hydrogen fuel cell vehicle uses the least energy per mile out of the fuel cell vehicles studied.

Choosing a vehicle/fuel system could be a difficult task as some of the fuels use high energy per mile (such as E85) but have low green house gases (GHGs) emission. Figure 6 shows the best and worst case GHGs emission of the different fuel types considered.

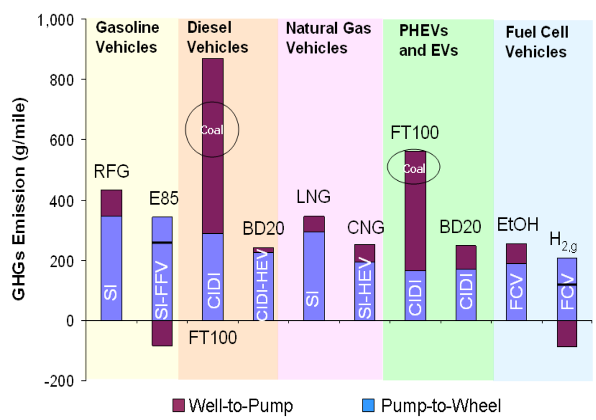

Figure 6: Greenhouse gases emission by passenger cars

For gasoline based vehicles, the reformulated gasoline (RFG) has the most GHGs emissions per mile while the E85 has the least emission per mile. The corn used to make E85 is renewable and uses CO2 from the atmosphere when it is growing and therefore counts as a negative GHG emission in that part of its life cycle. Out of the fuel type studied, the FT100 has the most GHGs emission due to its feedstock coal. The mining, transportation and processing of coal produces a lot of GHGs emission. It should be noted that using coal as the feedstock for FT100 uses a lot of energy per mile and emits a lot of GHGs in it life cycle. However, coal is strategic to the US because of its abundance and it is seen as an energy source that helps lead to energy independence. The least emitting diesel fuel type is 20% biodiesel also called (BD20) used with the HEV. This is because of the combined efficiency of the CIDI-HEV and the 20% renewable energy (from soybean) contained in the biodiesel. Similar trend is found in the PHEVs and EVs except that the energy used and emission is lower in this case due to the energy efficiency of the PHEVs and EVs. The natural gas vehicle with the least emission is the CNG SI-HEV while that with the most emission is the LNG SI vehicle technology. Three fuel cell vehicles (FCVs) methanol, ethanol and hydrogen were considered in this study. The methanol FCV has the most GHGs emission while the ethanol FCV has the least GHGs emission. This is because methanol and hydrogen were made from natural gas which is a fossil fuel while ethanol is made from corn and woody biomass which is renewable.

In one of the scenarios studied, corn and woody biomass was varied in market shares to see the energy and environmental effect of both on ethanol production. Figure 7 is a well to wheel analysis showing the total energy used per mile for 100%, 70% and 0% market share of corn for ethanol production.

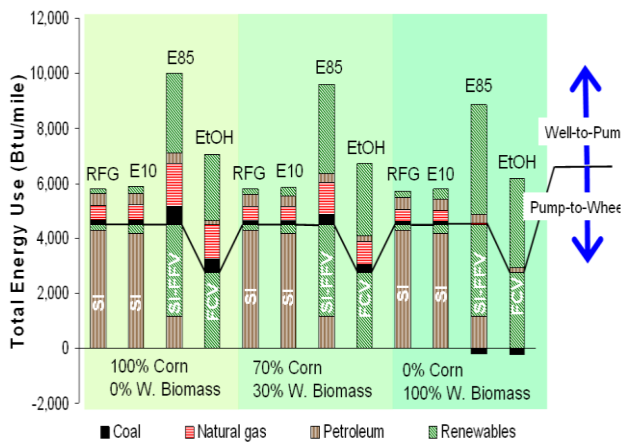

Figure 7: Total energy use for passenger cars using various ethanol shares

From figure 7 it can be seen that there is a little reduction in the total energy used to produce ethanol when moving from 100% corn, 0% woody biomass to 0% corn and 100% woody biomass. Woody biomass has several advantages over corn as a source for ethanol production. The main advantage is that woody biomass is not a food crop and will not negatively affect the price of food produce for human consumption. Also, since lesser energy is used to process, transport and distribute woody biomass as compared to corn, lesser fossil fuel is being used by woody biomass.

The overall greenhouse gas emission from woody biomass is significantly lesser than that from corn for ethanol production. Figure 8 is a plot showing the green house gases emission from varying market shares of corn and woody biomass for ethanol production.

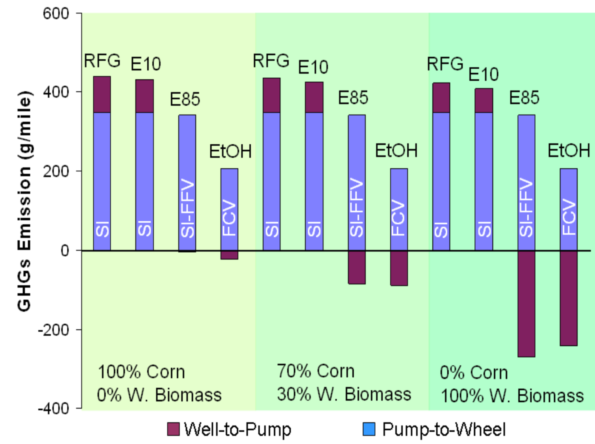

Figure 8: Green house gases emission for passenger cars using various ethanol shares

From figure 8 it can be seen that the GHGs emissions in the well-to-pump analysis decreases from 100% corn, 0% woody biomass to 0% corn and 100% woody biomass. This shows that woody biomass has more GHGs emission reduction during its growth, fuel processing, transportation and distribution compared with corn. The production of ethanol through corn fermentation reduces GHGs emission by about 24 g/mile while ethanol production via fermentation of woody biomass reduces GHGs emission by about 249 g/mile. Thus, it is favorable to produce ethanol from woody biomass from an energy, emission and social viewpoint.

