Impact of Biofuels on the Reduction of Greenhouse Gas Emissions

Over the last few decades, renewable energy sources have surged into the energy arena, providing viable alternatives to the non-renewable energy sources that humans have been consuming at alarming rates. Renewable energy is a source of energy that does not deplete as it is used; it can be regenerated naturally over and over, and is therefore theoretically an infinite pool of energy. While there are many different kinds of renewable energy sources in existence—including solar power, wind power, and geothermal energy—one option seems particularly promising, because it could actually be used as a direct substitute for fossil fuels. Bioenergy is one of the only renewable resources that can be made into liquid fuel, called biofuel, which could ultimately replace gasoline and diesel used in vehicles today.

According to the Department of Energy, “in the future, renewable liquid fuels that are functionally equivalent to petroleum fuels will be available, meaning older cars will not need to be replaced to be renewable” (2018). Alternatively, other renewable solutions for transportation, such as electric cars—while undoubtedly better for the environment than the burning of fossil fuels—would necessitate replacing every vehicle that is currently on the road. Hence, biofuels offer an appealing opportunity for a more sustainable future. However, the reality of producing bioenergy is a complex process, and this resource may not be as efficient as it seems. Considerations such as land use, water use, the effect on surrounding biodiversity, and the overall energy efficiency of this renewable resource need to be taken into account in order to interpret if this bioenergy is indeed a viable option to replace fossil fuels.

According to the 2013 Intergovernmental Panel on Climate Change (IPCC) report, it is “extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century” (IPCC, 2013). Since one of the two main anthropogenic causes for climate change is greenhouse gas emissions (Kump, 2010), governments worldwide are promoting the development of these renewable resources that would eliminate the need to burn conventional fuels, and would consequently reduce the emission of greenhouse gases. If biofuels were to completely replace petroleum-made fuels, nearly 900 percent of all corn cropland in use would be necessary to meet the demand (Patzek, 2004). This kind of massive overhaul of existing farmland—and the ensuing creation of more croplands—would undoubtedly have immense impacts on the environment, and therefore should only be considered under careful analysis.

Let’s take a step back and look at the basics of how biofuels work. Bioenergy is a renewable energy source that is derived from organic matter (including plant materials or animal waste), called biomass.

The process is straightforward: in order to grow, plants preform photosynthesis, a process that removes carbon dioxide from the atmosphere in order to create the energy they need. Through this process, plants convert atmospheric carbon into organic carbon that remains within the plant itself. When biomass is converted into bioenergy and is burned, the combustion releases back into the atmosphere the same amount of carbon that it initially removed during the photosynthesis that took place during the growth of the supply of biomass (Delucchi, 2010).

This seems like a clearly preferable option over the burning of fossil fuels, which releases carbon into the atmosphere that had been sequestered in the earth’s crust for millions of years—a process that is a leading cause of climate change (IPCC, 2013).

There are two types of biofuels that are currently in widespread use today: ethanol and biodiesel. Of the two, ethanol production has been developed and researched more thoroughly by far, and will therefore be the focus of this paper. Ethanol is an alcohol that can be made from a variety of plant materials through a process called fermentation, in which microorganisms, such as yeast and bacteria, consume the sugars in biomass plants and produce ethanol as a byproduct (Department, 2018). Ethanol is currently used as a blending agent with gasoline—most gas stations currently offer a blend that is made up of 90 percent gasoline and 10 percent ethanol—in order to make vehicles more efficient and to cut down on emissions that cause smog. According to the Department of Energy, “roughly 97% of gasoline in the United States contains some ethanol” (2018). The majority of the ethanol in the U.S. today is made from corn, though it is also currently being sourced from wheat, barley, potatoes, sugar cane, and other crops (Ethanol, 2018). Researchers are currently attempting to develop technologies that would allow the large-scale production of ethanol from other, non-edible sources of biomass; several such refineries that are operational today (Department, 2018).

The concept of biofuels replacing petroleum fuels would be would be foolproof, were it not for the fact that supplies of biomass, called feedstock, do not simply pop out of the ground in large quantities of their own accord. Massive amounts of energy must be put into planting, growing, harvesting, processing, and transporting the feedstock—so much energy, in fact, that some believe that this particular resource has a net impact that is actually worse than the burning of fossil fuels. One study found that powering a vehicle with ethanol would have caused more carbon emissions than powering that same car with non-renewable gasoline (DeCicco, 2016). Over an eight-year period, DeCicco et al. took into account such factors as carbon emissions and uptake between the vehicle and the atmosphere, land-use changes due to increased need for biomass growth, and production emissions, and concluded that the long-standing notion that biofuels were “inherently carbon neutral” was incorrect (2016). It should be noted, however, that this particular study was funded by the American Petroleum Institute, which has great monetary interest in the continued use of fossil fuels, and therefore is not likely to conduct an unbiased review of biofuels (Upton, 2016). DeCicco et al. concluded that ethanol was not a valuable resource for governments to invest in; however, they were only concerned with ethanol that was made from corn, which, it turns out, may not be the most effective source of biomass.

