THE NET ENERGY OF BIOFUELS

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1. Introduction

The present study evaluates the net energy of biofuels in terms of economy, which is related to the main topic of the intensive course EPROBIO which focuses on the energy production from biomass in the European Union.

It is well known that petroleum reserves are limited resources and the date of the global peak in oil production is fixed between 1996 and 2035. This is the reason why new sources of energy and preferably renewable energies (e.g. biomass, wind, solar energy) are being deeply studied and gradually applied in order to substitute fossil fuels.

Biomass energy technologies use waste or plant matter to produce energy with a lower level of greenhouse gas emissions than fossil fuel sources. Biomass can be converted into liquid and gaseous fuels through thermochemical and biological routes. The term biofuel is referred to liquid or gaseous fuels for the transport sector that are mainly produced from biomass. A variety of fuels can be obtained from biomass resources including liquid fuels, such as ethanol, methanol, biodiesel, Fischer-Tropsch diesel, and gaseous fuels, such as hydrogen and methane (Dermibas, 2008). Liquid biofuels are primarily used to fuel vehicles, but can also fuel engines or fuel cells for electricity generation.

It can be distinguished two types of biofuels: first generation and second generation. Second generation biofuel technologies have been developed because first generation biofuel manufacture has important limitations. First generation biofuel processes (e.g. fermentation of sugar) are useful, but limited in most cases because there is a threshold above which they cannot produce enough biofuel without threatening food supplies and biodiversity. Many first generation biofuels are dependent of subsidies and are not cost competitive with existing fossil fuels. Second generation biofuels can help to solve these problems and can supply a larger amount of fuel and with greater environmental benefits. The goal of second generation biofuel processes is to extend the amount of biofuel that can be produced sustainably by using biomass consisting of the residual non-food parts of current crops, such as stems, leaves and husks that are left behind once the food crop has been extracted, as well as other crops that are not used for food purposes (non food crops), such as switch grass, jatropha and cereals that bear little grain, and also industry waste such as woodchips, skins and pulp from fruit pressing, etc. The problem that second generation biofuel processes are addressing is to extract useful feedstock from this woody or fibrous biomass, where the sugars are locked in by lignin and cellulose.

Many studies have investigated the net energy balance of biofuels in terms of savings in comparison of fossil fuels and assessed the reductions in greenhouse gas emissions from substituting biofuels for fossil fuel. These studies provide very different results, with net energy balance ranging from highly positive to negative.

Since the early 2000's, biofuel production in both developed and developing countries has been increasing and popularizing. More than a third of the corn production in United States, more than a half of the rapeseed production in Europe and almost half of the sugar cane production in Brazil is being channelled into the energy market (Bureau, *et al.*, 2010). The rapid and continuing growth of bioethanol production in US and biodiesel production in EU is mainly due to public policies. The EU and the US support the development of biofuels through subsidies, tax exemptions or mandatory blending in gasoline or diesel.

Public authorities justify and legitimize support for biofuel production based on several reasons. One of the main ones is the encouragement for the production of renewable energies to substitute the conventional fossil fuels in an attempt to mitigate climate change and reduce dependency on energy imports. Other motives include providing an outlet for agricultural production to support farm incomes and help in the reform of agricultural policies. However, the promotion of biofuels has some potentially negative effects especially in the developing countries, e.g. competition for land and water between food production and energy crops.

The increased utilization of biofuels for heat and power production has provided to increase political support in European countries. This has resulted in a large number of biofuels being processed for energy conversion necessities and suitability for choosing the most appropriate method of valorising the conversion products with depending on the variability of using raw materials as well as their composition. In addition, new standard analytical methods are necessary to develop in order to apply new technologies for biofuel production from biomass materials.

In his study it is considered only two kinds of liquid biofuels, bioethanol and biodiesel, simply because they can be used in low percentage blends with conventional fuels in most vehicles right now and can be distributed through the existing infrastructure. The net energy value of each biofuel mainly depends on the feedstock, as it is the most important cost in terms of energy and also economy. Figure 1.1 shows different raw materials to produce biodiesel and bioethanol from energy crops as rapeseed, soybean, wheat and maize and so on.

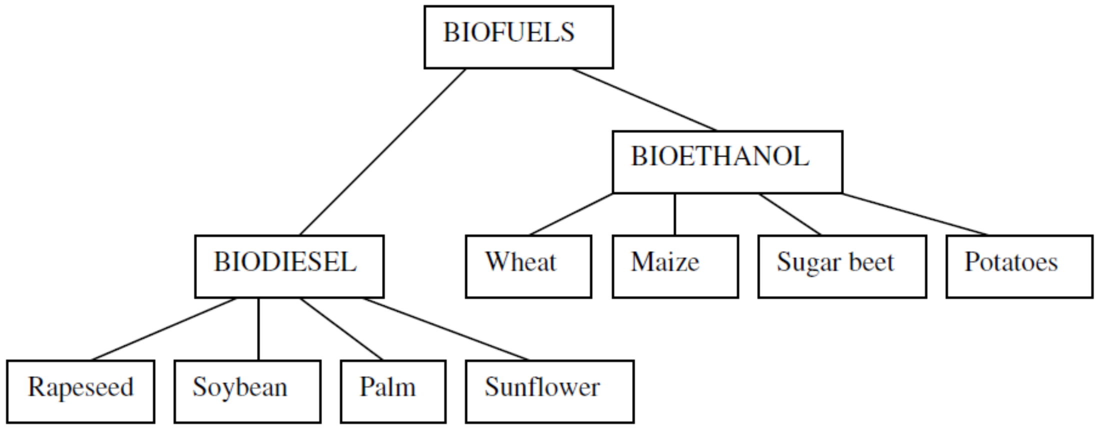

Figure 1.1. Resources of biodiesel and bioethanol (Dermibas, 2008)

The automobile industry has indicated that blending up to 10% of biofuels with conventional diesel and petrol could be introduced without major problems in terms of vehicle technology. For blends above 10%, it is important to assess their potential effects on existing and future vehicles. Replacing a percentage of diesel with biodiesel or gasoline with bioethanol is therefore the simplest way for the transport sector to make an immediate contribution to the Kyoto targets, particularly given that the benefits would apply to the entire vehicle fleet.

Biodiesel is a methyl-ester produced from vegetable oil (e.g. soy bean, sunflower, palm oil and rapeseed oil), animal oil (all kind of animals) or recycled fats and oils of diesel quality. Rapeseed production and subsequent transesterification (using methanol to produce rapeseed methyl ester) and distribution are established technology in Europe. Biodiesel is domestically produced and has an energy ratio compared to diesel of about 1.1 to 1, which means that its energy contents are 87% of those of diesel.

