Bio fuels

“A review and comparison of available bio fuels, techniques and their environmental, economical, political and social consequences”
Word of Thanks

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Preface

High oil prices and growing environmental awareness are leading to new developments on the fuel markets in the world. The best known developments are in the field of bio fuels. Bio fuels have the potential to replace a part of our need for fossil fuels, especially in the transport sector. The biggest advantage of these bio fuels is the assumed unlimited availability of them and their perceived environmental benefits. This thesis will concentrate on a comparison between fossil fuels and bio fuels based on costs per MJ, calorific value per MJ, grams of CO₂ per MJ and their environmental, economical, political and social impact. Bio fuels are in this thesis restricted to Bio Diesel, Bio Ethanol and Bio Hydrogen since these fuels have a lot of potential as transport fuels. Fossil fuels used for the comparison are Petrol and Diesel. I have also added solar energy to complement the comparison. The bio fuels have been subdivided on basis of their origin to determine the environmental, economical, political and social impact. In the first chapter bio fuels will be discussed and the different generation’s bio fuels will be explained. In the second chapter we will focus on the production and extraction of the different generation’s bio fuels. The third chapter will go into further depth specifically on the latest development in the field of Bio Hydrogen. The fourth chapter will cover the environmental, economical, political and social impact of bio fuels. This will be followed by chapter five with ethical concerns regarding food vs. fuel, land use, energy efficiency of bio fuels and patents on bio fuels and bio fuel technology. Finally in chapter six there will be a table with a comparison of bio fuels, solar energy and fossil fuels on the different aspects and a model explaining the relations between all the aspects covered in this thesis. This will result in a discussion and recommendations for further research.


Abstract

There are three different generations of bio fuels the first being made out of mainly eatable crops, the second made of energy crops and waste from agricultural products and the third generation bio fuels made of algae and bacteria. The extraction of bio fuels out of these products can be done in several ways and several products can be obtained, like bio diesel, bio ethanol and bio hydrogen. In most cases of bio diesel the oil is being pressed out of the seeds or algae and being further processed and purified, resulting in bio diesel and glycerine as end products. Bio ethanol is being won out of sugar rich crops like sugar beets and maize and being fermented into alcohol. New techniques also make it possible to gain ethanol out of cellulose crops, which offers good possibilities for future use. Bio hydrogen is a special type of fuel still in testing stages in laboratories. The hydrogen is being released by sulphur deprivation of algae in bio reactors. The hydrogen released is collected and can be used as end product. These processes still need to be scaled up and this will still take a long time to become commercially viable.

Bio fuels have an impact on different aspects like the environment, economy, politics, social life and ethics. Environmental aspects concerning bio fuels are the use of land, water, pesticides and whether the net CO$_2$ balance of the production of bio fuels is positive or negative. Still discussion on these topics is going on to determine which crops would in the end be suitable for the production of bio fuels without harming the environment more than they help. Bio fuels also have an economical impact; in this regard we can refer to the rise in land and food prices due to the extensive use of land for energy crops. Subsidies given for bio fuels have disastrous consequences in the poorest countries of our world. The political aspect of bio fuels need to be sought in the current dependency on oil producing countries which have in many cases authoritarian regimes in power. To become less dependent on their oil, alternatives are being developed which is also becoming more important with the high oil prices. The social aspects of the bio fuels need to be seen in the light of all the other aspects mentioned before. Bio fuels and the higher oil and food prices have led to social instability in some of the poorest countries in the world. We should consider whether we find it appropriate in the west to cause social instability and hunger due to our subsidies and need for alternative fuels.
Ethical concerns raised by the use of bio fuels are about food vs. fuel, land use practices, efficiency and cost, patent rights, population growth and energy use. The food vs. fuel debate concentrates on if we should use food for fuel purposes while still many people are dying. Land use practices concentrate on the soil depletion and cutting and burning down of tropical rain forests for agricultural land; another aspect is the extensive use of pesticides and herbicides leading to water pollution. The efficiency and cost of bio fuel deals with the problems on efficiency of bio fuel production. For the production of bio ethanol some studies show more energy is being used to make the bio ethanol than it delivers in the end. Patent rights are only very recently becoming a problem with bio fuels. Due to the boom in the energy prices, bio fuels are being researched more and more and patents are obtained by large companies. Potentially patent right issues could slow down progress on the research in bio fuels. The risk only few companies have patents on critical technologies in the future is an issue to be aware of. Last but not least the link needs to be made with population growth and the massive raise in energy demand in the last hundred years. This gives an idea of the challenges we face to find a solution for our energy consumption without compromising on living standards and wealth for our children and for developing countries.

When the bio fuels are being compared on the variables cost, social & ethics, environment, politics and technology we get a good overview on the bio fuel landscape and the problems we need to solve in the discussion. Most important aspects we need to overcome are the price of the bio fuels and the direct and indirect emissions of the bio fuels. The second and third generation bio fuels are more successful in this respect and in particular bio ethanol from waste products and bio diesel from algae. The fossil fuels have basically, except the CO₂, energy security and limited availability, no specific drawbacks. Solar energy has also some drawbacks like the price and limited availability of resources for the production of solar panels.

To overcome the energy problems we are facing, worldwide action is needed. To make bio fuels successful a global well coordinated approach is necessary. Action is needed on energy saving, population growth and consumption patterns. In order to deal with these problems a global institution like the International Panel on Climate Change (IPCC) for climate change is needed on energy as well. Global action and agreement is the only solution to address the problems we face in our world. Whether this will be accomplished on an acceptable term can however be questioned if we look at the process of the climate discussion.
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1. **Bio fuels and the different generations**

In this chapter I will be explain what a bio fuel is and which generations of bio fuels there are. The line between the different generations is not very strict however.

1.1 **What are bio fuels?**

Bio fuels are fuels derived out of recently dead organic material (VROM, 2008) in comparison to fossil fuels which are made out of dead organic material as well but have been around for a long time. Bio fuels can be made out of most photosynthetic plants and their seeds. Bio fuels can be solid, fluid or gaseous depending on the source and the process used for the extraction of bio fuel. In this thesis liquid fuels used for cars will be discussed. Solid and gaseous bio fuels are mainly used for cooking purposes in third world countries or for the generation of electricity in power plants. The use of bio fuels for cooking and electricity is beyond the scope of this thesis.