Another scenario was studied to compare the energy use and GHGs emission of Fischer-Tropsch (FT) diesel using natural gas and coal as feedstock. At present, natural gas is cheaper than gasoline on a parity basis and is the cleanest fossil fuel available. There has been suggestion to convert natural gas to a liquid fuel through FT synthesis so as to increase its energy density and make it a suitable alternative transportation fuel.
Coal is the most abundant fossil fuel available in the US. Most people have suggested that in order for the US to be energy dependent and be *free* from foreign oil, it has to look for a way to convert coal into a liquid fuel for transportation. The conversion of coal to liquid can be done by first gasifying the coal and then passing the syngas product through the FT synthesis. Figure 9 shows the well-to-wheel analysis of the total energy used for FT diesel in a passenger vehicle using coal and natural gas feedstock.

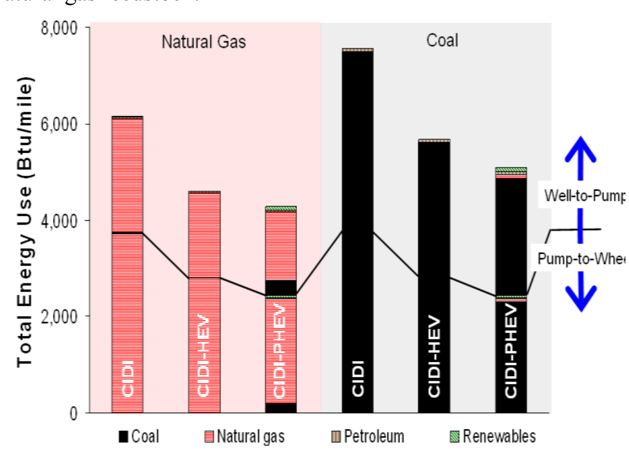

Figure 9: Total energy use for passenger cars using FT diesel from coal and natural gas

From figure 9 it can be seen that depending on the vehicle technology, coal uses about 1000 Btu/mile more than natural gas for the whole life of the FT diesel. At the moment, natural gas has a share of about 0.1% of transportation fuel and is relatively cheap. Therefore, it will be logical to use natural gas for FT diesel rather than use coal. However, if the share of natural gas as a transportation fuel increases, the price will also increase and natural gas might become too expensive the higher energy life cycle analysis of coal counterbalances that of natural gas from an economic viewpoint.

The GHGs emission from coal was significantly larger than that from natural gas as expected since natural gas has a lower carbon ration while coal has a higher nitrogen and sulfur content. Figure 10 shows a comparison between the GHGs emission from FT diesel using coal and natural gas as feedstock.

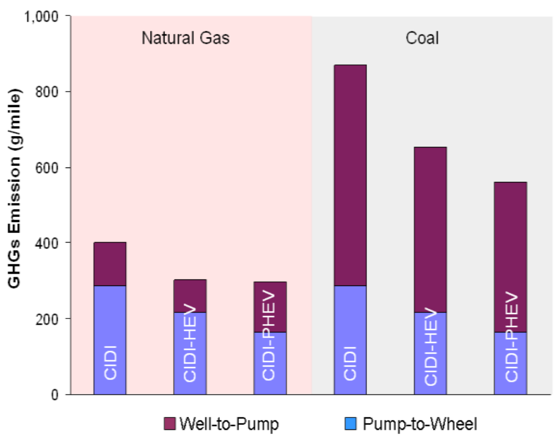

Figure 10: Green house gases emission for passenger cars using FT diesel from coal and natural gas

From figure 10 it can be seen that depending on the vehicle technology used, the GHGs emission from coal is two times or more than that from natural gas. If carbon capture and sequestration (CCS) were considered in this analysis, the GHGs emission from coal would reduce significantly and could be as low as that of natural gas.

CONCLUSION

The life cycle analysis of the alternative transportation fuels for passenger cars has been performed using the GREET model. The analysis is divided into two stages, Well-to-Pump (WTP) and Pump-to-wheel (PTW). The fuel spark and compression ignition vehicle types have the same PTW energy use but the WTP energy use varies due to different feedstock processing and transportation. Reformulated gasoline (RFG) has the same PTW energy use with low level ethanol blend (E10) and high level ethanol blend (E85) but has a lower WTP energy use than E10 and significantly lower than E85. About half of the WTP energy use for E85 is renewable energy; however its fossil energy use is still higher than the WTP energy use for RFG due to the high energy required to process corn. Using woody biomass to replace corn as a feedstock for ethanol production will reduce both the total life cycle energy of the fuel as well as the GHGs emission.

Vehicle technologies play a major role in reducing the GHGs emission in the transportation sector. Hybrid electric vehicles and plug-in hybrid electric vehicles reduce GHGs emission by about 28% and 32% respectively compared with conventional gasoline while hydrogen fuel cell vehicles can reduce GHGs emission by about 51%.

The production of Fischer-Tropsch (FT) diesel from coal is inefficient from both energy and emission viewpoints. FT diesel from coal has the same PTW energy use and GHGs emission compared with that for natural gas. However, FT diesel from coal has a much higher WTP energy use and GHGs emission due to its processing, distribution and transportation. Therefore, FT diesel from natural gas is a better alternative when compared with FT diesel from coal. However, it uses more energy over its life cycle when compared to compressed natural gas. Green house gases emissions can be reduced from the transport sector by improving the efficiency of the vehicle through technological advances in vehicle technologies and through the use of automotive fuels that have lower carbon atoms.

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