Renewable Non-GHG Fuels for U.S. Transportation

Rama Subba Reddy Gorla*, Rashid Salako and Robert Hatszegi

Department of Mechanical Engineering, Cleveland State University, Cleveland, OH, USA

Abstract: The U.S. non-renewable crude oil reserve is diminishing at the rate of billion barrels per year and the climate change has been a growing concern over the past decade. Both challenges can be solved by using renewable non-greenhouse gas (GHG) alternative fuels that will secure cleaner fuel for the transportation industry and provide benefits to the environment. Renewable fuels for the U.S. transportation are biofuels (ethanol and biodiesel) and their secondary sources (hydrogen and electricity) derived from biomass energy source. The objective of this article is to demonstrate the pathway for replacing the U.S. transportation non-renewable fuels (oil and petroleum, hydrocarbon gas liquids, natural gas) with renewable fuels. The goal of this article is to systematically phase-out all greenhouse gas causing U.S. transportation fuels with clean and most efficient hydrogen-based renewable fuels by 2050, the year predicted for the U.S. crude oil depletion.

Keywords: Biomass, Biofuel, Fossil fuel, Hydrogen, Electricity, Transportation, Energy, Renewable.

1. INTRODUCTION

The U.S. Congress created the renewable fuel standard (RFS) program to reduce greenhouse gas emissions and expand the nation's renewable fuels sector while reducing reliance on imported oil. This program was authorized under the Energy Policy Act of 2005 and expanded under the Energy Independence and Security Act (EISA) of 2007. The Clean Air Act requires EPA to set the RFS volume requirements annually. The annual standards are based on the statutory targets. EISA requires EPA to evaluate and in some cases adjust the standards. The EISA includes four categories of RFS, displayed in Figure **1**, where a category with higher greenhouse gas reduction percentage can be used for a lower counterpart's requirement. For example, cellulosic biofuel (D3) can be used to meet conventional renewable fuel (D6) standards requirements.

In 2010, EPA established a process for companies to petition for new fuels pathways to qualify for Renewable Fuel Standard (RFS) [1]. A fuel pathway is a specific combination of three components: (1) feedstock, (2) production process and (3) fuel type. Assessment of lifecycle greenhouse gas (GHG) emissions is necessary to determine which fuel pathways can qualify. A feedstock is a type of renewable biomass that is converted into a renewable fuel. The production process is the type(s) of technology used to convert renewable biomass into renewable fuel. Renewable fuels include liquid and gaseous fuels and electricity derived from renewable biomass energy sources. To qualify for the RFS program, the fuel must be intended for use as transportation fuel, heating oil or jet fuel.

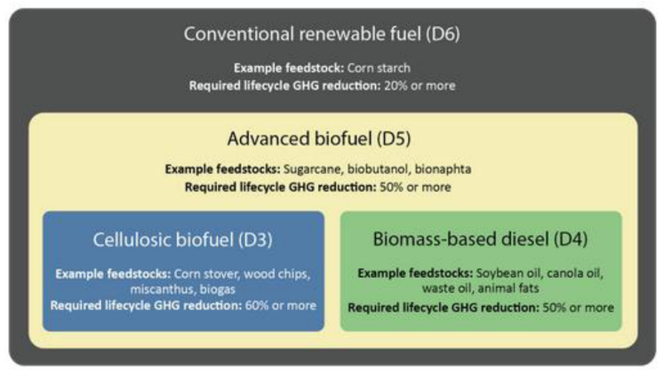

Figure 1: Renewable Fuel Standards Requirements.

This system puts emphasis and incentive on the production and biofuel conversion by use of advanced biofuels, however, these advanced biofuels may not perform as well compared to cornstarch nor be economically viable when considering the net energy balance. For example, soybean consumes large amounts of energy than it produces when compared to corn starch. Therefore, the following Figure **2** supports this statement since the U.S. federal government requires larger volumes of corn use compared to conventional biofuel volume.