1.2 **First generation bio fuels**

With first generation bio fuels we mean fuels made from (oil) seeds from eatable crops or animal fat. Since the first generation bio fuels are made from eatable crops they are discussed by various international organisations (World Bank, 2008 and UN, 2007) and NGO’s (Oxfam Novib, 2008) for their competition with food. As a result of the fuel competing with food, rises in food prices and changes in land use practices occur. This eventually results in higher CO$_2$ emissions eliminating the CO$_2$ reduction achieved with bio fuels. (OECD, 2007 and MNP, 2008)

1.3 **Second generation bio fuels**

Second generation bio fuels are in contrast to the first generation not made out of food crops. These fuels are being extracted from waste biomass, stems and leaves, sewage sludge and energy crops. The advantage of the second generation bio fuels is the fact that the food vs. fuel debate is not fully applicable. However there is still competition with food. Due to the need for arable land for energy crops they compete with food crops for land resulting in higher prices. Biomass used for second generation bio fuels is not leading to conflicts when local biomass is being used. Importing biomass from foreign countries will result in energy use for long distance transports affecting the energetic balance of the bio fuel. This needs to be taken into account when reductions in CO$_2$ emissions are being calculated. Also the
changing land use practices and land clearing for production of crops for bio fuels needs to be taken into account when emission reductions are calculated. (MNP, 2008)

### 1.4 Third generation bio fuels

Third generation bio fuels are made from algae and bacteria. Oil producing algae are grown in ponds and harvested. The oil content gets extracted out of the algae and upgraded to bio diesel (New Scientist, 2007). Another option with algae and bacteria is the production of bio hydrogen. For this process photosynthetic bacteria or algae are manipulated in order to increase the production of hydrogen during the photosynthetic process. The organisms are grown in bioreactors under optimal circumstances in order to increase yields. Yields of algae and bacteria are very interesting in comparison to first and second generation bio fuels and can be up to 30 times higher than the best known production crops. (Mora Associates, 2007)

Another advantage is the fact algae and bacteria do not compete with food crops and land. Algae waste can be used as animal food so this even contributes to the animal food chain. Land use is no problem because algae can be grown on non arable lands e.g. deserts. (TWAnetwerk, 2008)

Bio fuels from algae could become commercially attractive when oil prices are being maintained on extremely high levels of $120 a barrel. Bio Hydrogen is nevertheless still in its early stages and will take several years to become available on commercial scale. (Melis, 2008)
2. Production and extraction of bio fuels

In this chapter the different production and extraction techniques will be explained and described. Bio fuels are produced in several ways. The production process of first and second generation Bio diesel is very similar. Bio ethanol production is for first and second generation quite similar as well. The production process for third generation bio fuels however, is significantly different. First the production of Bio diesel and bio ethanol will be described. Secondly the process for algae oil and finally the process of bio hydrogen will be explained.

2.1 Production and extraction of Bio Diesel & Bio Ethanol

Bio diesel is being produced by mainly rapeseed oil but can also be produced from sunflower oil, soybeans, palm oil or jathropa oil and can replace diesel from fossil fuels. Bio diesel is said to be more environmental friendly due to the production out of natural resources. The supposed environmental friendliness of bio fuels will be discussed later.

During production first the oil will be pressed out of the oil seeds to gain the crude oil. Rest products of the seeds can be used as either cattle feed or for the production of electricity from biomass. After the pressing the oil needs to be refined. The next step is to transform the oil in bio diesel trough the process of base catalyzed transesterification (a Ph factor of 8-9 is required). There are other processes available to convert oil into biodiesel but due to the attractive economics, low temperatures needed and high conversion yields of 98% (ESRU, 2008) base catalyzed transesterification is preferred.

![Flowchart of production process of bio diesel (ESRU, 2008)]
To get biodiesel a catalyst (normally sodium hydroxide) is used and put in a vessel together with methanol. The oil is being added and a reaction takes place on 71 degrees Celsius for 1 to 8 hours. The amounts of water and fatty acids in the oil need to be monitored in order to prevent problems further downstream in the process with the separation of the glycerine.

After the reaction two main products are available, glycerine and bio diesel. The glycerine and diesel need to be separated which can be done by gravity separation resulting in the glycerine being drawn to the bottom. This is sometimes being done by a centrifuge in order to speed up the separation process. After the separation the excess alcohol is being removed by flash evaporation or distillation, the alcohol is reused.

After the removal of water and alcohol the glycerine is ready to be sold as crude glycerine (80-88% pure). The glycerine can be distilled to a higher purity (99%) to be sold to the cosmetic or pharmaceutical industry.

The bio diesel from the process needs to be analysed in order to check if it meets the required specifications. The diesel needs to be checked on the following aspects in order to guarantee problem free usage in engines: Complete reaction, Removal of glycerine, Removal of catalyst, Removal of alcohol and absence of free fatty acids. In figure 2 the simplified production process is given.

![Figure 2: Simplified production process of bio diesel](image)
Bio ethanol has been used for a long time and consists mainly of ethyl alcohol. In the production process sugars are fermented into alcohol. These sugars can be found in several agricultural crops, but not every crop is as suitable for the production of bio-ethanol. Most common crops used for the production of bio ethanol are sugar cane (Brazil) and corn (USA) but also wheat, rapeseed and sugar beets can be used as well as leftovers from the food processing industry.

New techniques are already available and being improved in order to ferment bio ethanol out of cellulose in straw, biomass or wood residue in order to prevent the use of food for fuel.

As mentioned before fermentation is being used to create the bio ethanol. In order to ferment crops like corn and wheat, enzymes are used to convert starch into glucose that can be fermented into alcohol. With sugarcane and sugar beets a sugar rich fluid needs to be gained to make them suitable for fermentation.

After the fermentation process the fluid still contains significant amounts of water which needs to be removed. To distil the alcohol out of the water the fluid is being boiled resulting in the evaporation of the alcohol due to its lower boiling point compared to water. The ethanol vapour can be condensed and separated from the water.

Figure 3 Production process bio ethanol
2.2 Production and extraction of Algae Oil (for Bio diesel)

The main method for the production of large amounts of algae for oil is in large ponds where the water is being stirred around and CO\textsubscript{2} is added as well as other necessary nutrients. (ASP, 1998) (Putt, 2007). This is a very basic method for the production of algae. Different types of algae can be used for the production of algae oil depending on the percentage of fatty acids.

