A REVIEW ON SECOND GENERATION BIOFUEL: A COMPARISON OF ITS CARBON FOOTPRINTS

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ABSTRACT

The aim of this paper is to compare the First-generation and Second- generation biofuels in terms of their carbon footprint in the environment. From this study, the carbon footprint of First generation biofuels was found to reduce the greenhouse gas effect by 78% while the Second generation biofuels reduce greenhouse gas by 94% when compared to the greenhouse gas effect caused by Fossil fuels. The viability of the first generation biofuels production is however proved to be less attractive because of the conflict not only with food supply but also because of its high carbon footprint. Moreover, energy balance and energy efficiency of different types of biofuel were analyzed and variable factors were proposed so as to provide a balanced analysis. Also, areas of research and development need in second –generation biofuels technology were highlighted.

Keywords: Second Generation, Biofuel, Carbon, Footprint.

INTRODUCTION

Biofuels are drawing increasing attention worldwide as substitutes for petroleum-derived transportation fuels to help address energy cost, energy security and global warming concerns associated with liquid fossil fuels. The term biofuel is used here to mean any liquid fuel made from plant material that can be used as a substitute for petroleum-derived fuel. Biofuels can include relatively familiar ones, such as ethanol made from sugar cane or diesel-like fuel made from soybean oil, to less familiar fuels such as Di methyl ether (DME) or Fischer-Tropsch liquids (FTL) made from lignocellulosic biomass.

One of the primary arguments currently facing biofuel scientists involves the use of first-generation versus second-generation biofuels. First-generation biofuels, primarily consisting of ethanol and biodiesel, are derived from sugars, starches, and oils, and the crops used to create these fuels compete with food crops for the use of agricultural land and water. Moreover, although burning ethanol and biodiesel releases less carbon than burning petroleum, these biofuels are frequently made and processed in ways that harm the environment and can result in more deforestation, pollution, water use, and release of greenhouse gases than with fossil fuels (Fargione , 2008). As a result, scientists, politicians, and the public are looking to genomics to find new energy sources and ways to convert biomass into usable energy.

Efforts in this area have led to advances in second-generation biofuel production that focus on the extraction of energy from lignocellulosic biomass sources. Unlike the easily processed sugars and oils in first-generation biofuels, lignocellulosic biomass consists of matter composed of the woody, inedible parts of plants, such as grasses, crops, and forest waste. One advantage of using these materials is that they are not typically grown on agricultural land, thus removing competition between use of this land for food production and use of this land for fuel production.

However, the challenge in the use of lignocellulosic biomass is that its cellulose comes bonded to Hemicellulose and lignin. Hemicellulose is more difficult to ferment than cellulose, but through genome-scale studies of the various enzymes present in yeasts and fungi, various cellulases and hemicellulases have been identified and used to successfully enhance the degradation of cellulose (Turner et al., 2007). Lignin, however, remains the primary obstacle to saccharification, as it is itself immune and protects both the cellulose and Hemicellulose from enzymatic conversion. Lignocellulosic biomass is therefore more difficult to degrade than first-generation feed stocks like corn, sugarcane, soya, palm, or grape seed.

The use of bio energy crops for energy generation and transport fuel production has great potential to reduce GHG emissions if the fuels replace traditional fossil feedstock. However, the use of these crops has recently come under serious criticism, with some groups questioning their true environmental cost (Stricklen 2006, USNRS 2004). Although there is a large body of research in this area, the environmental costs and benefits associated with bio energy crops can be difficult to assess because of the complexity of the production systems. One technique which has been used extensively in the literature to compare the energy and GHG balances of bio energy chains is life cycle assessment (LCA). Hence, the aims and objectives of this presentation are as follows:

- To classify biofuels based on their feed stocks of production.
- To compare the carbon footprint of second generation biofuels to other biofuels.
- To compare the energy balances of second generation biofuels and other fuels.
- To highlight areas of research and development (R&D) needs within the field of second generation biofuels technology.