Bioethanol is ethanol produced from biomass (e.g. corn, grains, sugar beet and sugar cane) and the biodegradable fraction of waste. Light-duty vehicles, medium and heavy-duty trucks and buses are flexible fuel vehicles that can be fuelled with E85 (85% ethanol), gasoline or any combination of the two fuels. Bioethanol is produced domestically, it is renewable and has an energy ratio compared to gasoline of 1.42 (67% of gasoline).

In the EU, the biofuels directive (2003/30/EC of 8 May 2003) a 2% market share was targeted for biofuels in 2005 and a 5.75% share in 2010. For the EU, the target would require 18.6 mton (million of tonnes) of biofuels by 2010 (Randelli, 2009). In 2000, biofuels contributed about 0.2% of energy, in terms of all fuels used in the EU. If member states had achieved the national indicative targets they adopted under the biofuel directive, the contribution of biofuels would have reached 1.4% by 2005. Although the national targets are, on average, significantly lower than the reference value of 2% that the directive laid down, some member states have not met them. That is the reason why on the 8 February 2006 the European Commission proposed to review the strategy for renewable energy from agriculture, because the targets will not be met with a biofuels directive as it stands now.

The global warming is a serious problem, our World requires a solution. The production of biofuel is a solution because gives an important contribution to reduce GHG emissions. Economies of scale and experience acquired by the biofuel's producers every where, make convenient the production process.

Talk about economic profit in issues linked with environment is a paradox, but the technology innovation make it possible. The cost of production of biofuels varies significantly according to feedstock, process and location. Location determines access to particular feedstocks and energy supplies, the price of which to a large degree are driven by market developments and the global scale – including, increasingly, the demand for crops to supply biofuel production itself. The basic processes currently used for producing bioethanol and biodiesel do not vary so greatly, though the scale of actual plants does. Moreover, rapid developments in the design of bioethanol plants in order to make more-efficient use of energy, or to improve the profitability of by-products, are having a profound effect on the economies of new plants.

2. Economic issues

2.1 Net Energy Balance, NEB

"The true value of energy to society is the net energy, which is that after the energy costs of getting and concentrating that energy are subtracted." - H.T. Odum (1973)

The net energy balance (NEB) means the ratio between the amount of energy available after the transformation process (output) and the total energy used in the process (input):

NEB = Net energy/energy expended

The NEB of ethanol and biodiesel change in accordance with several factors such as: geographical place of production, the kind of agro-system (high or low input) and the kind of feedstock (grain, sugar cane, sugar beet, sunflower, rapeseeds, etc.).

Every region in the world can have a different NEB for bioethanol or biodiesel and in some places it could be more convenient to produce biodiesel instead of bioethanol, or may be both or not even one of them. In Italy, and in general in Europe, there is more interest in biodiesel than bioethanol, probably because in Europe feedstock rich in sugar does not grow as for example sugar cane in Brasil, and to extract ethanol by corn is not very convenient in terms of NEB.

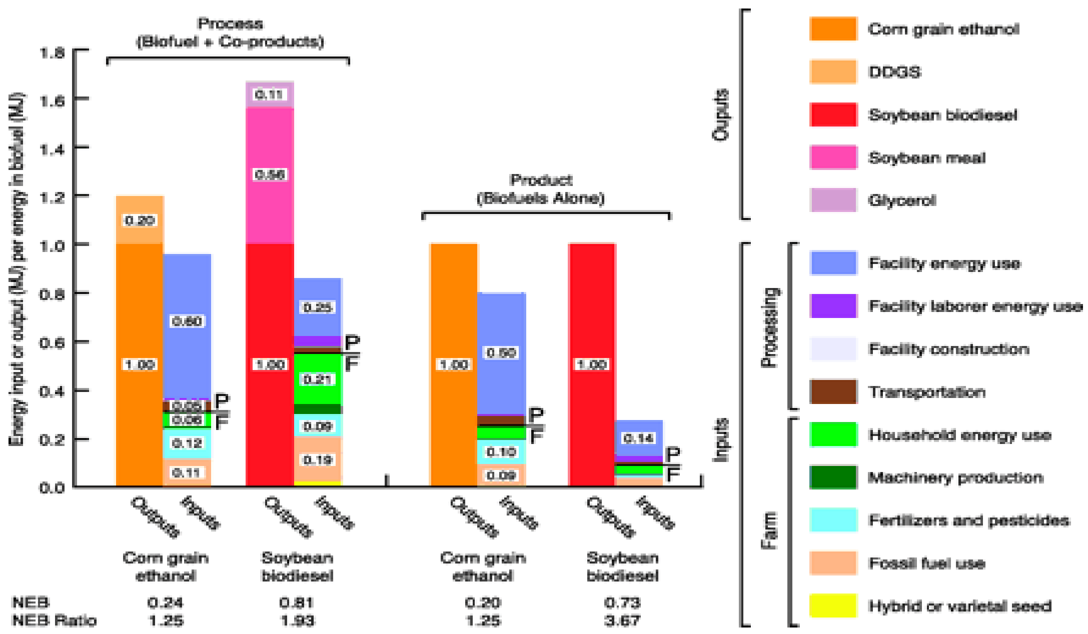

Figure 2.1. NEB of corn grain ethanol and soybean biodiesel production. (2006, The National Academy of Sciences of the USA)

Energy inputs and outputs are expressed per unit energy of the biofuel. All nine input categories are consistently ordered in each set of inputs, as in the legend, but some are so small as to be nearly imperceptible. The figure 2.1 shows that corn grain ethanol and soybean biodiesel production result in positive NEBs. However, the NEB for corn grain ethanol is small, providing ≈25% more energy than required for its production. Almost all of this NEB is attributable to the energy credit for its DDGS coproduct (*Dried Distillers Grains with Solubles* - When ethanol plants make ethanol, they use only starch from corn and grain sorghum. The remaining nutrients - protein, fiber and oil - are the by-products used to create livestock, which is animal feed, rather than to the ethanol itself containing more energy than used in its production. Corn grain ethanol has a low NEB because of the high energy input required to produce corn and to convert it into ethanol. In contrast, soybean biodiesel provides ≈93% more energy than is required in its production. The NEB advantage of soybean biodiesel is robust, occurring for five different methods of accounting for the energy credits of coproducts. The NEB (energy output − energy input) and NEB ratio (energy output/energy input) of each biofuel are presented both for the entire production process (*Left*) and for the biofuel only (i.e., after excluding coproduct energy credits and energy allocated to coproduct production) (*Right*).