Research of the aquatic species program shows it is wise to use local algae for the production of bio fuels. This means that for each location it needs to be determined which algae strain is best for production. This needs to be done since it has been shown local algae take over ponds in the long run anyway. (ASP, 1998).

![Algal ponds with a factory in the middle](image)

**Figure 4** Example of algal ponds with a factory in the middle.

Production of algae in ponds is rather difficult since algae can be quite demanding. (Nature, 2007) Below problems with the growth of algae are listed:

- Too much sunlight kills algae
- Temperature needs to be steady
- Overcrowded ponds inhibit growth
- CO\textsubscript{2} bubbles in the ponds can rupture algal cells.
- Evaporation, rainfall an Ph value need to be controlled in order to prevent imbalances

These problems need to be overcome in order to produce stable amounts of bio fuels. Research concentrates on these factors, and is trying to build bio reactors where yields can be optimized and the environment can be held in an optimal and steady condition.
When algae are grown the possibilities are diverse and shown in the figure below. After the algae are grown in ponds, different processes can be used to make different end user products. Most common end products at the moment are bio diesel and even foods. Since demand for bio fuel is very high this is commercially the most attractive route. For the future hydrogen from algae seems to be a very promising route and will be mentioned in the next paragraph.

**Figure 5** Algae from production to end user product (Edwards, 2007)

**Extraction of algae oil**
There are a few techniques to extract oil out of algae. Most of these techniques are already being used for the extraction of oil from oilseeds.

**Expeller/ Press**
With the press method algae are being dried and pressed to get the oil out. With this process 70 to 75 percent of the oil can be extracted. For the other part chemical processes can be used like the hexane solvent method, which unfortunately is very pollutant.

**Hexane solvent method**
This method is using chemicals to extract oil out of the algae. Benzene and ether can be used, but the most popular solvent because of the price is hexane. Drawback of the chemical solvent process is it has the general risks of working with chemicals, like explosions for example. Another risk is the carcinogenetic properties of benzene. From an environmental point of view using these chemicals is not preferred due to the wastewater concerned with this method.
Supercritical fluid extraction
With supercritical fluid extraction nearly 100% of the oil can be extracted out of the algae. Drawbacks are the costs involved with the specific equipment needed for containment and pressure. The price of algae oil depends on the production process and extraction of the oil. Therefore cheap methods are being preferred.

Beside the known common techniques we have also less well known and in general for the moment too expensive techniques. These techniques are:

Enzymatic extraction
In this process enzymes are being used to degrade the cell walls with water being used as the solvent for enzymes. The use of water makes fractionation of the oil easier. The costs of this process are much higher than the quite similar process of hexane extraction and therefore not yet attractive.

Osmotic shock
With osmotic shock the osmotic pressure is suddenly reduced, causing the cell walls to rupture when being in a fluid. It is sometimes being used to release cellular components such as oil in the case of algae.

Ultrasonic assisted extraction
Ultrasonic extraction can speed up the extraction process. An ultrasonic reactor creates waves causing cavitation bubbles in a solvent material. When these bubbles collapse near the cell walls of the algae shock waves and liquid jets cause the walls to break and release the their content (in this case oil) into the solvent.

When the oil is extracted from the algae the rest of the production process is similar to the production of bio diesel from oil seeds.
2.3 Production and extraction of Bio Hydrogen

Bio hydrogen can be produced in different ways, in the table below the different production routes will be highlighted.

<table>
<thead>
<tr>
<th>Process</th>
<th>Reaction</th>
<th>Micro organisms used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Bio Photolysis</td>
<td>$2H_2O + \text{Light} \rightarrow 2H_2 + O_2$</td>
<td>Micro algae, Cyano bacteria</td>
</tr>
<tr>
<td>Photo Fermentation</td>
<td>$\text{CH}_3\text{COOH} + 2H_2O + \text{Light} \rightarrow 4H_2 + 2\text{CO}_2$</td>
<td>Purper bacteria, Micro Algae</td>
</tr>
</tbody>
</table>
| Indirect Bio Photolysis        | a) $6H_2O + 6\text{CO}_2 + \text{Light} \rightarrow \text{C}_6\text{H}_12\text{O}_6 + 6\text{O}_2$  
  b) $\text{C}_6\text{H}_12\text{O}_6 + 2H_2O \rightarrow 4\text{H}_2 + 2\text{CH}_3\text{COOH} + 2\text{CO}_2$  
  c) $2\text{CH}_3\text{COOH} + 4\text{H}_2\text{O} + \text{Light} \rightarrow 8\text{H}_2 + 4\text{CO}_2$  
  Overall Reaction: $12H_2O + \text{Light} \rightarrow 12\text{H}_2 + 6\text{O}_2$ | Micro Algae, Cyano Bacteria              |
| Water Gas Shift Reaction       | $\text{CO} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{H}_2$ | Fermentative bacteria, Photosynthetic bacteria |
| Two phase fermentations        | a) $\text{C}_6\text{H}_12\text{O}_6 + 2\text{H}_2\text{O} \rightarrow 4\text{H}_2 + 2\text{CH}_3\text{COOH} + 2\text{CO}_2$  
  b) $2\text{CH}_3\text{COOH} + 2\text{CH}_4 + 2\text{CO}_2$ | Fermentative bacteria, Methanogenic bacteria |
| High Yield Dark fermentations  | $\text{C}_6\text{H}_12\text{O}_6 + 6\text{H}_2\text{O} \rightarrow 12\text{H}_2 + 6\text{CO}_2$ | Fermentative bacteria                   |

Table 1 Different production processes of bio hydrogen (Reith, Wijffels and Barten, 2003)

Fermentation and bio photolysis are most promising and most research focuses on these processes. Hydrogen fermentation out of biomass has as a disadvantage that the availability of biomass is limited. Biomass is increasingly being used as a source of green energy and this will lead to shortage in biomass in the long run especially when demand passes supply, prices will increase sharply, as is currently happening with oil.
Direct bio photolysis is a very interesting route. Bio photolysis is the shortest route from sunlight to hydrogen. Hydrogen is being produced by algae as a by-product of photosynthesis. The production of hydrogen is marginal though. Scientists are trying to manipulate algae and upgrade the ability to produce hydrogen by photosynthesis to a commercially viable level. (Melis and Happe, 2003)

Bio hydrogen can be produced in bioreactors. Production of bio hydrogen from algae through bio photolysis is still in its experimental stages, therefore no large bio hydrogen reactors have been built yet. It is expected this will happen when research is getting further. Eventually bio hydrogen could be produced in closed ponds or reactors on a large scale where photosynthetic microbes can split water into hydrogen and oxygen. (DOE, 2005) On the picture below a small scale reactor is shown. When successful, the prototypes can be scaled up in order to produce larger amounts of hydrogen.