CLASSIFICATION OF BIOFUELS

A recently popularized classification for liquid biofuels includes "first-generation" and "second-generation" fuels (Kartha and Larson, 2000). There are no strict technical definitions for these terms. The main distinction between them is the feedstock used. A first-generation fuel is generally one made from sugars, grains, or seeds, i.e. one that uses only a specific (often edible) portion of the above-ground biomass produced by a plant, and relatively simple processing is required to produce a finished fuel. First-generation fuels are already being produced in significant commercial quantities in a number of countries. Second-generation fuels are generally those made from non-edible lignocellulosic biomass, either non-edible residues of food crop production (e.g. corn stalks or rice husks) or non-edible whole plant biomass (e.g. grasses or trees grown specifically for energy). Second-generation fuels are not yet being produced in large commercial plants in most country (Larson, 2006).

Table1. Classification of Biofuels

First –generation Biofuels	Second –generation Biofuels
• Petroleum – gasoline substitutes: -ethanol or butanol by fermentation of starches(corn,wheat,potato)or sugars(sugar beets and sugar cane) • Petroleum diesel substitutes: -Biodiesel by transesterification of plant oils, also called fatty acid methyl and fatty acid ethyl. -From rapeseed, Soybeans, sunflower, e.t.c - pure plant oils	• Biochemically produced petroleum-gasoline substitutes: -ethanol or butanol by enzymatic hydrolysis • Thermochemically produced gasoline substitutes: -methanol -Fischer Tropsch gasoline -Mixed alcohol • Thermo-chemically produced petroleum diesel substitutes: -Fischer-Tropschdiesel,Dimethyl ether,green diesel

(Source : Kartha and Larson, 2000)

METHOD OF ANALYSIS
LIFE CYCLE ASSESSMENT (LCA) OF BIOFUELS

Life cycle assessment is an internationally recognized technique for evaluating the natural resource requirements and environmental impacts from the whole process and materials involved in the manufacture of a product or service (ISO, 2006). It has been used extensively in the bio energy sector to investigate the energy and carbon balances of bio energy chains, and in a smaller number of cases has been used to look at wider environmental impacts. In order to get a complete understanding of the net greenhouse gas emissions from combusting biofuels, previous research investigating biofuels from a full fuel life cycle perspective has to be examined. Sheehan et al (2004) studied a generalized inventory of the life cycle phases of biofuel system as shown in Figure 1. The dotted line represents the boundaries of the systems. Greenhouse gases (GHGs) are the only input or output of concern. GHG emissions arrows represent the aggregate of emissions measurable at the process underway and all upstream emissions associated with the manufacture of consumed products during each process. The process steps for each bio energy chain differ, depending on the feedstock used and the fuel manufactured. The complete diagram of lifecycle assessment will therefore show all of the process steps included in the calculation, and the emissions or energy requirement associated with each process step.

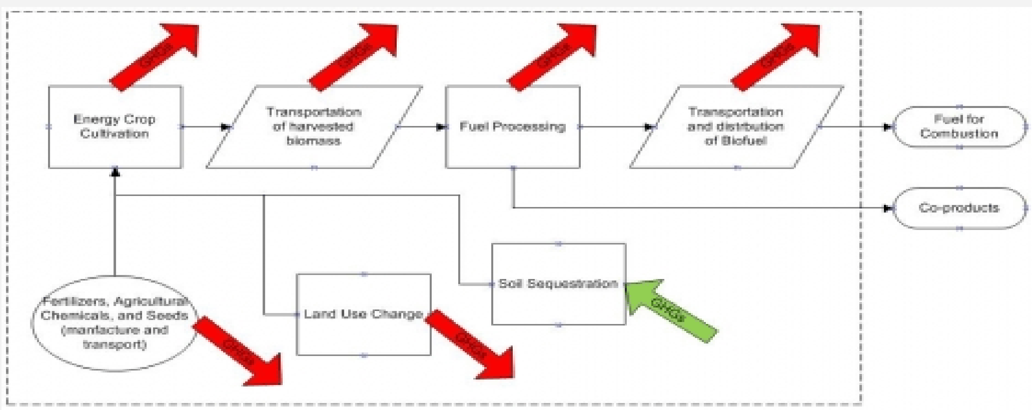

Figure 1: Life Cycle Biofuel System Diagram

(Source:
Sheehan et al,2004)