2. U.S. DEMAND FOR TRANSPORTATION FUELS

The United States is a nation on the move. About 29% of U.S. energy consumption in 2016 was for transporting people and goods from one place to another [1]. There are different types of energy sources or fuels used for transportation in the U.S. Petroleum

*Address correspondence to this author at the Department of Mechanical Engineering, Cleveland State University, Cleveland, OH, 44115 USA.;
Tel: 216-687-2567;
E-mail: r.gorla@csuohio.edu;
salakosolar@gmail.com; mailto:r.gorla@csuohio.edu

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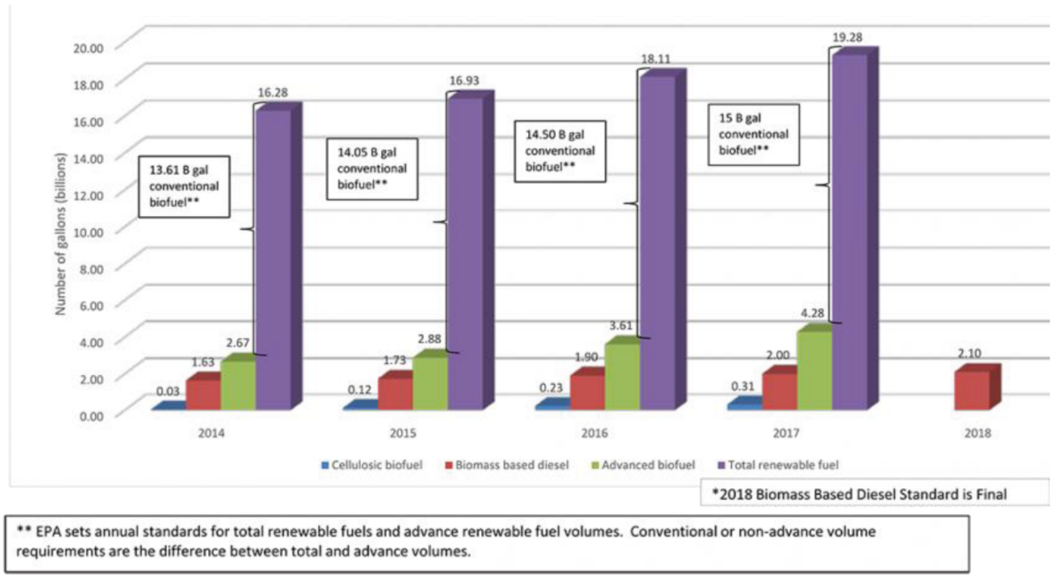

Figure 2: Final Renewable Fuel Volume Standards from 2014 to 2018.

products made from crude oil and petroleum liquids that result from natural gas processing, including gasoline, diesel fuel, jet fuel, residual fuel oil, and propane; biofuels made from ethanol and biodiesel; natural gas; and electricity produced from many different energy sources.

Petroleum is the main source of energy for U.S. transportation. In 2016, petroleum products provided about 92% of the total energy the U.S. transportation sector used [1]. Biofuels (ethanol and biodiesel) were some of the first fuels used in automobiles, but they were later replaced by gasoline and diesel fuel. Today, most of the biofuels used in vehicles are added to gasoline and diesel fuel. Biofuels, such as ethanol and biodiesel, contributed about 5% of the total energy the transportation sector used, and natural gas contributed about 3%. Electricity provided less than 1% of the total energy used. Illustrated in Figure **3** is the average annual fuel use (per vehicle) of major vehicle categories in the US. Fuel use is measured in gasoline-gallon equivalents (GGEs), representing a quantity of fuel with the same energy content as a gallon of gasoline.

Gasoline is the most commonly used U.S. transportation fuel. Gasoline includes aviation gasoline and motor gasoline used in vehicles and in landscaping and construction equipment. Gasoline, excluding fuel ethanol, accounted for 55% of total U.S. transportation energy use in 2016 [1]. According to the U.S. Energy Information Administration's (EIA) ***INTERNATIONAL ENERGY OUTLOOK 2017*** (IEO2017), the global supply of crude oil, other liquid hydrocarbons, and