2.2 Cultivation of oil crops

There are many different types of oil crops, but sunflowers and rape are the most used in Italy. The process to obtain the final product can be divided into unit processes:

- Production of seed: includes all the operations to produce seed, it is important because it represents the impact that the use of the seed has in the entire chain.
- Tillage: includes all the preparatory work of the soil before sowing, excluding chemical treatments.
- Seeding: only includes sowing, excluding chemical treatments.
- Fertilization: includes the operations for the production of fertilizers used.
- Chemical treatment: shall include the chemical treatment of the crop and the production of compounds used.
- Collection: includes the collection without carriage.
- Transportation to company: includes transport operations through the farm tractor and wagon from the field.
- Storage: includes storage operations on the farm and its buildings.

For each of them it is possible to analyze INPUT (fossil energy utilized, machinery, buildings, fertilizers, pesticides) and OUTPUT (CO_2 emissions, yields, by-products). The industrial side of the production of biodiesel is composed of extraction, refinement and transesterification. Several researches, including CTI's study (Comitato Termotecnica Italiano), have verified that the most expensive phase in terms of energy expenditure is the extraction (41%), followed by refinement (23%) and transesterification (5%); the remaining 31% represents the energy contents of methanol.

2.3 Net energy balance of biodiesel (Italy)

Randelli (2009) compares the production of biodiesel from sunflowers and rapeseed in every farm in Emilia Romagna (Central Italy); each one with two different types of cultivation: high input (HI) and low input (LI), in which the input variability concerned: ground working, topdressing, grow over and parasite control.

This study have measured the energy consumption (in MJ/kg of biodiesel) during the entire biofuel production, starting from feedstock production (with HI or LI method), through the oil extraction and the esterification process, up to the transportation to final destination (see Figure 2.2).

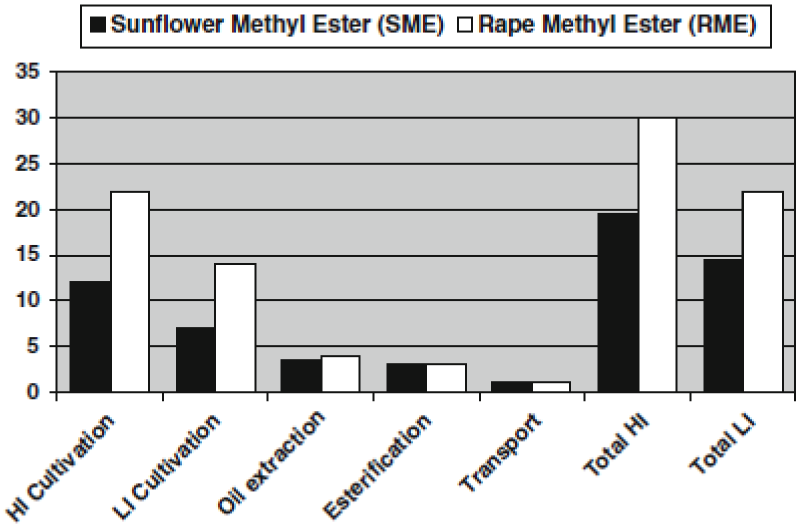

Figure 2.2. Energy consumption during the full production chain of biodiesel in MJ/kg (Randelli, 2009)

In this case study, energy consumption in rape cultivation is higher than for sunflower. This is a consequence of different factors: in this region there are more skills in the sunflower production and especially because few locations were less fertile (hilly and not level land).

In the biodiesel production the majority of the total energy used in the entire process is consumed for growing feedstock and this means that it is possible to improve significantly the NEB changing the cultivation process. Final results could be different somewhere else and, even in this study, with different locations, *but the general information about NEB is still an important indicator of biodiesel potentiality.*

Table 2.1 shows the NEB for sunflower and rape cultivation with the two methods considered in the study. In the better cases the NEB can be over 10 units, which means that by growing sunflower or rape to produce biodiesel we can obtain 10 times the energy used in the entire process, including esterification and transportation. In this case study, sunflower had better energy performance than rape for the reasons explained before (better skills, soil fertility). The average NEB is still quite positive, especially using a cultivation method with LI: 6.4 for rape and 13.2 for sunflower.

Table 2.1. NEB for sunflower and rapeseed in GJ/ha (Randelli, 2009)

Method of cultivation	Input			Output			NEB		
	Average	Max	Min	Average	Max	Min	Average	Max	Min
Rapeseed									
HI	23.9	34.0	4.7	65.6	86.5	55.0	4.3	12.1	1.9
LI	12.0	18.7	3.6	52.0	71.5	28.0	6.4	15.3	4.0
Sunflower									
HI	13.2	24.7	7.9	38.4	117.0	27.2	6.1	11.1	1.81
LI	7.3	13.3	2.9	68.9	117.0	21.8	13.2	29.2	3.45

HI high input, LI low input

The processes of creation and use of bioenergy in Emilia-Romagna are very limited and mainly still experimental. The *Regional Rural Development Program 2007-2013* provides aid to the creation of small plants and the use of renewable energy sources, also provides contributions to the sustainability of crops herbaceous energy purposes (Action 5, size 214) of 150 euros per hectare for annual crops. The support is combined with the help crop energy of 45 euros per hectare under the EU Regulation 1782/2003. In this way try to go the EU programme *BETTER* (*Biofuel chain Enhancement for Territorial development of European Regions*). This is the subject involved in research: Province di Forlì-Cesena e Ravenna, Ervet, Centuria Rit, Dipartimento di Economia e Ingegneria Agrarie dell'Università di Bologna, Crpv, Dipartimento di Scienze applicate ai Sistemi complessi dell'Università Politecnica delle Marche, *Ec Brec Institute for renewable energy* (Polonia), *Podkarpackie voivodship* (Polonia), *Anatoliki s.a. development Agency of Eastern Thessaloniki* (Grecia), *Enterprise development foundation of Tolna county* (Ungheria), *Association municipal energy agency* (Bulgaria).

2.4 Net energy balance of bioethanol (USA)

Studies conducted since the late 1970's have estimated the net energy value of corn ethanol. However, variations in data and assumptions used among the studies have resulted in a wide range of estimations. This study identifies the factors causing this wide variation and develops a more consistent estimation, for instance, the net energy value of corn ethanol has become positive in recent years due to technological advances in ethanol conversion and increased efficiency in farm production and it is possible to talk about a positive net energy balance. There is clearly no doubt that fuel ethanol contains more energy than it takes to produce.