It is possible to produce biofuels from many different crops—and some are more environmentally friendly than others. For example—even though the majority of today’s ethanol comes from corn—soybeans, sugarcane, switchgrass, poplar trees, and more can all be made into ethanol. A key factor in keeping the environmental impact of biofuel low is the use of crops that don’t require as much fertilizer, water, or other energy-intensive inputs. Many studies have been conducted on the overall efficiency of different types of biomass, using such comparisons as net energy yield, energy inputs and outputs, and carbon dioxide and other greenhouse gas emissions needed to produce the crops, and nearly all of them agree that corn is not an efficient source of biomass. One study found that corn-based ethanol yields less energy overall than is actually required to produce it (Pimentel, 1991). Dias de Oliviera et al. concluded that, in addition to the greenhouse gas emissions associated with corn-based ethanol, there were additional problems as well, such as soil erosion and substantial groundwater usage, that make corn a poor choice for a source of biofuel (2005).

Yet another review of corn ethanol concluded that, while there was a marginal greenhouse gas emission reduction associated with biofuels when compared to petroleum fuel, biofuels could cause other environmental and human risks (such as the release of airborne pollutants and pesticide use) that ultimately disqualified it as an environmentally friendly substitute for fossil fuels (Hill, 2006).

Cellulosic ethanol—or ethanol that is made from low-impact perennial crops like switchgrass and poplar trees—may have greater potential to be an energy efficient source of biofuel, as it requires far less energy input to cultivate than corn does (Hoover, 2009). For example, fewer fertilizers and pesticides are needed to cultivate switchgrass than are required in order to grow corn (Schmer, 2008). Perennial crops, which are plants that are alive all year-round and can be harvested many times before they need to be re-planted, do not need to be completely cleared and re-planted each season, which translates into reduced use of farming equipment, water, and fertilizers. Therefore, the net carbon dioxide emissions are much lower for perennial-grown ethanol than for ethanol made from corn, which is an annual crop (Hoover, 2009).

The type of land that is used to grow the crops can also have an impact on the net efficiency of any biomass used to make biofuel. Corn must be grown on premium cropland that could otherwise be used for growing edible crops (Hoover, 2009). Cellulosic crops, on the other hand, can be grown on marginal cropland, which is land that is of little value in agriculture, and therefore is not being put to good use as cropland, economically speaking. Additionally, multiple types of plants can be cultivated on marginal cropland, which helps to alleviate the disadvantages of a monocultured plot of land, which include larger water requirements, decreased soil fertility, and soil erosion (Schmer, 2008). The pollution runoff from marginal cropland is far lower than that of premium cropland as well (Schmer, 2008). According to one research review conducted by Hoover et al., which took into account many individual studies on the on the efficiency of different types of biomass, “taken together, the advantages of cellulosic ethanol over corn-based ethanol is strongly apparent” (Hoover, 2009).

It is important to note that Field et al. did conclude that marginal croplands produce biofuels that, in turn, produce a lower yield of energy (2018). However, the efficiency of biofuels cannot be the only factor taken into account in this analysis. Since corn is grown on land that is healthy enough to be used to cultivate food, repurposing this land to make fuel could lead to increased food prices, or even food shortages in the long run (Hoover, 2009). Overall, the use of marginal cropland to grow biofuels is the most efficient option: very little energy input is needed to cultivate crops on marginal cropland and is therefore worth the trade-off of slightly less efficient biofuels (Hoover, 2009).

Where the croplands are physically located is yet another factor to consider when examining the total environmental impact of biofuel production. Croplands situated nearer to a biorefinery have an exceptionally lower environmental impact than those that are located farther away from a refinery (Field, 2018). This is due to the fact that the raw organic material would not have to travel very far by truck or train in order to become biofuel, so the transport emissions of those biofuels would be reduced.