Figure 6 Small scale bio reactor for algae hydrogen production (flickr.com, 2008)
3. Developments on Bio Hydrogen

It has been known since the early forty’s (Melis & Happe, 2003) that with the process of photosynthesis a small amount of hydrogen is being produced every now and then. Scientists have tried to figure out how the process of hydrogen production and the switching on and off worked without success.

As a result of the oil crises in the seventies interest in algae revived especially in the oil producing algae. The Department of Energy (DOE) of the United States decided to set up a program for research into algae and algae oil by the national renewable energy laboratory (NREL). This program was suspended in 1996 due to the fact algae oil was not expected to become economically viable in the near term. In 1996 the oil price was very low which helped to make the decision to end the program. (NREL, 1998) Many researchers who worked on the aquatic species program (ASP) continued their research at universities. Out of this program research into bio hydrogen has evolved further. One of these scientists was Anastasious Melis.

It was in the late nineties Melis from the University of Berkley in California discovered the mechanism behind the hydrogen production and how to influence the algae in a way it is able to produce more hydrogen. The enzyme responsible for the production of hydrogen is called hydrogenase and in the presence of oxygen this process does not take place. Melis discovered sulphur deprivation interrupts the internal oxygen flow causing the algae to produce hydrogen. (Melis, 2007)

Currently bio hydrogen is being developed further in laboratories and is still in its testing phase. Breakthroughs are being realized in percentages hydrogen produced, and algae and bacteria are tested and genetically manipulated in order to determine which type has the best production potential. The bio hydrogen produced in laboratory reactors is only small in quantity. These processes need to be improved, tested and upgraded in order to get commercially viable on the long term.
4. Impact of bio fuels.

This chapter will cover the impact of bio fuels on environmental, economical, political and social aspects and the imbalances created by the production of bio fuels. Ethical concerns will be discussed in chapter 5.

![Diagram of environmental, economical, political, and social impacts]

4.1 Environmental impact

The environmental impact of bio fuels remains controversial and there is no consensus yet whether bio fuels help or harm the environment. (New Scientist, 2007) The main discussion is about the emission reduction of bio fuels in comparison to fossil fuels. The direct emissions of bio fuels are lower. There is no controversy about this, but the problem lies within the calculations of the indirect CO$_2$ emissions. For the production of bio fuels, crops need to be grown. For the growth of these crops land is needed as well as extensive amounts of fertilizers and herbicides. Changes in land use for the production of bio fuel crops have significant influences on CO$_2$ emissions especially when tropical rainforest are being cut and burned. (Searchinger et al, 2008, Charles et al, 2007) The problems with the fertilizers regard the emission of nitrous oxide. This green house gas is about 310 times more powerful than carbon...
dioxide, which makes it important to take into account when calculating emissions. How to calculate these indirect emissions, so they can be compared is still an unsolved problem. This is necessary before adequate comparisons can be made between fossil fuels and the different generation’s bio fuels. (Patzek et al, 2004)

This problem plays a major role with the first and second generation bio fuels. In general the third generation bio fuels have no complications with regard to changes in land use. Algae consume CO$_2$ and arable land is not necessary for algae cultures to grow. This offers potential environmental opportunities for carbon capture from coal fired power plants in combination with algae farms. (Nature, 2007). CO$_2$ carbon capture by algae will however be a short term solution since the carbon will be stored in the algae and released when burned. When CO$_2$ captured from coal fired power plants is used for the growth of algae the CO$_2$ emissions will take place but the cycle before this happens only gets prolonged. If the algae grow by using the sun and the CO$_2$ in the air, algae growth will be much slower without the addition of captured CO$_2$. The advantage of algae growth using sun and CO$_2$ in the air will be the balance of the CO$_2$ captured and released. Disadvantage will be lower growth volumes which result in higher production prices of algae fuel.

Reijnders and Chisti (2008) are having a discussion on CO$_2$ balances of second and third generation bio fuels and on whether algae farms offer the large CO$_2$ reductions as promised in relation to energy crops. Especially the building of a bioreactor and the fossil fuels needed for the construction are subject of discussion. It is important to take the complete life cycle into account in order to make adequate CO$_2$ balances of the several bio fuels. How these balances should be made is still being debated and there are no generally accepted rules known on how to calculate the CO$_2$ balances of bio fuels. Action should be taken by scientist in order to solve this problem and reach consensus so proper decisions can be made by governments. Without calculations accepted by the large majority of the scientific community the issue will drag on.

4.2 Economical impact

The economical impact of bio fuels is mainly found in the secondary effects of the production of first and second generation bio fuels. Due to competition with food and arable land bio fuels of the first and second generation are causing food inflation in countries which rely on food imports. At this moment it is estimated that due to the rise in food prices around 100 million people have fallen back below the poverty line or are on the verge of falling under it.
Subsidies on first and second generation bio fuels in the EU and the US are leading to an increased demand for bio fuels and an increase in arable land used for the production of energy crops instead of food. The poorest countries are feeling the effects of this subsidies directly where the industrialized countries do not feel these effects straight away.