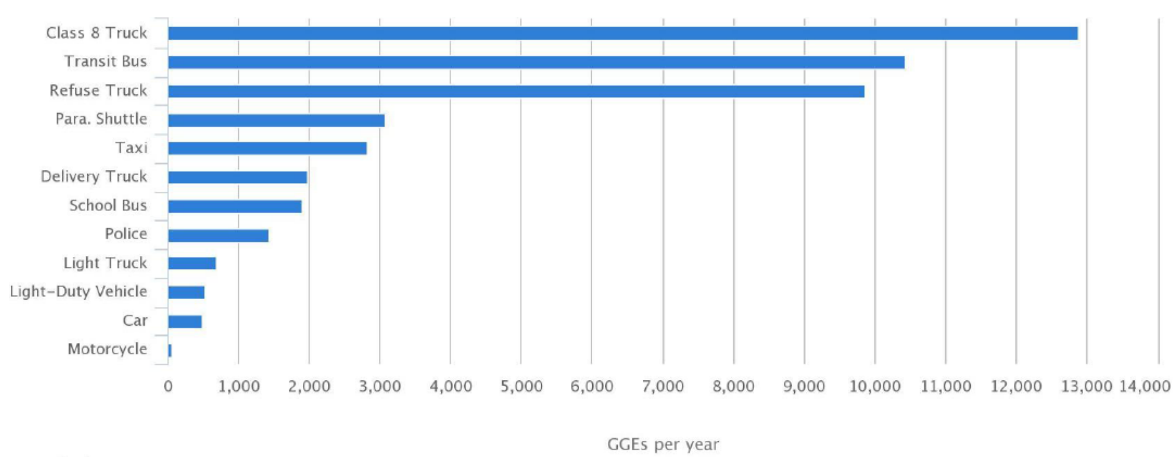

Figure 3: Average Annual Fuel Use (per vehicle) of Major Vehicle Categories in the US, Federal Highway.

biofuels is expected to be adequate to meet the world's demand for liquid fuels through 2050.

Today, the U.S. gets most of its imported oil from Canada and Latin America, and roughly the same amount of oil from Africa as it does from the Persian Gulf [2]. Whereas the developments in oil production have been widely reported and appreciated, far less attention has been paid to U.S. petroleum consumption's remarkable decline relative to both recent levels and past projections. Petroleum consumption in the U.S. was lower in 2014 than it was in 1997, even though the economy grew almost 50% over this period. As illustrated in Figure **4**, consumption rose steadily from 1984 through the early 2000s, peaking in 2004 before decreasing in conjunction with rising oil prices.

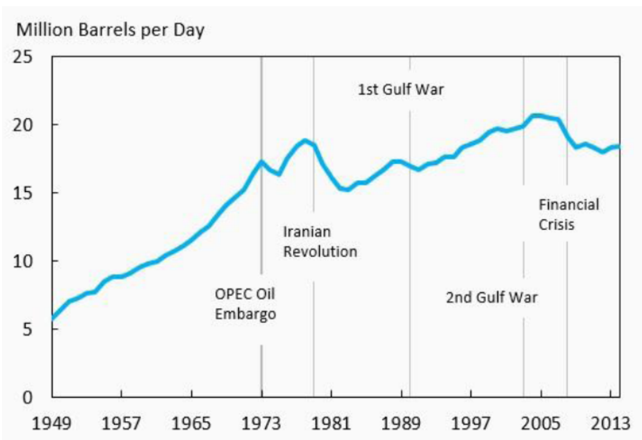

Figure 4: US petroleum consumption, 1949-2014, EIA.

The leveling off US petroleum consumption was largely unanticipated. In 2003, the U.S. EIA, projected that consumption would steadily grow at an average annual rate of 1.8% over the subsequent two decades. Consumption in 2025 was projected to be 47% higher than its 2003 level. The actual path that consumption has taken, however, diverges dramatically from this projection, as illustrated in Figure **5**. Consumption in 2014 was slightly below 2003 consumption, and about 25% below the projections for 2014 that were made in 2003. In 2016 and 2017, U.S. consumed an average of about 19.63 and 19.88 million barrels of petroleum-per day, respectively.