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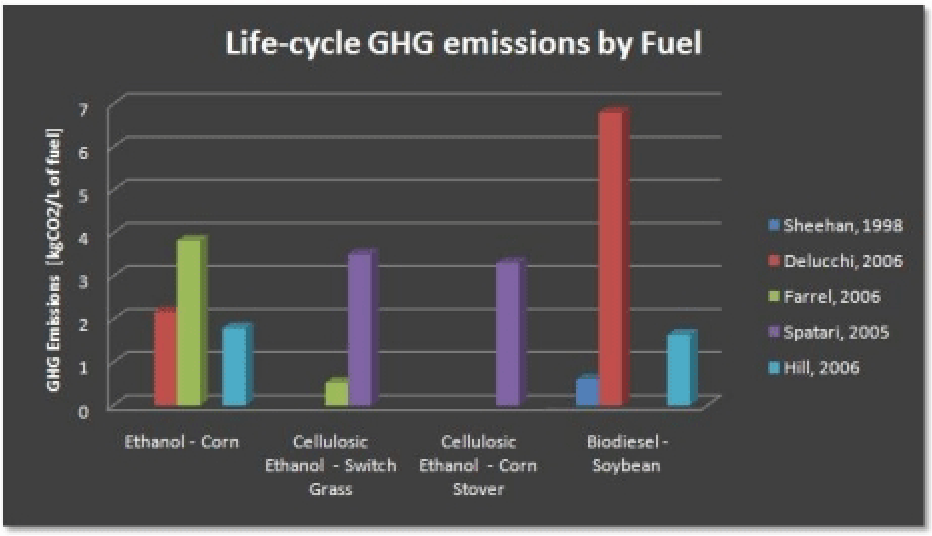

Figure 2: Life-cycle GHG Emissions by fuel type and Source

(Source: Larson, 2006)

RESULTS AND DISCUSSION

COMPARISON OF CARBON FOOTPRINT OF BIOFUELS

According to the USEPA, for each gallon of gasoline burned in an automobile, 19.4 lb of CO_2 are emitted to the atmosphere. This is just from the carbon actually contained in the gasoline and does not include the carbon from extracting the crude oil, transporting the crude oil, refining the crude oil, and transporting the gasoline. By comparison, the net global warming potential of an equivalent amount of ethanol (1.4 gallons of ethanol per gallon of gasoline) is significantly lower. This is because the carbon contained in biofuel ethanol is autotrophically derived, meaning it came from the atmosphere in the first place (through photosynthesis of the corn plant from which the ethanol was made). When burned, the ethanol carbon is simply recycled back to the atmosphere from where it came. It is not new carbon added to the atmosphere. However, using international carbon accounting practices established by the International Panel on Climate Change (IPCC), we should consider the fossil fuel carbon used in producing ethanol. Using typical Michigan corn production inputs, a 150 bushel per acre corn crop will require approximately 28,000 seeds; 150 lb of N, 55 lb of P_2O_5, and 85 lb of K_2O fertilizers; 2 quarts of herbicide, and 5 gallons of fuel/lub/oil. On a per acre basis, these inputs would run up a carbon debt of about 1250 lb CO_2 per acre. The same acre would produce about 420 gallons of ethanol, giving a carbon footprint of only 2.9 lb. of CO_2 per gallon of ethanol. Or, on a gasoline equivalent basis, 4.2 lb of CO_2 emitted for each 1.4 gallons of ethanol burned which represents a 78% reduction in net global warming potential simply by using ethanol instead of gasoline . Even more promising, the carbon footprint of 2nd generation biofuels made from perennial grasses will be substantially lower yet – estimated at a 94% reduction from gasoline as shown in Figure 3. (USEPA ,2005).

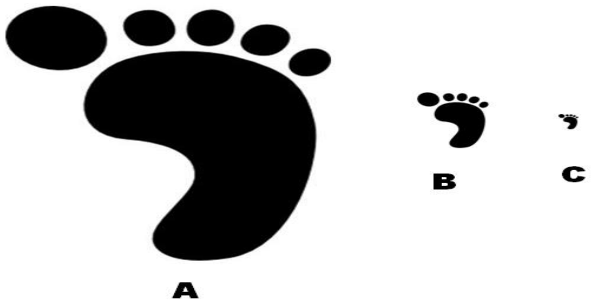

Figure 1. Relative carbon footprint from direct effects of combusting A = gasoline; B = grain ethanol; and C = cellulosic ethanol. A = 19.4 lb CO_2/gal., and B and C represent a 78 and 94% respective reduction (on an energy equivalent basis) in carbon footprint relative to A.