4.3 Political impact

Bio fuels can have a significant impact on the reduction of political tensions. Bio fuels can be produced in more stable (western) countries and can cause a better diversification in oil supply. This will result in less dependency on Middle Eastern countries reducing political tensions. Due to the high oil prices caused by the expected decline of oil production in the short term and the concentration of major oilfields in the Middle East tensions over oil are increasing (CNN, 2008). Tensions in the Middle East have grown since the U.S. invaded Iraq under the flag of war on terrorism and presumed nuclear weapon facilities in Iraq, destabilizing the oil market. (Campbell, 2006) Still markets are under severe stress since supply and demand are out of balance. Major oil supplying countries gain more power over countries with no oil reserves. Especially for the United States, which consume 25% of the total oil produced, this is an ever increasing problem. (NRDC, 2008) Due to their addiction to oil (State of the union, 2006), the U.S. is forced to deal with corrupt regimes and accept their terms and conditions to get the oil they need. In order to get less dependent on foreign oil the U.S. is promoting bio fuels and spends tremendous amounts of money and subsidies on the production and development of bio fuels. These subsidies have led to a strong increase in the production of bio fuels. Critics say these subsidies have led to increased food prices and unfair competition. First and second generation bio fuels which are subsidized at the moment will not lead to improved political stability since there is much discussion on the food vs. fuel and unfair competition. Also third world countries will oppose the further development of bio fuel when this leads to significant appreciation of food prices. Therefore third generation bio fuels could give a more stable solution, because local algae strains can be grown in nearly every climate, produce high yields and don’t need arable land. Potentially patent rights issues could cause problems in the future of third generation bio fuels. However a change in energy dependency can be established by third generation bio fuels, leading to a new relationship between non energy producing countries and energy producing countries like the OPEC members.
4.4 **Social Impact**

Bio fuels have lead to social instabilities in several countries. The higher food prices resulting from the production of first and second generation bio fuels have led to food riots in Pakistan, Egypt, Cameroon and other countries (World Bank, 2008). Food inflation has led millions of people back to poverty. This means if no policy regulations become in place which regulate bio fuels and the influence on foods. Poor people will even suffer more when the current trend continues. Especially the link between oil and food prices needs to be broken and the influence of speculation on food needs to be restricted.

Higher food prices do however offer new opportunities to rural communities. Due to the higher food prices people can make a better living on the countryside. This prevents them from migrating to the major cities, a development going on in most developing countries. Most developmental countries have a large agricultural population and for these people bio fuels can offer new opportunities in the sense that they can grow different crops for energy instead of food crops which may be a good alternative in dryer regions. In this way the farmers in the rural communities can earn a fair amount of money in order to foresee in their daily needs. It needs to be said that the earnings from fuel crops could be diminished by the higher food prices and therefore offer no real sustainable alternatives for communities. Another potential long term problem is the fact larger companies will take over bio fuel production when prices continue to be high and start producing on a large scale in order to lower production costs. In this case the farmers without education will eventually become low paid employees for large bio fuel companies or will be unemployed when machines take over production.
5. Ethical Concerns regarding bio fuels

This chapter will be dedicated to the ethical concerns of bio fuels. Food vs. fuel, changing land use practices, the efficiency and costs of bio fuels and eventually patent right issues on new innovations will be discussed.

5.1 Food vs. Fuel

The most prevailing ethical aspect of bio fuels is the food vs. fuel debate. Ethically seen, food should not be used for the production of bio fuels as long as people are still dying because of a lack of food or malnutrition. This seems very obvious, but there are reasons to be in favour or against bio fuels from foods. Lack of food is still mainly a distributional problem instead of a supply problem. An important issue is the subsidies in the United States and Europe on agricultural products to protect their markets, causing massive production, oversupply and eventually dumping of food on world markets. In Europe and the United States it would not be a problem to use these oversupplies for fuel. In third world countries however the food for fuel problem is most eminent, food prices go up because they are being seen as a generic product for oil causing price to rise.

Overproduction of food could be used for fuel production to cover the lack of oil products and the urge for cleaner fuels without major problems in industrialized countries. But should these oversupplies be used for fuel in their own countries or be used for aid to third world countries? This should become part of a legal framework. Food can be used for fuel for domestic use when there is no hunger in the world as mentioned in the millennium goals by the United Nations. This would mean Western countries can not use food for fuel, but have to export these products to people in need, instead of making fuel.

Brazil is however a good example of a country where bio fuels are being produced for a long time without significantly effecting food supply or food prices. At the moment the techniques for production of fuels out of food crops in Brazil are highly developed. Although it is discussed whether bio fuels are energy efficient and contribute to Green House Gas reductions (see paragraph 5.3). On the long run the use of food crops for fuel production will always become a problem with growing energy demand and a growing population which needs to be fed in the end.
Taking everything into account makes it hard to justify the use of food for fuel or arable land use for energy crop production, if we consider the fact of justice. Everyone has the right to be fed and wants to be fed. Using food for fuel is a violation of this unwritten law of justice. If we did not know where we would be born on this planet and we were asked whether it is responsible to use food for fuel and let people die because we want to fill our fuel tanks, the answer would most certainly be no. Therefore it is strange the use of food for fuel is still common practice. (Rawls)

5.2 Land use practices

Bio fuels have an effect on the use of land in many countries. The biggest concerns are raised for changes in land use in third world countries and Brazil in order to produce bio fuels. Brazil and Indonesia are important producers of respectively bio ethanol and palm oil. Indonesia is clearing tropical rainforest in order to start palm oil production sites. Also in the U.S. concerns are raised regarding changes in land use and the contribution to the emission of Green house gases (GHG). (Searchinger et al, 2008)

The same concerns are raised for Brazil and the ethanol production. A study from Wolf et al (2002) shows that with high external input in 2050 55 % of the agricultural land is needed for the production of food. The other 45% could be used for the production of biomass. In the scenario of low external input no agricultural land would be available for biomass production in 2050. The scenario of high external input is due to its assumed maximization of crop production, chemical fertilizers and biocides clearly unsustainable and therefore not realistic. The low external input scenario fits into a more sustainable future. If we assume not the whole world will switch towards production according to the best technical and ecological means at once a small amount of biomass will be available for energy production in 2050.