Importantly, there has also been a large unexpected increase in ethanol consumption relative to 2003 projections. Given the large and growing importance of fuel economy standards and ethanol, this analysis suggests that federal government policy has, and will continue to have, a substantial effect on U.S. petroleum consumption and on overall carbon emissions reductions by the transportation sector.

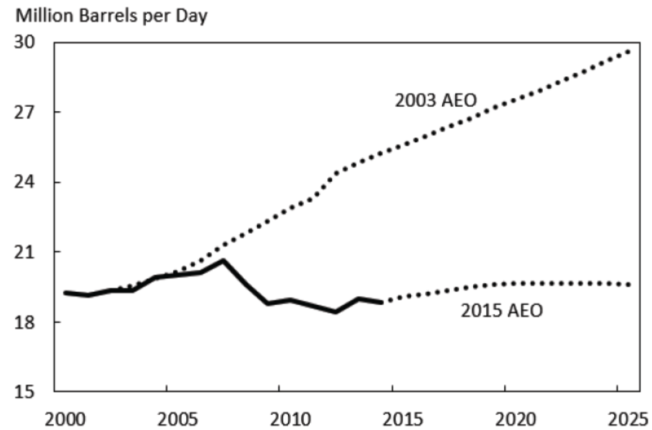

Figure 5: Total US petroleum consumption, 2000-2025, EIA.

3. U.S. SUPPLY OF BIOFUEL FOR TRANSPORTATION

Biofuel is currently the only viable replacement for hydrocarbon (petroleum) transportation fuels. Energy content in a liter of petrol gives 33.5 million Joules while ethanol gives 23.5 million Joules [3]. The concept of alternative biofuels has been around since modern transportation when the diesel engine was released. In 2007, the U.S. government promoted ethanol use as a transportation fuel to help reduce oil imports and CO_2 emissions. As a result, nearly all gasoline now sold in the U.S. contains some ethanol. Biofuels may be carbon-neutral because the plants that are used to make biofuels, such as corn for ethanol and soy beans for biodiesel, absorb CO_2 as they grow and may offset the CO_2 emissions when biofuels are produced and burned [3].

In 2007, the U.S. government set a target to use 36 billion U.S. gallons of biofuels by 2022. The EPA's standards also required that biofuel use and production increased annually at approximately 18%, for total renewable fuels from 2014 through 2018. This includes an increase in cellulosic biofuel of approximately 933%, biomass of approximately 23%, and advanced fuels of approximately 60%. EPA officials announced ethanol production for 2018 would be set at 19.29 billion gallons, up from 19.28 billion gallons in 2017. The table below provide the annual volume and percent standards that have been finalized for 2010 to 2013 and proposed for 2014-2017. Biofuels are broken down into generations, so here we talk about the four main categories under which biofuels fall: First-, second-, third-, and fourth-generation biofuels [4].

Annual Volume Standards (million gallons)								
	Final	**Final**	**Final**	**Final**	**Proposed**	**Proposed**	**Proposed**	**Proposed**
Biofuel Category	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Cellulosic biofuel	6.5	6	0	0.8	33	106	206	
Biomass-based diesel	1,150	800	1,000	1,280	1,630	1,700	1,800	1,900
Advanced biofuel	950	1,350	2,000	2,750	2,680	2,900	3,400	
Total renewable fuel	12,950	13,950	15,200	16,550	15,930	16,300	17,400	

Notes: (1) All volumes are ethanol-equivalent, except biomass-based diesel which is actual. (2) EPA has proposed to set the 2011 cellulosic standard at zero. (3) In a January 2013 decision, the D.C. Circuit Court vacated the 2012 cellulosic standard. (4) EPA reduced the 2013 cellulosic standard in the Direct Final rule in April 2014.

3.1. First Generation Biofuels

They are produced directly from food crops by abstracting the oils for use in biodiesel or producing bioethanol through fermentation [4]. In the U.S., corn is the most widely used feedstock for bioethanol while soya bean is for biodiesel. There is much debate over their benefit in reducing greenhouse gas and CO_2 emissions since some biofuels can produce negative net energy gains, releasing more carbon in their production than their feedstock's capture in their growth. The most contentious issue with first generation biofuels is fuel vs food.