In June 2004, the U.S. Department of Agriculture (USDA) updated its 2002 analysis of the issue and determined that the net energy balance of ethanol production is 1.67 to 1. For every 100 BTU's of energy used to make ethanol, 167 BTUs of ethanol is obtained. In 2002, USDA had concluded that the ratio was 1.35 to 1. A BTU is defined as the amount of heat required to raise the temperature of 454 grams of water from 60 to 61 degrees Fahrenheit.

The USDA findings have been confirmed by additional studies conducted by the University of Nebraska and Argonne National Laboratory. In fact, since 1995, twelve independent studies found ethanol has a positive net energy balance, while only two studies by the same author– which used outdated data – found the energy balance to be negative.

A Michigan State University study (2002) found that ethanol produced from corn provided 56 percent more energy than is consumed during production (1.56 to 1). This study focuses on the production of ethanol from both dry and wet milling of corn—and included corn grain production, soybean products from soybean milling and urea production.

These studies take into account the entire life cycle of ethanol production—from the energy used to produce and transport corn to the energy used to produce ethanol to the energy used in the distribution of ethanol in gasoline.

It is also important to note that energy from ethanol is not the only result of ethanol production. By-products such as distiller grains, gluten feed, carbon dioxide, and corn sweeteners are also created in ethanol production. That means that not all the energy used by an ethanol plant is directed at manufacturing ethanol, thus further improving the net energy balance of ethanol production.

As part of the comprehensive Energy Independence and Security Act of 2007 that was signed into law Dec. 2007, the Renewable Fuels Standard (RFS) helps define the role that renewable fuels such as ethanol and biodiesel will play in America's quest to improve homeland security through increasing our use of renewable, domestically produced transportation fuels—and improve our environment by reducing toxic exhaust emissions.

The RFS provides stable demand for the use of renewable fuels such as ethanol while providing refiners with the flexibility to blend ethanol more efficiently in areas of the country where it makes the most sense economically and environmentally. The measure sets the minimum annual level of renewable fuel blended into the nation's fuel supply at 36 billion gallons per year by 2022. The legislation guarantees a robust future market for corn and allows for continued opportunities for farmer investment in new ethanol plants.

The RFS schedule requires 9 billion gallons of renewable fuels to be blended into the national gasoline supply in 2008, with incremental increases each successive year (see Figure 2.3). An RFS will also reduce the cost of the farm bill by slightly raising the price of corn, creating more value-added opportunities for farmers and strengthening rural economies.

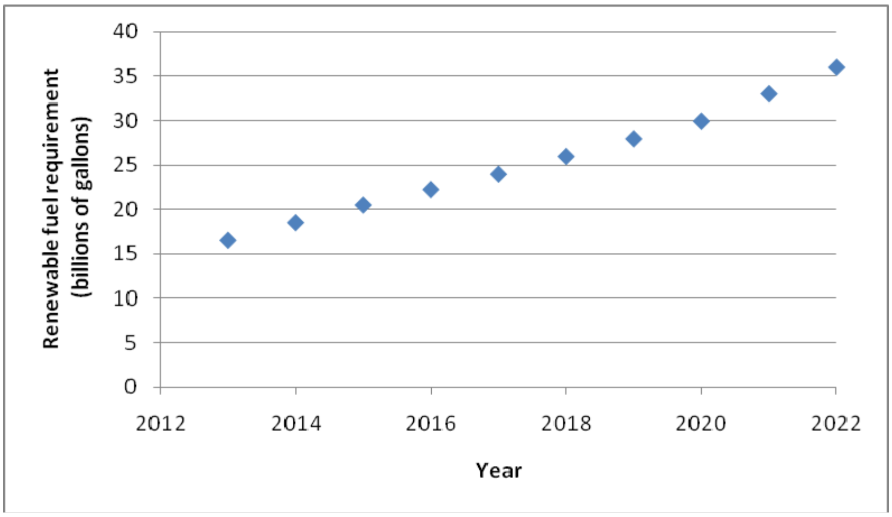

Figure 2.3. Renewable fuel requirements per year

3. Energy Return on Investment, EROI

3.1 Definition and Interpretation

Energy returns on investment, EROI is defined as the ratio of quantity of energy delivered by a biofuel society to the energy used as an input in the process to produce it (Hamerschlag, 2006; Lynch, 2008). Cleveland et al. (2000) also defined it as the ratio of the energy output to both direct and indirect energy input. Several other definitions exist but the central idea is that the EROI measures the energy that is obtained from a biofuel and the amount of energy utilized during the process to produce the biofuel. It is calculated by the formula:

$$\text{EROI} = \frac{\text{Quantity of energy supplied (energy output)}}{\text{Quantity of energy used by the process (energy input)}}$$

The EROI is always dimensionless since both energy supplied and energy used in the process is quoted in the same unit. When the EROI value is higher than one, it means the quantity of energy supplied by the biofuel is more than the energy used in the process to produce a ton of the biofuel. In this case, the production process of the biofuel can be said to be energy advantageous and yielding positive returns on investment. Conversely, if the EROI is less than one, then the quantity of energy supplied by the biofuel is lower than the energy used in the process to produce it. Similarly, the production process of the biofuel becomes energy disadvantageous and implies that it generates negative energy returns on investment. It follows from this explanation that the EROI must necessarily be greater than one in order for the production process to be worthwhile in terms of energy usage. EROI is usually greater than zero because the quantity of energy supplied by the process (*also termed as energy out in some studies*) and the quantity of energy used in the production process (*energy in*) are both positive numbers are usually greater than one (Hammerschlag, 2006). In some occasions, EROI is used as the step to calculate the greenhouse savings allowed by biofuels (Cleveland et al., 2000).

The energy return on investment for biofuels like that of the fossil fuels has been greatly debated in literature. This stems from the fact that differences exist in the EROI reported for biodiesel and bioethanol by different authors. These have mainly resulted from the different assumptions, allocation rules of energy requirements for biodiesel and bioethanol and their associated by-products and also the system boundaries set by the different researchers (Russi, 2008). However, the most influential factor has been the method of allocating energy. This is allocation of energy to either the main biodiesel or bioethanol product or the by-products tat results from production process. It has been observed that if more energy requirements or inputs are allocated to the by-products, the EROI becomes higher and the process thus seems to be more efficient in terms of energy returns on investment (Russi, 2008). This method has been used very often in most life cycle assessments and other studies that that look at energy use in biofuels production.