Converting more land to feedstock farms would also have an impact on the surrounding water supply. As stated above, we would need 900 percent of the corn cropland in use to produce enough biofuels to replace fossil fuels completely (Patzek, 2004). It stands to reason that we would also need 900 times the fresh water that is being used to grow corn now, in order to make that dream a reality. Of all the water on the planet, only 2.5 percent is fresh water, the majority of which (about 70 percent) is stored in the polar ice caps and is unavailable for human use (Facts, 2018). The remaining 30 percent flows through lakes, rivers, aquifers, and soil, or is held in the atmosphere. Conventional agriculture practices are already the largest user of freshwater around the world (Facts, 2018). Before biofuels can be considered a sustainable resource, their water needs must be addressed. Since cellulosic crops require far less water to cultivate than does corn, a shift toward cellulosic crops would already greatly reduce the strain on this limiting resource.

Other steps can be taken in addition to help conserve fresh water. One solution is to use treated or recycled water instead of fresh ground and surface water for crop irrigation. All across the United States, farms are collecting their livestock's liquid waste in wastewater lagoons, where the liquid is treated to reduce the nutrient concentration and then stored (Singh, 2013). A study conducted by Stone et al. found that using this wastewater on biomass feedstock actually increased the yields of that particular crop (2008). This led to a greater overall biofuel energy yield from the same size cropland. In this sense, the benefits of the use of treated wastewater are threefold: it provides enough water to make the increase of biomass cultivation a viable option in the future without putting as large a strain on the natural water supply; it increases the potential energy available from the feedstock; and it offers a waste management solution for the farmers who own the livestock.

Another possible way to conserve water is to implement controlled drainage practices. In this scenario, man-made structures control the water level in croplands so that water can be held in times of draught, or released to avoid submerging in times of plentiful rainfall (Singh, 2013). This process increases a crop's water-use efficiency, and can also greatly reduce the fertilizer-rich run-off from agricultural lands that can often cause damage to the local water supply (Singh, 2013).

Yet another concern is the effect of an increasing amount of cropland on the surrounding biodiversity. Biodiversity itself is a broad concept that encompasses every plant, insect, and animal species, as well as the subtle ways in which they interact, and can often be difficult to measure or quantify; therefore, it can be overlooked when considering large-scale land-use shifts, such as the conservation of wild acreage into cropland. Habitat loss, invasive alien species, pollution, and climate change can all wreak havoc on the delicate balance of an ecosystem, and have all been associated with the introduction of biofuel production in any given environment (Singh, 2013).

However, there are some ways in which these negative effects on the local biodiversity can be mitigated or avoided. First and foremost, new cropland should not be created in areas where there are endangered or threatened species present, so as not to disrupt their habitats. It is also beneficial to use lands that are already degraded, such as marginal croplands or previously abandoned croplands and pasture lands, as they can still serve a purpose while reducing the need for deforestation. Additionally, while an increased production of corn cropland would likely negatively impact local wildlife, perennial biomass crops may have potential conservation benefits (Singh, 2013). A study conducted by Robertson et al. found that grassland birds—which have seen dramatic population loss as their habitats have been converted into croplands—could thrive in certain perennial biomass feedstocks (2011). This benefit could be twofold, because these birds would also provide a level of pest control, which would decrease the need for harmful pesticides (Robertson, 2011).

Again and again, it has been shown that the use of perennial biomass crops, especially on marginal cropland, are a far superior choice for biofuel production. Why then, is corn-based ethanol still being produced in such large quantities? The answer is simple: because it is cheap to grow. Field et al. found that the choices a farmer may make—with regards to which crop to grow, what type of land to use for feedstock growth, and how much fertilizer to use—directly related to the price of clean fuels and the cost of greenhouse gases (2018). They concluded that if carbon pollution were taxed, farmers would be motivated to choose to grow efficient biomass for biofuels (such as perennial crops like switchgrass and poplars), which would reduce greenhouse gas emissions and make the farmers a profit at the same time (Field, 2018). In the absence of a carbon tax, farmers may choose to spend more money on fertilizers, which would ultimately lead to more carbon emissions and would reduce the efficiency of this type of renewable resource.

We must forget the longstanding notion that biofuels are inherently sustainable just because they are technically a renewable resource. In fact, much of the biofuel production that is currently in place is actually releasing more greenhouse gas emissions into the atmosphere than the combustion of conventional fossil fuels is. There is great potential for biofuels to become a better alternative to fossil fuels, but there would need to be a delicate, carefully considered balance in order to ensure that this solution did not cause further environmental damage. If the correct crops are chosen, if those crops are grown on the right type of cropland, if they are grown with the most sustainable practices, and if the best interests of the surrounding ecosystems are kept in mind, biofuels could one day be a viable substitute for conventional fossil fuels.