These land use practices could be overcome when third generation bio fuels come into play. No arable land is needed for the growth of algae. They can be grown on barren land e.g. deserts or rocky bottoms. Also the use of bio waste or sewage sludge has no drawbacks when it comes to the production of sustainable bio fuels and the competition with agricultural lands. Solutions for the energy problems should be found in this segment rather than in the bio energy crops. (Nowak, 2008)
To make the potential of algae as a source of biofuels clear, a table with oil production yields per hectare is added. Compared with the highest possible yield of terrestrial plants, algae easily beat this yield, even with very low expected growth. With algae as the best alternative concerning yields per hectare, the question comes into mind how algae compare to solar energy from for example PV-cells or concentrated solar production (CSP)? Photosynthesis only uses a small amount of the solar energy coming in especially when we compare this with PV-cells (15% conversion into electricity) or CSP. However, comparisons are difficult to staff since algae produce oil and PV-cells and CSP produce electricity and heat. The comparison should be made on the number of MJ one hectare can produce. A comparison is made below.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Oil production (litre/Ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>168</td>
</tr>
<tr>
<td>Cotton</td>
<td>327</td>
</tr>
<tr>
<td>Soy beans</td>
<td>449</td>
</tr>
<tr>
<td>Mustard seeds</td>
<td>571</td>
</tr>
<tr>
<td>Sunflower seeds</td>
<td>954</td>
</tr>
<tr>
<td>Rapeseeds</td>
<td>1.188</td>
</tr>
<tr>
<td>Jatropha</td>
<td>1.889</td>
</tr>
<tr>
<td>Palm oil</td>
<td>5.939</td>
</tr>
<tr>
<td>Algae oil (10g/ m² /day 15%TAG)</td>
<td>11.223</td>
</tr>
<tr>
<td>Algae oil (50g/ m² /day 50%TAG)</td>
<td>93.526</td>
</tr>
</tbody>
</table>

Table 2 Oil production in litre per Ha of different energy crops. (Bron: NREL, 2008)

<table>
<thead>
<tr>
<th>Units</th>
<th>Factor Low</th>
<th>Factor Middle</th>
<th>Factor High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algae Low</td>
<td>368.114</td>
<td>0,08</td>
<td>0,05</td>
</tr>
<tr>
<td>Algae Middle</td>
<td>1.717.900</td>
<td>0,35</td>
<td>0,24</td>
</tr>
<tr>
<td>Algae High</td>
<td>3.067.653</td>
<td>0,63</td>
<td>0,44</td>
</tr>
<tr>
<td>Solar Panels Low</td>
<td>4.860.000</td>
<td>13,20</td>
<td>2,83</td>
</tr>
<tr>
<td>Solar Panels Middle</td>
<td>7.020.000</td>
<td>19,07</td>
<td>4,09</td>
</tr>
<tr>
<td>Solar Panels High</td>
<td>9.180.000</td>
<td>24,94</td>
<td>5,34</td>
</tr>
</tbody>
</table>

Table 3 Comparison of energy production per Ha of algae and solar panels

What can be concluded out of the comparison is that even with the highest possible yield of algae production, one hectare of regular solar panels produces in the low case of 900 kWh per m² insolation and a conversion of 15%, 1.5 times more energy. This means algae need more land than solar panels in order to foresee in our energy needs.
5.3 Efficiency and costs of bio fuels

A major item is the current efficiency and energetic balance of bio fuels vs. fossil fuels. Should we produce bio fuels when the energetic balance is negative? Can we defend the fact we use food crops for fuels while the energetic balance is negative? The conclusion should be no. But the calculation of the energetic balance and all the variables such as fertilizer use, water depletion, changes in land use etc should all be taken into account when calculating the energetic balance. This is not easy. There have been several studies on the energetic balance of bio fuels in particular bio ethanol (Pimentel 2003, Shapouri et al 2002). The results are mixed and follow different methods which make comparisons difficult. Therefore there is no consensus on whether the energy balance of bio fuels is positive or negative (Charles et al, 2007). The disagreement concentrates on the energy spent to fertilize soil with nitrogen (Patzek et al, 2004). To make a comparison on energy efficiency possible Patzek pleads for a panel to compare bio fuels like the IPCC does for climate change. Consensus needs to be achieved on social, environmental and relations to other energy sources in order to be able to tell which fuels are truly sustainable and which are not. This can help to decide in which technology to invest and whether food needs to be used to produce fuel. This controversy is very important to solve in order to make appropriate decisions on the use of bio fuels.

5.4 Patent rights on Bio Fuels

Patent right issues on bio fuels are expected to become more and more prevalent in the future. Patent rights are starting to form an increasing problem for the development of bio fuels and new techniques (King & Stabinsky, 1999). The biggest threat can be expected from genetically modified plants and production techniques. There is and has been a long going debate whether life forms such as plants, animals and humans can be patented or not. Since a ruling of the US Supreme Court in 1980 (Rathenau Institute, 2007) it seems the tide has turned and patents on life forms have increased steadily after this ruling. The patents on life forms and in the case of bio fuels mainly plant seeds and micro biological strains has led to a situation where a few large companies own the patents of the most important food crops and are gaining patents over energy crops and micro biological strains as well. This leads to unfair competition, slow down in scientific developments due to patent issues and eventually higher prices for seeds, algae and eventually bio fuels. There is still strong opposition towards life patents. Life patents are seen as ethically unacceptable especially when it concerns goods for the public interest such as food. Bio fuels can be seen as public interest as well if we broaden
this category. (Rathenau Institute, 2007) It is very difficult to find an appropriate balance between patent rights and public and scientific interest. Discussions on how to solve these issues are led by the Bio Bricks Foundation (Bio Bricks Foundation, 2008) two options are open. The first option is a change in the interpretation of patent law which is difficult in a competitive environment. The second and more viable option is the creation of an open source system like is happening with ICT-systems. In this case new inventions are open to the public and can be developed further in the public interest. An example of such a project is the Biological Innovation for Open Society. (BIOS, 2008)

More and more patents are being issued and granted on plants but also on production techniques. The bio fuels patents have increased from 147 in 2002 to 1045 in 2007. (Cleantech, 2008) this is a very strong increase and is reason for concern.

![Graph](image)

**Figure 8** Development of patents on bio fuels 2002-2007
5.5 Overpopulation and energy use

When we are discussing bio fuels and energy use we cannot simply deny the human population. Humans are responsible for the massive amount of energy used on our planet. In the last hundred years the world population has increased in a rapid pace (nearly a factor four).