However this procedure has been greatly debated by different researchers with some supporting its use and others strongly against it. Ulgiati (2001), Hammerschlag, (2006) and Russi (2008) argue that this method is not correct in its entirety because on a large scale production of biodiesel and bioethanol, it is possible that after a large amount of by-products may be produced that would be greater than their demand. Russi (2008) further argues that for a large scale biofuel industry the by-products may become a waste that must be disposed of with associated economic and energy costs. It is essential to allocate the energy inputs for both the main products of the biodiesel and bioethanol process and the by-products as well. In this way, the EROI value calculated will give a fare idea of the actual energy returns on the investments made on producing biodiesel and bioethanol. Hammerschlag (2006) is of the view that some of the process energy is spent manufacturing ethanol, and some is spent manufacturing the by-products. Therefore, the net energy input divided by the gross energy input seems a give a better understanding of a fraction of the process energy being allocated to bioethanol.

3.2 EROI for Biodiesel

Biodiesel is seen to have great prospect as a green fuel to replace fossil fuel use. The EROI for biodiesel is reported differently by different studies as discussed above. In this report, EROI for biodiesel is taken from studies conducted in Europe, particularly in Italy. The differences in EROI due to the differences in the procedure for the allocation of energy requirements for biodiesel production in Italy are presented in Figure 3.1.

Reference	Biodiesel EROI
Kallivroussis et al. (2002)	• 4.5 if meal is used as fuel • 3.4 if meal is used as animal feed
Bernesson et al. (2004)	• Physical allocation: 3.5 (after the energy content) • Economic allocation: 3.2 (after the economic value) • No allocation: 2.5
Cardone et al. (2003)	1.08–1.67
Venturi and Venturi (2003)	Without allocation: • Sunflower: 0.3–0.9 • Rapeseed: 0.7–1.0 • Soybean: 0.2–0.6 With allocation: • Sunflower: 0.4–1.2 • Rapeseed: 1.0–1.5 • Soybean: 0.7–1.6
Janulis (2004)	With no allocation: 1.04; 1.19; 1.43; 1.59 for 2; 2.5; 3; 3.5 tonnes/ha, respectively (other figures with an allocation procedure are provided)
Giampietro et al. (1997)	0.6–1.3
Giampietro and Ulgiati (2005)	• Use of residues as energy source, credit for feedstock: 1.21 • Use of residues as energy source, no credit for feedstock: 0.98 • No residues as energy source, credit for feedstock: 1.51 • No residues as energy source, no credit for feedstock: 1.16

Figure 3.1. EROI for biodiesel from different studies with different allocation methods

3.3 EROI for First and Second Generation Bioethanol

The EROI for bioethanol has been observed to be on the average higher than one which suggests that the energy produced per ton of bioethanol is higher than the energy used in the production process for one ton of bioethanol. Hammerschlag (2006) analyzed six research results on the EROI for bioethanol produced from corn and four different results on bioethanol produced from cellulose or lignocellulose (the woody parts of trees and plants, perennial grasses, or residues) in the USA. The EROI from the different research are indicated in Figure 3.2a&b. For corn ethanol, the EROI was found to range from 0.84 to 1.65 and 0.69 to 6.61 for cellulosic ethanol. In most cases the EROI was greater than one which indicates that the amount of energy obtained per ton of bioethanol from either corn or cellulose is more than the energy invested to produce one ton of bioethanol from either source. It can also be explained that ethanol production from both corn and cellulose return renewable energy which offset its fossil energy used to produce them (Hamerschlag, 2006). This is supported by Solomon et al. (2007) who revealed that corn-based ethanol result in positive energy returns on investment and has other environmental benefits including 10 to 15% reduction in CO_2 emissions.

Depending on the sources of energy materials used, it is essential to note that different EROI for bioethanol occurs. This is evident in the EROI values for corn-based and cellulosic ethanol shown in Figure 3.2. Comparing the EROI values for bioethanol from corn and cellulose, it can be observed that cellulosic ethanol has higher EROI than corn ethanol. This means that investment to produce one liter of cellulosic ethanol is more energy advantageous and also returns more renewable energy from the use fossil energy in its production process than investment to produce bioethanol from corn. This is in line with what Solomon et al. (2007) observed that ethanol produced from cellulose is expected to be much more cost-effective, environmentally beneficial, and have a greater energy output to input ratio than ethanol obtained from grains such as corn. Therefore, ethanol from cellulose can be used to replace more fossil energy especially gasoline than corn ethanol. Estimates by Solomon et al. (2007) suggest that production cost for cellulosic ethanol could be lower than that of gasoline. Also, lignocellulose or cellulosic ethanol is reported to reduce net CO_2 emissions to nearly zero even though the same cannot be said for conventional air pollution (Solomon et al., 2000). However, with the values indicated in Figure 3.2, the average EROI for bioethanol produced from both corn (1.36) and cellulose (4.0) is greater than one. According to Hammerschlag (2006) both have EROI higher than gasoline implying that they are energy advantageous than some of the fossil fuels.

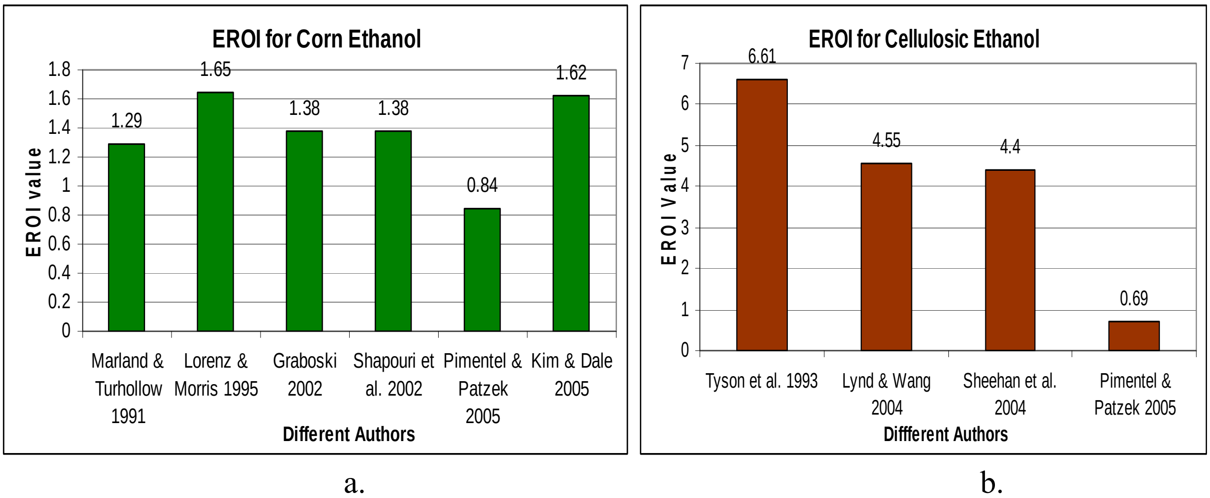

Figure 3.2. EROI for bioethanol obtained from corn (a) and cellulose (b) from different research results. Source: Adapted from Hamerschlag (2006).