Figure 3: Comparison of carbon footprint of fuels (Source:USEPA,2007)

ENERGY BALANCE AND EFFICIENCY OF BIOFUELS

The energy balance is defined as the ratio of energy contained in the biofuel to the energy used by the human efforts to produce it. Typically, only fossil fuel inputs are counted in the calculations. Biomass inputs, including the biomass feedstock itself are not counted. This is the criterion for comparing different biofuels. (Bugaje and Mohammed, 2008).

The energy ratios of biofuels depend on the energy input of the whole lifecycle and the energy output for the final fuel. Typically for all biofuels, different steps of the lifecycle are characterized by a huge variation which depends on feedstock, agricultural practices, regional feedstock productivity and process technology. Therefore, the validity of data about biofuel energy balances has to be carefully evaluated. Hence, biofuels from tropical plants (such as Nigeria) have more favourable energy ratios than biofuels from temperate regions(such as Britain),as tropical crops grow under more favourable climatic conditions. Furthermore, they are often cultivated manually with fewer fossil energy requirements and fewer inputs of fertilizer and pesticides. In contrast, biofuels from temperate regions usually require more energy input. The energy balance ensures that less energy is consumed in their production from primary sources than they give out. There are two primary measures for evaluating the energy performance of biofuel production pathways, the energy balance and the energy efficiency (El-Sayed et al, 2003).

A more accurate term for energy balance is fossil energy balance and it is a measure of bio fuel's ability to slow the pace of climate change. The ratio number of the energy balance must exceed one for it to make any sense. For example, Fossil transport fuels have energy balances between 0.8 and 0.9.Biofuels significantly contribute to the transportation fuel needs only when these numbers are exceeded. The energy balances of ethanol from wheat ,sugar beets and corn are between 1 and 2.5. Ethanol from sugar cane is reported to have an energy balance of approximately 8.The energy balances of vegetable oil derived fuels are between 2.5 and 9.These numbers show that the energy balance of all biofuels is better than that of fossil fuels (Bugaje and Mohammed, 2008).

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The energy efficiency is the ratio of energy in the biofuel to the amount of energy input, counting all fossil and biomass inputs as well as other renewable energy inputs. This ratio adds an indication of how much biomass energy is lost in the process of converting it to a liquid fuel and helps to measure more or less efficient conversions of biomass to biofuel. The ratio number of the energy can never exceed one, because some of the energy contained in the feedstock is lost during processing. For example, biodiesel has an energy efficiency of 0.69, means that it requires only 0.31 units of fossil energy to make 1unit of fuel (Bugaje and Mohammed, 2008).

A current problem of evaluating energy balances is the definition of the system boundaries. There are debates on whether to include items like the energy required to feed the people processing the feedstock, the amount of energy a tractor represents and so on. Therefore, to get a complete picture about the energy balance of biofuels, at least the following variables have to be considered:

i. The type of feedstock and agricultural production process
ii. The geographical and climatic conditions of the producing region.
iii. The utilized technology for fuel processing.
iv. Production capacity and scale.

Evaluation of these factors could also lead to a better evaluation of the carbon footprints of all fuels in view of the global concern on environmental degradation due to energy usage(Bugaje and Mohammed, 2008).

Table 2 illustrates this with a comparison (based in United States) of the energy balance for gasoline production from petroleum, ethanol production from corn, and second-generation ethanol production from corn Stover. While there are differences among the energy balances for various first generation biofuels and among those for different second-generation biofuels, the two ethanol fuels in Table1.can be considered to be broadly representative of the spectrum of first-generation and second-generation biofuels, with one important exception – sugar cane ethanol in which the energy inputs include all energy sources associated with producing the raw material used for fuel production (crude oil, corn or corn Stover), transporting it to the conversion facility and converting it into liquid fuel.