This increase was possible due to the industrial revolution, better hygiene, better food security, better medical care and increase in wealth. With this increased wealth and world population and relatively low energy prices, more and more people were able to buy consumer goods like fridges, washing machines and cars. This led to a significant increase in energy use (figure 10). As can be seen the energy use in the year 2000 has been somewhat twenty times higher as at the start of the 20th century, especially after the Second World War energy use exploded. This explosion of energy use continued until the oil crises of the seventies, when the dependency on oil became apparent for the first time. This can be seen in the graph where the line becomes flatter, this led to several new technologies like solar and wind power and an interest in different forms of fuel like algae oil and hydrogen, but with the conflict resolved the oil prices dropped and interest in renewable energy sources declined and became commercially unattractive again until now.
5.6 Power over energy sources

With an increased use in energy the role of energy producing countries becomes increasingly more important. Due to the abundance of energy like oil, gas and coal this has, except in the 1970’s, caused no major problems. Now energy markets are becoming tighter and oil production is about to go into decline, the industrialized countries become more and more dependent on oil from countries in the Middle East, Russia and former Russian states. This problem will become more apparent in the coming years. Due to this dependency, oil producing countries are gaining power over industrialized countries, causing tensions. With sky high oil prices money is flowing to the oil rich countries causing changes in political power and purchasing power. On the other side, the oil producing countries have always been dependent on knowledge, skills and techniques from western countries in order to keep their production up to date and efficient. The trend however is shifting, since more and more people from Middle Eastern countries get high quality education abroad and are bringing this knowledge to their own countries. Still there are interdependencies to be found, oil producing countries want to sell their oil in order to earn large amounts of money and they still depend on knowledge from foreign countries. In this tense playing field a stable road needs to be found in order to secure energy efficiency for the time being. In order to become less dependent large oil consuming countries are trying to become less dependent on oil from instable regions. Bio fuels play a role in this struggle for power over energy.
6. **Comparison of bio fuels and relations**

In this chapter a comparison between bio ethanol, bio diesel, bio hydrogen, solar panels, diesel and petrol will be made. The bio fuels are subdivided on basis of the different generation bio fuels except from the bio hydrogen. This first table gives an overview of the influence of the bio fuels on different factors. Later the relations between the different factors and actors will be shown in a relation diagram. The information used for the comparison comes mainly from the previous chapters.

In the table four different colours are being used to make the influence of the bio fuel on each aspect clear. Green represents a low influence or impact, orange a medium impact and red a high impact. In this way it is easy to see where the problems of the different fuels can be found. Literature research has been done to staff the impacts, although it was hard to find, obtain and compare the information at times. More research still needs to be done to improve the table, especially on the field of social, ethical, technological and political aspects with regard to bio fuels. On the environmental side much research has been done as well as on the side of bio fuel prices. The relations and the effects of the different parts of the model need to be tested in order to gain a better insight.

Here a first step will be made in the creation of a method to measure the impact of bio fuels. The items selected for the comparison come from the literature studied. The items have been selected and categorized. The following fuels and aspects will be covered in the comparison:

- Bio diesel, bio ethanol, bio hydrogen, solar panels and petrol and diesel.
- Energy per litre/ m² and price per Mega joule (MJ)
- Social & ethical aspects like effects on poor communities and food vs. fuel.
- Environmental aspects like use of water, fertilizer, CO₂ emissions for growth, production, harvesting, refining and burning the fuel and land used for growth.
- Political aspects like energy security, subsidies and legislation.
- Technological aspects like patent rights and energetic balance.
<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Energy &amp; Prices</th>
<th>Social &amp; Ethical</th>
<th>Environmental</th>
<th>Political</th>
<th>Technological</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MJ per m²</td>
<td>$ct per MJ</td>
<td>Food vs.</td>
<td>Water use</td>
<td>Land Use</td>
<td></td>
</tr>
<tr>
<td>Low (influence) or positive</td>
<td>Medium (influence) or not positive or negative, High (influence) or negative</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bio ethanol 1st (Corn)</td>
<td>3.96</td>
<td>0.0369</td>
<td></td>
<td></td>
<td></td>
<td>37</td>
</tr>
<tr>
<td>Bio ethanol 2e (grass etc.)</td>
<td>13.57</td>
<td>0.0369</td>
<td></td>
<td></td>
<td></td>
<td>11</td>
</tr>
<tr>
<td>Bio ethanol 3e (algae)</td>
<td>123.60</td>
<td>n/a</td>
<td></td>
<td></td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>Bio diesel 1ste (Palm oil etc.)</td>
<td>20.90</td>
<td>0.0284</td>
<td></td>
<td></td>
<td></td>
<td>57</td>
</tr>
<tr>
<td>Bio diesel 2e (Energy crops)</td>
<td>4.18</td>
<td>0.0284</td>
<td></td>
<td></td>
<td></td>
<td>47</td>
</tr>
<tr>
<td>Bio diesel 3e (Algae)</td>
<td>184.36</td>
<td>n/a</td>
<td></td>
<td></td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>Bio hydrogen (Algae)</td>
<td>n/a</td>
<td>0.3803*</td>
<td></td>
<td></td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>Solar Energy (Electric) 1 M2 of panels (MJ)</td>
<td>702</td>
<td>0.0592</td>
<td></td>
<td></td>
<td></td>
<td>9,9*</td>
</tr>
<tr>
<td>Diesel (fossil)</td>
<td>n/a*</td>
<td>0.0184</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>81</td>
</tr>
<tr>
<td>Petrol (Fossil)</td>
<td>n/a</td>
<td>0.0190</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>78</td>
</tr>
</tbody>
</table>

Table 4 Overview (bio) fuels and the influence of the various factors on development and acceptance of the (bio) fuel

Low (influence) or positive, Medium (influence) or not positive or negative, High (influence) or negative

Bio Fuels
6.1 **Explanation of the choices made in the comparison**

Here I will clarify on what basis choices in the comparison have been made. I have added various sources and calculations to staff the results in the table. I will discuss the different columns of the table in a logical order, starting with MJ per litre/m² and ending with the energetic balance.

**MJ per litre/ m²**

To determine the MJ per litre fuel the high heating values (HHV) have been used. HHV are most commonly used when determining MJ in the USA. In Europe the lower heating values are most commonly used. The difference in MJ between high and low heating values can be in the order of 8%. Data of the State University of Iowa have been used for the heating values of bio ethanol, bio diesel, diesel, petrol and hydrogen.