In contrast to the above discussion, Lynch (2008) argues that the sustainability of corn ethanol is in doubt by indicating that a gallon of corn ethanol produced in USA gives approximately 76 KBtu of energy, while the production of a gallon of corn ethanol requires energy equivalence of about 40-50 KBtu signifying EROI of about 1.5. This is much lower compared with fossil fuel sources such as crude oil with an EROI of 20 while coal can reach an EROI of 80 in some instances and EROI of more than 20 for gasoline (Figure 3.3). In this case it becomes obvious that ethanol production from corn is more energy intensive than fossil fuels and unsustainable (Lynch, 2006). It also implies that with EROI of close to one, the profitability of bioethanol from corn will depend in the price of fossil fuels. This is conflicting with what (Hammerschlag, 2006) reported that the EROI of both corn cellulosic ethanol is higher than gasoline. It is also conflicting with what Hamerschlag (2006) reported that with EROI of higher than one, it seems safe to suggest that corn ethanol reduces fossil fuel consumption when used to displace gasoline. In addition, corn ethanol has the advantage of yielding renewable energy and since the EROI is more than one it means it supplies energy to compensate for the use of fossil fuels in the production process and less greenhouse gas emissions associated with fossil fuels.

3.4 EROI of Biodiesel, Bioethanol and Fossil Fuels Compared

From Figure 3.3 it can be observed that sugarcane ethanol (produced from Brazil) has EROI of almost 10. Therefore sugarcane ethanol supplied much more energy than the energy used in its production process. Thus with much improved production process, bioethanol from sugarcane can compete adequately with fossil fuels. Another interesting point to note from Figure 3.3 is the EROI of soy biodiesel. With an EROI of about 5, seems to be more energy advantageous than corn ethanol (first generation ethanol) and cellulosic ethanol (second generation) ethanol to some extent (Figure 3.2a&b). Soy biodiesel is also found to supply more energy than the energy used in the process to produce it and becomes an energy advantageous venture. In this situation, biodiesel can be seen as having the potential to replace some fossil fuels and supplies enough energy to offset the fossil fuel used to produce it than bioethanol.

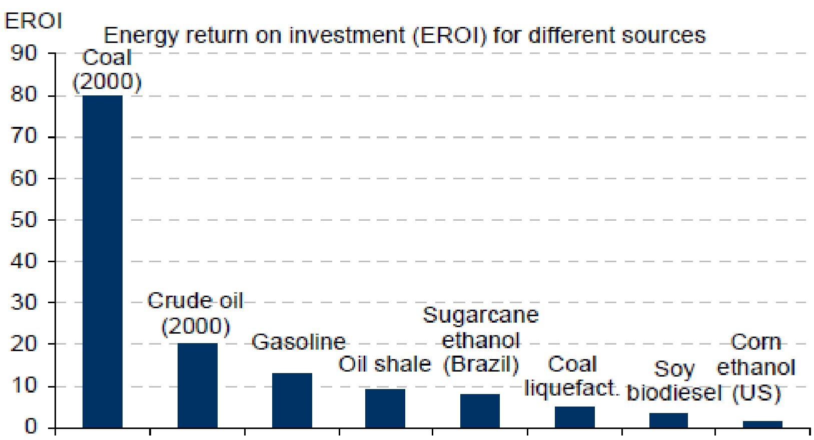

Figure 3.3. Energy return on investment for different sources (fossil and biological). Source: Lynch (2008).

Contrary to this assertion, Pimentel and Patzek (2005) stated that energy outputs from biodiesel produced from soybeans and sunflower as well as ethanol produced using corn, switchgrass, and wood biomass were each less than the respective fossil energy inputs used in the production process. These represent conflicting views on the energy return on biofuels.

4. Cost Comparison

It can be helpful to consider the cost comparison between the biofuels and fossil fuels. Production costs of biofuels vary geographically and are dependent on the prices of raw materials, the method of production, the extent of refining undertaken, and the supplementary utilization of by-products and waste. To be profitable, biofuel prices must be competitive in comparison with conventional transport fuels.

Table 4.1. Cost comparison of biofuels with fossil fuels

Biofuels	Biofuels costs €/toe	Fossil fuel pre-tax costs €/1,000 1	Cost difference €/1,000 1
Biodiesel (EU)	691	548	143
Biodiesel (EU)	660	548	112
Bioethanol (corn in USA)	338	566	−228
Bioethanol (sugar beet in EU)	671	566	105
Bioethanol (sugarcane in Brazil)	283	566	−283

In Table 4.1, we compare the pre-tax fossil fuel price (biodiesel is compared with diesel price and bioethanol with gasoline price) with biofuel costs production (€/toe). A consideration must be taken into account when comparing the current production costs of biofuels with conventional fuel costs: fossil fuel prices are strictly dependent on the crude oil price, which it is reasonable to predict will not go back to a low price in the future; biofuels costs are based on current conditions (feedstock prices of oil seeds not on large scale production), ignoring the possibility of a reduction of production costs of biofuels in the medium and long term.

It is clear that biofuels are not cost competitive with conventional fossil fuels in Europe unless imported from Brazil or the USA, even if the gap has been reduced during the last few years.

But, if we consider the consumer prices of petroleum products inclusive of duties and taxes in Europe, it can affect the cost-effectiveness considerably. The weighted average price in force on 1 August 2006 in the EU has been €/litre 1.174 for gasoline and €/litre 1.054 for diesel (source: EU Oil Bulletin), which means that 48% of the gasoline price and 52% of the diesel price are government taxes.

During 2008, gasoline and diesel prices have grown till to 1.4/l, but even agriculture products grew up dramatically: for instance price of sunflower seeds, which can be used as no food product to produce biodiesel, has grown of 178% between december 2006 and december 2007 (Source: Borsa Merci Bologna) . Given the cost differential with fossil fuels, government intervention is needed in order to promote the market introduction of biofuels and a remission of excise duty would be sufficient to equalise the prices between fossil and biofuels. The Energy Taxation Directive makes it possible for Member States to grant tax reductions or exemptions in favor of biofuels, under certain conditions.