The biodiesel industry has steadily grown over the past decade, with commercial production facilities from coast to coast. The industry reached a key milestone in 2011 when it crossed the one-billion-gallon production mark for the first time. In 2016 the market was record high 2.8 billion gallons, according to EPA. The industry's total production continues to significantly exceed the biodiesel requirement under the RFS Standard and has been enough to fill most of the Advanced Biofuel requirement. Biodiesel reduces greenhouse gas emissions by up to 86 percent, according to the EPA.

3.2. Second Generation Biofuels

Also known as advanced biofuel have been developed to overcome the limitations of first generation biofuels. They are produced from non-food crops such as wood, organic waste, food crop waste and specific biomass crops, therefore eliminating fuel vs food. They are aimed at being more cost competitive in relation to existing hydrocarbon fuels. Their life cycle assessments have indicated that they will increase net energy gains [4]. There's increased efficiency that uses most of the biomass feedstock, avoiding the waste seen in first-generation biofuel production. However, they are little more difficult to extract and need advanced conversion technologies in the process, which is also why they are known as advanced biofuels.

U.S. cellulosic ethanol production rose to 10 million gallons in 2013, a milestone but still a tiny fraction of the 2007 Energy Bill's original 5.5 billion-gallon mandate for 2017 and a small part of total U.S. ethanol production of 15.8 billion gallons. Switchgrass cellulosic ethanol can meet the demand if making it on a commercial scale. A perennial prairie grass native to North America, switchgrass requires little water or fertilizer to grow and thrives in places unsuitable for most crops, ranging from the Gulf of Mexico to Canada and from the Atlantic to the Pacific. Some five to nine feet tall, this gangly weed also yields twice as much ethanol per acre as does corn. According to "Growing Energy," a 2004 Natural Resources Defense Council (NRDC) report on biofuels, the U.S. is on track to consume 290 billion gallons of gasoline for transportation in 2050. By boosting fuel efficiencies and reigning in urban sprawl, the report says, we could feasibly cut this figure down to 108 billion gallons. NRDC has forecasted that the number of gallons of ethanol produced per ton of dry switchgrass could jump from 50 gallons to 117 gallons by 2050. Crop experts say that current averages of five dry tons of grass per acre could easily double under a standard breeding program. These combined boosts in efficiency mean that enough switchgrass could be grown on a reasonable chunk of land to produce 165 billion gallons of ethanol by 2050. And because one gallon of ethanol contains 66 percent of the energy content of gasoline, 165 billion gallons of ethanol equates to 108 billion gallons of gasoline. The biochemical process for producing cellulosic ethanol is illustrated in Figure **6**.

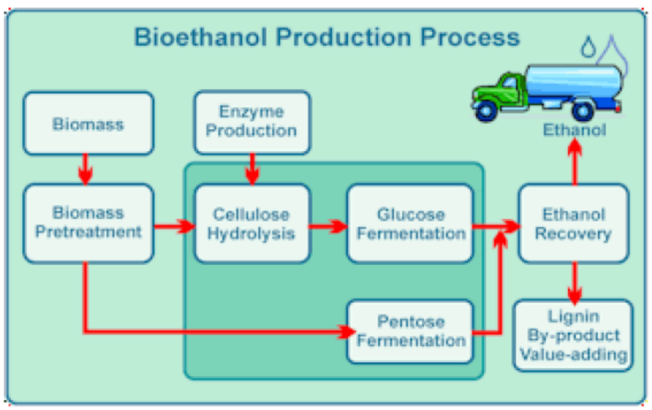

Figure 6: Making ethanol from cellulosic feedstocks.

3.3. Third Generation of Biofuels

They are based on improvements in the production of biomass. Algae impressive diversity can produce such fuels as biodiesel, butanol, gasoline (petrol), ethanol, and even jet fuel. Algae higher yields can produce much more than its other feedstock counterparts, and with lower resource inputs. It takes advantage of specially engineered energy crops such as algae as its energy source [4]. The algae are cultured to act as a low-cost, high-energy and entirely renewable feedstock. It is predicted that algae will have the potential to produce more energy per acre than conventional crops. Algae can also be grown using land and water unsuitable for food production, therefore reducing the strain on already depleted water sources. A further benefit of algae-based biofuels is that the fuel can be manufactured into a wide range of fuels such as diesel, petrol and jet fuel.