Three observations are worth making from table 2. First, the overall energy ratio (OER), defined here as the energy in the liquid fuel divided by the sum of all energy inputs to the process, is highest for gasoline and lowest for cellulosic ethanol. However, a large portion of the energy input for the latter is biomass (or, indirectly, solar energy), a renewable energy input. Therefore, a second energy ratio, the fossil energy ratio (FER), is more meaningful. This is the liquid fuel energy output by the total non-renewable fossil energy input. For gasoline, the FER is the same as the OER, about 0.8. For corn ethanol, the FER is about 1.4, and for cellulosic ethanol, the FER is about 5. Table 2 summarizes these numbers and shows the same metrics for first-generation soy biodiesel in the United States and Brazilian sugar cane ethanol. The latter gives the highest FER values among all fuels, because most of the energy input to produce the ethanol comes from the fibre in the sugar cane itself.

Table 2: Energy ratios for gasoline and some first- and second-generation biofuels

	Overall Energy Ratio (OER)	**Fossil Energy Ratio (FER)**
Liquid Fuels	*Liquid fuel output/ Fossil + biomass Input*	*Liquid fuel output/ Fossil Input*
Gasoline (United States)	0.81	0.81
Corn ethanol (United States)	0.57	1.4
Soy biodiesel (United States)	0.45	3.2
Cellulosic ethanol (United States)	0.45	5.0
Sugar cane ethanol (Brazil)	0.30	10

(Bugaje and Mohammed, 2008 and Shapouri, et al, 2002)

GREENHOUSE GAS EMISSIONS

The effectiveness with which greenhouse gas emissions (GHGs, including CO_2, CH_4, and others) can be avoided using biofuels is related to the amount and carbon intensity of the fossil fuel inputs needed to produce the biofuel, as well as to what fossil fuel is substituted by use of the biofuel. A proper GHG accounting considers the full life cycle of the biofuel, from planting and growing the biomass to conversion of the biomass to biofuel, to combustion of the biofuels at the point of use. (In the case of vehicle applications, this full life cycle analysis is sometimes referred to as a "well-to-wheels" analysis.) If the harvested biomass is replaced by new biomass growing year-on-year at the same average rate at which it is harvested, then CO_2 is being removed from the atmosphere by photosynthesis at the same rate at which the already-harvested biomass is releasing CO_2 into the atmosphere – a carbon-neutral situation (USEPA, 2005).

Higher GHG savings with biofuels are more likely when sustainable biomass yields are high and fossil fuel inputs to achieve these are low, when biomass is converted to fuel efficiently, and when the resulting biofuel is used efficiently. Conventional grain- and seed-based biofuels can provide only modest GHG mitigation benefits.

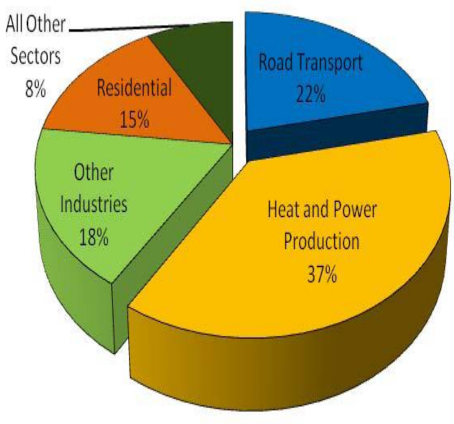

Figure 4: Contribution of different sectors to UK's total greenhouse gas emissions in 2005 [Source: DTI, 2007].

CONCLUSION

Second-generation biofuels are made from non-edible feed stocks, which limit the direct food verse fuel competition associated with most first generation biofuels. Such feed stocks can be bred specifically for energy purposes, thereby enabling higher production per unit land area, and more of the above-ground plant material can be converted to biofuel, thereby further increasing land-use efficiency compared to first-generation biofuels. These basic characteristics of the feed stocks hold promise for lower feedstock costs and substantial energy and environmental benefits for most second-generation biofuels compared to most first-generation biofuels. On the other hand, second-generation biofuel systems require more sophisticated processing equipment, more investment per unit of production, and larger-scale facilities (to capture capital-cost scale economies) than first-generation biofuels. In addition, to achieve the commercial energy and economic potential of second-generation biofuels, further research, development and demonstration work is needed on feedstock production and conversion.

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