These tax concessions are considered as state aids, which may not be implemented without prior authorization by the Commission. However, reducing excise duty on fuels would affect an important source of government revenue.

Revenue from transport fuel excise duty in 2002 for the 15 member states in the EU reached €178 billion. Energy and transport taxes in 2002 made up 2.6% of total GDP and 6.3% of total taxation in EU (Commission of the European Communities 2004).

5. Theoretical application

5.1 The many benefits of biofuels

Biofuels have two important features that favour their rapid, wider take-up. First, biofuel blends are used in modern car engines without modifications so for the consumer there is a smooth transition to using biofuel.

Second, they can be made widely available through the existing distribution system, from the same petrol stations that provide conventional fuels so investment in new infrastructure is avoided. These two features are vital advantages for the rapid penetration of biofuels into the passenger transport market.

As biofuels are sourced from plants and trees they are renewable and contribute to Europe's 12 % renewable energy sources target. They are also roughly 'carbon neutral' over their life cycles. The greenhouse gases emitted from a biofuel-powered car are balanced by the absorption of greenhouse gases during the growth of the organic source material, although there are some emissions from the chain of biofuels production. So overall, present-day biofuels over their life cycle typically produce approximately two thirds less greenhouse gas emissions than conventional transport fuels. As 28 % of European greenhouse gas emissions are due to transport, the emission reductions achievable from using biofuels go a long way towards Europe's commitments under the Kyoto Protocol.

Unproductive agricultural land could produce up to 5% of Europe's transport fuel needs, and forest, grasslands and waste could supply much more. It's important to improving the security of energy supply in the vulnerable transport sector by diversifying the places from which imports come.

It is estimated that a 1 % biofuel contribution to transport fuel consumption would create between 45 000 and 75 000 new jobs mainly in rural areas.

5.2 Biofuels for transportation

The world is on the verge of unprecedented growth in the production and use of biofuels (liquid fuels derived from plants and other biomass). Rising Transportation is responsible for 25 percent of the world's greenhouse gas (GHG) emissions, and this share is rising.

Oil prices, national security concerns, the desire to increase farm incomes, and a host of new and improved technologies are propelling many governments to enact powerful incentives for the production and use of these fuels.

Aviation provides the only rapid worldwide transportation network, is indispensable for tourism and facilitates world trade. Air transport improves quality of life in countless ways. The air transport industry generates a total of 32 million jobs globally. Aviation's global economic impact (direct, indirect, induced and catalytic) is estimated at USD 3,560 billion, equivalent to 7.5% of world gross domestic product. Aviation is responsibly reducing its environmental impact. Air transport's contribution to climate change represents 2% of man-made CO_2 emissions and this could reach 3% by 2050.

Fuel is one of the biggest operating costs for the aviation industry. The changing price of crude oil also makes it very difficult to plan and budget for operating expenses long-term. Sustainable biofuels may offer a solution to this problem since their production can be spread worldwide, and across a number of different crops, thereby reducing airlines' exposure to the fuel cost volatility that comes with having a single source of energy.

Biofuels can also provide economic benefits to parts of the world that have large amounts of marginal or unviable land for food crops, but are suitable for growing second-generation biofuel crops. Many of these countries are developing nations that could benefit greatly from a new industry such as sustainable aviation biofuels.

Learning from the experience of other industries, the aviation industry is therefore looking at second, or next-generation, biofuels that are sustainable. Each of the second-generation feedstocks has the potential to deliver large quantities of greener and potentially cheaper fuel.

It is unlikely, however, that the aviation industry will rely on just one type of feedstock. Some feedstocks are better suited to some climates and locations than others and so the most appropriate crop will be grown in the most suitable location. It is likely that aircraft will be powered by blends of biofuel from different types of feedstocks along with jet fuel.

Second-generation biofuels must have the ability to directly substitute traditional jet fuel for aviation (known as Jet A and Jet A-1) and have the same qualities and characteristics. This is important to ensure that manufacturers do not have to redesign engines or aircraft and that airlines and airports do not have to develop new fuel delivery systems. At present, the industry is focused on producing biofuels from sustainable sources that will enable the fuel to be a “drop-in” replacement to traditional jet fuel. Drop-in fuels are combined with the petroleum-based fuel either as a blend or as a 100% replacement.

Key advantages of second-generation biofuels for aviation

• Environmental benefits: sustainably produced biofuels result in a reduction in CO2 emissions across their lifecycle.

• Diversified supply: second-generation biofuels offer a viable alternative to fossil fuels and can substitute traditional jet fuel, with a more diverse geographical fuel supply through non-food crop sources.

• Economic and social benefits: sustainable biofuels provide a solution to the price fluctuations related to fuel cost volatility facing aviation. Biofuels can provide economic benefits to parts of the world, especially developing nations, that have unviable land for food crops that is suitable for second generation biofuel crop growth.

Why use biofuels for aviation?

Developing sustainable biofuels for aviation will:

• provide the aviation industry with an alternative to petroleum-based fuels;

• enable the industry to reduce its carbon footprint by reducing its greenhouse gas emissions;

• allow it to draw upon a variety of different fuel sources;

• be easier to implement than for other transport modes.

The aviation industry has seen huge growth since its beginning. Today, more than two billion people enjoy the social and economic benefits of flight each year. The industry worldwide provides jobs to some 32 million people and has a global economic benefit of around 7.5% of world gross domestic product. The ability to fly conveniently and efficiently between nations has been a catalyst for the global economy and has shrunk cultural barriers like no other transport sector. But this progress comes at a cost.

In 2008, the commercial aviation industry produced 677 million tonnes of carbon dioxide (CO2). This is around 2% of the total man-made CO2 emissions of more than 34 billion tonnes. While this amount is small compared with other industry sectors, such as power generation and ground transport, these industries have viable alternative energy sources currently available. For example, the power generation industry can look to wind, hydro, nuclear and solar technologies to make electricity without producing much CO2. Cars and buses can run on hybrid, flexible fuel engines or electricity. Electric-powered trains can replace diesel locomotives.

The aviation industry has identified the development of biofuels as one of the major ways it can reduce its greenhouse gas emissions. Biofuels provide aviation with the capability to partially, and perhaps one day fully, replace carbon intensive petroleum fuels. They will, over time, enable the industry to reduce its carbon footprint significantly. Figure 5.1. shows the total tonnes of CO_2 emissions attributable to commercial aviation and a forecast for the coming years.

