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Environmental impact and sustainability study on biofuels for transportation applications

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ABSTRACT

A review on lifecycle analysis of energy consumption and greenhouse gas (GHG) emission for various biofuel vehicles has been performed. Four potential vehicular biofuels are simulated: corn ethanol, switchgrass ethanol, soybean biodiesel, and bio-hydrogen from corn ethanol. A fuel-cycle model developed at Argonne National Laboratory, called the GREET model, is employed to evaluate the biomass-to-tank (BTT) energy and emissions impacts of various biofuels. The fuel economies of three types of vehicles, i.e., flexible fuel vehicles (FFVs), diesel vehicles (DVs), and fuel cell vehicles (FCVs) are also determined using the simulation tools in MATLAB/Simulink. The effects of replacing conventional gasoline vehicles (GVs) by the aforementioned biofuel vehicles on the lifecycle GHG emission and energy consumption are examined. The results showed that the FFVs fueled with an ethanol fuel blend of 85% switchgrass ethanol and 15% gasoline (E85) have the greatest benefits in GHG emission reduction by 59.4%, but suffer from 101.3% total energy consumption compared to the baseline system.

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1. Introduction

Currently, the transportation sector accounts for approximately 50% of the global oil consumption and produces approximately 25% of the global energy-related CO_2 emissions [1]. Therefore, improving energy security and decreasing vehicle contributions to greenhouse gas (GHG) emissions and air pollution become primary goals compelling governments to seek alternatives to the petroleum fuels currently dominating transportation. Over the past few decades, several fuel candidates have emerged, such as liquefied petroleum gas (LPG) [2–5], compressed natural gas (CNG) [6–9] and electricity for electric vehicles (EVs) [10–15]. The above fuel alternatives have some benefits over petroleum, but they also show a number of drawbacks that reduce their ability to capture the market share. For example, they all require significant vehicle modifications and a new fueling infrastructure. As a result, except in a few places, both automakers and fuel suppliers are disinclined to make substantial investments in such an uncertain market. In contrast, biofuels have the potential to overcome the traditional barriers mentioned above. They have been regarded as sustainable options for reducing petroleum-dependence and GHG emissions in the transportation sector. In addition, biofuels could share the existing distribution infrastructure with little modification. In fact, many countries are implementing the use of biofuels. Low-percentage bioethanol blends, such as 10% bioethanol in conventional gasoline (known as E10), are already dispensed in many refueling stations worldwide [16], with a high level of compatibility with materials and equipment. In addition, biodiesel is also currently blended with conventional diesel in many countries, ranging from 5% (BD5) in France to 20% (BD20) in the USA, and is used as a neat fuel (100% biodiesel) by some trucks in Germany [17]. Expanding the use of biofuels would support several major policy objectives:

- Energy security: Biofuels can readily replace petroleum fuels and, in many countries, can provide a domestic rather than an imported source of transport fuel. Even if imported, ethanol or biodiesel will likely come from regions other than OPEC (Organization of Petroleum Export Countries), creating a broader global diversification of supply sources of transport fuels.
- Environment: With lower GHG emissions over the whole fuel chain, biofuels are generally more climate-friendly than petroleum fuels. Either in their neat form or as blends with conventional petroleum fuels, vehicles running on biofuels emit less of some pollutants that exacerbate air quality problems, particularly in urban areas. Reductions in some air pollutants are also achieved by blending biofuels, though some other types of emissions (e.g., NOx) might be increased this way.
- Fuel quality: Refiners and automakers have become interested in the benefits of ethanol to boost fuel octane, especially where other potential octane enhancers, such as MTBE, are discouraged or prohibited.

The objective of the present paper is to study the lifecycle performance of biofuel vehicles using simulation tools. A biomass-to-wheels (BTW) analysis is performed to assess the potential benefits in energy savings and GHG-emission reductions for applying biofuels to the transportation sectors. As shown in Table 1, three types of biofuel vehicles, i.e., flexible fuel vehicles (FFVs), diesel vehicles (DVs), and fuel cell vehicles (FCV), are studied to investigate the effects of replacing conventional gasoline vehicles (GVs) on the GHG emission and the total energy consumption. First, the fuel economy is determined by using the simulation tools in MATLAB/Simulink [18]. Then, a comprehensive analysis of fuel-cycle energy consumption and GHG emissions for various biofuels is conducted using the GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) code. As shown in Table 2, three types of biomass-feedstock are studied in the pre-

Table 2
Assumptions of biofuel production.

Feedstock	Items	Unit	Assumptions
Corn	CO2 emissions from domestic land use change by corn farming	g/bushel	447
	CO2 emissions from foreign land use change by corn farming	g/bushel	285
	Corn farming energy use	Btu/bushel	9142
	Ethanol production energy use: dry mill	Btu/gallon	26,856
	Ethanol production energy use: wet mill	Btu/gallon	47,409
Switchgrass	CO2 emissions due to domestic land use change by switchgrass farming	g/dry ton	−433
	CO2 emissions due to foreign land use change by switchgrass farming	g/dry ton	541
	Switchgrass farming energy use	Btu/dry ton	123,700
	EtOH yield from switchgrass fermentation plant	gallons/dry ton	90
	Electricity co-product in switchgrass fermentation plant	kWh/dry ton	205
Soybean	Soybean farming: energy Use	Btu/bushel	16,560
	Soyoil extraction: energy Use	Btu/lb of soyoil	3551
	Transesterification: bio-oil se	lb of bio oil/lb fuel	1.04
	Transesterification: Energy Use	Btu/lb fuel	1844

Table 1
Biofuel vehicles associated with fuel pathways.

Vehicles	Biofuels	Feedstock		Production process
		Group	Specification	
Flexible Fuel Vehicles (FFVs)	Bioethanol	Starch-based biomass	Corn	Fermentation
		Lignocellulosic biomass	Switchgrass	
Diesel Vehicles (DVs)	Biodiesel	Soybeans		Trans-esterification
Fuel Cell Vehicle (FCVs)	Bio-hydrogen	Corn ethanol		Reforming