3.4. Fourth Generation Biofuels

They are aimed at not only producing sustainable energy but also a way of capturing and storing CO_2. Biomass materials, which have absorbed CO_2 while growing, are converted into fuel using the same processes as second-generation biofuels. This process differs from second and third generation production as at all stages of production the carbon dioxide is captured using processes such as oxy-fuel combustion [4]. The carbon dioxide can then be geo-sequestered by storing it in old oil and gas fields or saline aquifers. This carbon capture makes fourth generation biofuel production carbon negative rather than simply carbon neutral, as it locks away more carbon than it produces. This system not only captures and stores carbon dioxide from the atmosphere, but it also reduces CO_2 emissions by replacing hydrocarbon fossil fuels.

4. PHASING OUT GREENHOUSE GAS FUELS BY 2050

If the goal is to have a clean sustainable fuel for transportation, U.S. must also phase out plants and animals that produces GHG for transportation fuel. A most viable replacement for petroleum fuels are electricity and hydrogen. In the long-term, hydrogen will simultaneously reduce the dependence on foreign oil and the emission of greenhouse gases and other pollutants. Research is underway to develop other ways to produce hydrogen [5]. These methods include microbes that use light to make hydrogen such as in fermentative conversion organic, converting biomass into liquids and separating the hydrogen, and using solar energy technologies to split hydrogen from water molecules. Also, hybrid design methods involving CO_2 for steam-reforming-algae and biological-algae hydrogen.

4.1. Renewable Fuel Standard Hydrogen Fuel

Only hydrogen separated from biomass meets the fuels pathways to qualify for the RFS. The interest in hydrogen as an alternative transportation fuel is based on hydrogen's ability to power fuel cells in zero-emission electric vehicles, its potential for domestic production, and the fuel cell vehicle's potential for high efficiency. A fuel cell is two to three times more efficient than an internal combustion engine running on gasoline [5].

4.1.2. Steam-reforming-algae hydrogen (fourth generation)

Steam reforming is currently the least expensive way to produce hydrogen, and it accounts for most of the commercially produced hydrogen in the United States [6]. This method is used in industries to separate hydrogen atoms from carbon atoms in methane (CH_4). The steam reforming process results in carbon dioxide emissions. By some estimates, algae can produce 10-fold what even the best conventional feedstocks can generate [6]. While algae using CO_2 to generate fat is not new, it's the amount of fat produced by the algae that's noteworthy. Fatty algae make the strain more fit to eventually produce biofuels at an industrial scale. Success in developing algae-based biodiesel at commercial levels will provide several tangible benefits.

4.1.3. Biological-Algae Hydrogen (Fourth Generation)

Biological hydrogen can be produced in bioreactors that use feedstocks other than algae, the most common feedstock being waste streams. The process involves bacteria feeding on hydrocarbons and excreting hydrogen and CO_2. The CO_2 can be sequestered successfully by several methods, leaving hydrogen gas. A prototype hydrogen bioreactor using waste as a feedstock is in operation at Welch's grape juice factory in North East, Pennsylvania [7].

4.1.4. Fermentative Hydrogen

Fermentation hydrogen can be produced in fermentative conversion of organic substrate to biohydrogen manifested by a diverse group of bacteria using multi enzyme systems involving three steps like anaerobic conversion. Dark-fermentation reactions do not require light energy, so they are capable of constantly producing hydrogen from organic compounds throughout the day and night. Photo-fermentation differs from dark fermentation because it only proceeds in the presence of light. Electrohydrogenesis used in microbial fuel cells where hydrogen is produced from organic matter (*e.g*. from sewage, or solid matter) [7].