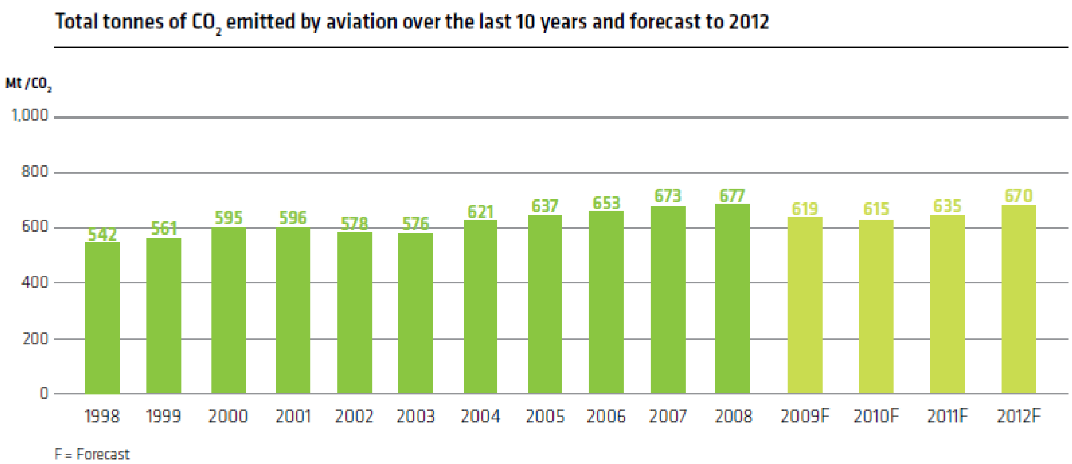

Figure 5.1. CO_2 emissions attributable to commercial aviation

However, the forecast emissions are simply based on a ‘business-as-usual’ scenario, not taking into account any major advances in technology or the introduction of biofuels. The decrease in emissions between 2008 and 2009 can partially be attributed to a fall in traffic due to the recession. However, 2% of this reduction comes from efficiency increases.

Implementing biofuels for aviation easier than for other transport modes:

The supply of fuel to the commercial aviation industry is on a relatively small scale and less complex than for other forms of transport. For this reason, it is anticipated that it will be easier to fully implement the use of sustainable biofuels in aviation than in other transport systems.

For example, there are 161,768 retail petrol stations in the United States alone. This compares to a relatively smaller number of airport fuel depots: 1,679 airports handle more than 95% of the world’s passengers.

Similarly, there are around 580 million vehicles on the road today, compared to around 23,000 aircraft. And while many of those road vehicles are owned by individuals or families, there are only around 2,000 airlines in the world.

The integration of biofuels into the aviation system is potentially a lot easier than it would be in a more dispersed, less controlled, public fuel delivery system. So the use of sustainable biofuels can provide the air transport industry with a near-term solution to provide a fuel with a lower environmental impact than petroleum-based. Figure 5.2 shows the fuel consumption expressed in millions liters by twenty countries of departure.

	Country of departure	Fuel*		Country of departure	Fuel*
1.	United States	74 584	11.	United Arab Emirates	4 038
2.	China	18 282	12.	Korea	4 037
3.	United Kingdom	11 804	13.	Netherland	3 983
4.	Japan	11 678	14.	Italy	3 974
5.	Germany	8 611	15.	Thailand	3 966
6.	France	6 715	16.	Singapore	3 889
7.	Australia	5 354	17.	Brazil	3 642
8.	Canada	5 121	18.	India	3 556
9.	Spain	4 953	19.	Mexico	3 054
10.	Russia	4 635	20.	Malaysia	2 374

Source: ICAO based on OAG timetable

*Fuel consumption expressed in millions liters

Figure 5.2. Fuel consumption by top twenty countries of departure

Hydrocarbon fuel is the only option for aviation for now. At this stage, there is no foreseeable new technology to power flight beyond hydrocarbon fuels. Hydrogen can be burned in a turbine engine for aviation. However, there are significant technical challenges in designing a hydrogen-powered aircraft for commercial aviation and in producing enough hydrogen in a sustainable way to supply the industry's needs. The use of sustainable biofuels can provide the air transport industry with a near-term solution to provide a fuel with a lower environmental impact than petroleum-based fuels.

Of course this type of technology is one of the possible applications of biofuels productions and before the implementation of this technology, we have to compare the advantages and disadvantages from the use of it.

6. Conclusions

The requirement of renewable sources of energy is an important issue nowadays because of the decreasing reserves of fossil fuels and the climate change. The production of fuels from biomass is an interesting option due to its potential, although there is a lot of controversy in terms of net energy about the first generation biofuels.

There is not a specific value of the net energy of biofuels because it depends on each situation and it can be very different from one case to another. The latest studies about the net energy balance of biofuels are positive, which means that it is possible to obtain more energy from biofuels than the energy expended in their production. Moreover, the factor that has more effect, in terms of energy consumption during the production of biofuels, is the cultivation of crops. In this sense, the choice of the optimal crop is essential to obtain a positive value of energy balance.

The values of net energy of biodiesel in Europe (focused on a specific case of Italy) and bioethanol in United States are both positive. However, biofuels are not competitive with fossil fuel due to their higher production costs.

Strategies and action plans to produce biofuels, in order to be effective and sustainable, have to be developed by looking at opportunities and constraints for their implementation at regional/local levels.

First generation biofuels do not seem to be the solution to supply the energy deficit for different reasons: high cost production, limited land availability and low NEB. Even with additional research and development efforts, only a small quantity of biofuels can be produced as alternative to oil because an incremental production will lead to the rising of agri-food prices. Second generation biofuels can in the future be a possible solution so it would be better to invest public money in their development rather than pushing first generation biofuels.

On the average, biodiesel and bioethanol each have energy return on investment higher than one. Thus the energy supplied or delivered by biodiesel and bioethanol respectively is higher than the energy used in the process of producing them. It implies that both biodiesel and bioethanol returns renewable energy to offset the amount of fossil fuels that may be used in their production process. This is not absolute as in some cases the EROI for biodiesel or bioethanol may be less than one indicating that energy supplied is lower than energy utilised in the production process. EROI for second generation bioethanol (cellulosic ethanol) seems to be higher and energy advantageous than first generation bioethanol (corn ethanol). Second generation ethanol therefore has a potential as biofuel in terms of energy and can to replace gasoline to some extent.

There is not a specific EROI for either biodiesel or bioethanol. Different studies have reported different values and these results mainly from several factors including different assumptions on the allocation of energy requirement to either main products or by-products. This has resulted in conflicted values for EROI for biofuels. Having a standard allocation method or a reference allocation procedure will be a good strategy to harmonise EROI values for fare comparisons.

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