4.2. Hydrogen Fuel Cells Vehicles

In the U.S., about 500 hydrogen-fueled vehicles are in use, and about 330 of those are registered in California [8]. Most hydrogen-fueled vehicles are automobiles and transit buses that have an electric motor powered by a fuel cell. A few of these vehicles burn hydrogen directly. The high cost of fuel cells and the limited availability of hydrogen fueling stations have limited the number of hydrogen-fueled vehicles. In the U.S., about 55 hydrogen refueling stations for vehicles are operating. About 30 of these stations are available for public use, nearly all of which are in California [5]. Hydrogen fuel cells vehicles have shown to produce zero emissions and can be used as a benchmark for other vehicle types for their greenhouse gas emissions. However, the environmental benefits from fuel cell vehicles are confirmed by using hydrogen from clean feedstocks and efficient production pathways. In terms of reducing total emissions with new advanced biofuels, General Motors concludes that well-to-tank and tank-to-wheel should be closely monitored to ensure the production and processing yields environmental benefits. Figure **7** demonstrates that fuel cell vehicles require substantially less energy to produce when comparing to conventional internal combustion engines (Well-to-Wheels, 2005) [9].

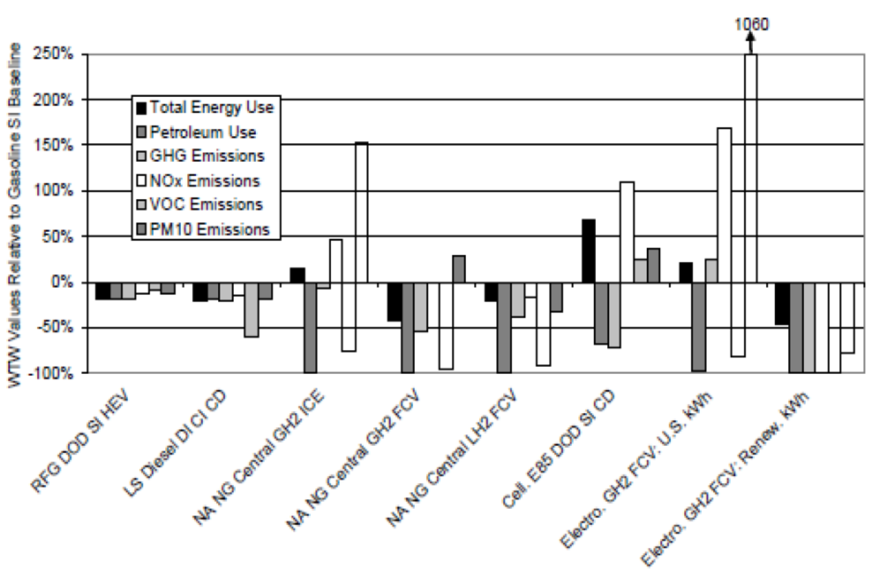

Figure 7: WTW Values - Comparison of HEV, ICE, FCV.

CONCLUSION

Using biomass for energy has positive and negative effects. The United States will use over 130 billion gallons of gasoline this year, and over 50 billion gallons of diesel. On average, one bushel of corn can be used to produce just under three gallons of ethanol. If all the present production of corn in the U.S. were converted into ethanol, it would displace 25% of that 130 billion. We should remember that humans originally switched from biomass to fossil fuels because biomass was so inefficient and took so much energy and space to produce. So far technology has not fully reversed these problems sufficiently to make widespread use beneficial. However, John Deere has made investments in autonomous vehicles for agricultural use to reduction the cost of production while Xyleco, Inc. has researched and invented advanced processes to produce cellulosic ethanol from corn stover [10, 11].

The production of hydrogen cars is limited because people won't buy hydrogen cars if refueling stations are not easily accessible, and companies won't build refueling stations if they don't have customers with hydrogen-fueled vehicles. The United States government should promote hydrogen as a transportation fuel as it did in 2007 for ethanol, to help fund the development of publicly accessible hydrogen refueling stations throughout the United States to promote a consumer market for zero-emission fuel cell vehicles.

A resurgence in the energy carrier is now underway, notably by the forming of the Hydrogen Council in 2017. Several manufacturers have now released hydrogen fuel cell cars commercially, with non-U.S. manufacturers planning to increase numbers of their cars into the hundreds of thousands over the next decade. The U.S. has the technology and know-how and should take the lead in hydrogen vehicle economy.

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