For solar energy the MJ are measured per square metre, the assumption has been made that the average insolation on one square metre is 1300 kWh and the conversion of solar panels is 15%. The kWh are conversed to MJ by multiplying by 3.6. (See appendix)

<table>
<thead>
<tr>
<th>Crops</th>
<th>Production litre/Ha</th>
<th>MJ per litre</th>
<th>MJ per m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol corn</td>
<td>168</td>
<td>23.6</td>
<td>3.96</td>
</tr>
<tr>
<td>Ethanol Grasses</td>
<td>5.750</td>
<td>23.6</td>
<td>13.57</td>
</tr>
<tr>
<td>Ethanol Algae</td>
<td>52.734</td>
<td>23.6</td>
<td>123.60</td>
</tr>
<tr>
<td>Diesel Palm Oil</td>
<td>5.939</td>
<td>35.2</td>
<td>20.90</td>
</tr>
<tr>
<td>Diesel Rapeseed (energy crop)</td>
<td>1.188</td>
<td>35.2</td>
<td>4.18</td>
</tr>
<tr>
<td>Diesel Algae</td>
<td>52.374</td>
<td>35.2</td>
<td>184.36</td>
</tr>
<tr>
<td>Bio hydrogen Algae*</td>
<td>n/a</td>
<td>9.3</td>
<td>n/a</td>
</tr>
<tr>
<td>Solar Panels</td>
<td>n/a</td>
<td>n/a</td>
<td>702</td>
</tr>
<tr>
<td>Diesel (Fossil)**</td>
<td>n/a</td>
<td>38.7</td>
<td>n/a</td>
</tr>
<tr>
<td>Petrol (Fossil)**</td>
<td>n/a</td>
<td>34.8</td>
<td>n/a</td>
</tr>
</tbody>
</table>

Table 5 Production litre/Ha, MJ per Litre and MJ per m².

* Cannot be determined since in laboratory phases.

** Cannot be compared since production per Ha is not available.

MJ per m² are determined by dividing the production in litres per Ha by 10,000 and then multiplying this by the energy content per litre, this gives the MJ per m².

Bio Fuels
U.S. Dollar ($) per MJ
To determine the price of one MJ in U.S. dollars ($) the average price of one gallon in the USA has been used. Data are from the department of energy (DOE) from October 2008, in the mean time prices have dropped, but before they have been much higher. U.S. Dollar ($) per MJ has been calculated by conversing the $ price per gallon to $ per litre and dividing this by the amount of MJ per litre. It needs to be noted that bio ethanol for example is being heavily subsidised (around 47 $ct per gallon) by the US government. Bio hydrogen is calculated on the basis of the hydrogen price because there was no alternative, it is expected the price of bio hydrogen is even higher. For algae no data has been found. The price of one MJ solar energy is determined by dividing the price of one kWh solar electricity by 3,6 MJ. Calculations can be found in the appendix.

Food vs. Fuel
The fuels which use food crops for fuel have been marked as red because they directly compete with our food source which is not acceptable. (paragraph 5.1) The crops using arable land to grow energy crops have been marked orange; this means that these could be grown when arable land is otherwise not used for food production. The other fuels are marked green in terms of food vs. fuel because they use no arable land or compete with arable land. Algae can be grown on barren land; solar panels can be placed on roofs or in deserts and oil is in general not being produced on places where agriculture occurs.

Poverty
Poverty is directly related to the use of food for fuel. When food is being used for fuel, prices of food rise resulting in high food prices for the poorest, who will feel the pinch first because food makes up the largest part of their very small income.

Water Use
When crops are grown for fuel use they use water, especially the food and energy crops use large amounts of water. This results in problems with water resources when these are scarce. Therefore the food and energy crops have been marked red. Grasses and algae use water as well but grasses use less water and algae can be grown in salt or brackish water as well and the water in the ponds can be recycled putting less strain on valuable water resources. Solar panels and fossil fuels have lowest water use and are therefore marked as green.
Land Use
The growing of palm oil and corn uses a lot of land which is either being used for food production or in the case of palm oil used to be tropical rainforests. (Paragraph 5.2) Growing these crops puts extreme strains on the use of the land and the minerals in the soil. Grasses can be grown on roofs and use therefore use less valuable land. Algae, solar panels and fossil fuels don’t use land in the way crops do and can use otherwise useless land e.g. deserts or rocky plateaus.

Fertilizers
To let the crops grow faster fertilizers are being used. Extensive use of fertilizers damages the soil and the water resources in the region because fertilizers are flushed out by rain. Fertilizers are mostly used for growing corn, palm oil and energy crops. Grasses and algae don’t need fertilizers or just little amounts. Solar panels and fossil fuels don’t use fertilizer at all.

Emissions gCO₂ per MJ
Emissions per MJ from the bio fuels are derived from the renewable energy directive for the European Union from 2008. With the emissions from bio fuels fertilizers, land use, processing and transport are included. For petrol and diesel emissions per MJ are calculated on the basis of data from the travelfootprint site which are based on emission number from universities and governmental organisations. These direct and indirect emissions are divided by the MJ per litre resulting in the emissions per MJ. The calculations of emissions per MJ solar electricity can be found in the appendix. Different solar panels (Thin film and mono crystal) and different insolation numbers (900 kWh to 1700 kWh per m²) are used and the average is calculated. Assumed is a conversion of 15% of sun into electricity from the solar panels. Avoided emissions are not included but if we assume a 50/50 production of electricity by gas and coal approximately 180 grams CO₂ can be subtracted from the numbers in the table. The average gCO₂ per MJ is 9,9 see table 3.

<table>
<thead>
<tr>
<th>Solar Panel Type</th>
<th>Low Insolation 900 kWh/Year/m²</th>
<th>High Insolation 1700 kWh/Year/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thin Film Technology (EU)</td>
<td>5.4 gCO₂ per MJ</td>
<td>2.72 gCO₂ per MJ</td>
</tr>
<tr>
<td>Mono Crystal (USA)</td>
<td>21.5 gCO₂ per MJ</td>
<td>11.4 gCO₂ per MJ</td>
</tr>
</tbody>
</table>

Table 6 CO₂ per MJ of different solar panels with different insolation. Ex avoided CO₂ by electricity production.
Energy Security

Energy security is mainly a concern with the fossil fuels. Fossil fuels are produced out of oil and the largest parts of the world's oil reserves are concentrated in the Middle East and Russia resulting in political tensions. (Paragraph 5.6) Energy security could become an issue with biofuels as well, since the crops cannot be grown everywhere and produce high yields. Also solar energy is most viable in countries with many hours of sunshine to be able to produce electricity at the lowest possible cost. This would mean the Middle East has a strong energy position here again.

Legislation

Legislation is nowadays turning slowly against fossil fuels and in favour of biofuels. However the biofuels from food crops are being subsidized mostly where subsidies should be concentrated on the newer techniques with most potential. In this case ethanol from grass and biofuel from algae should receive more governmental support.

Subsidies

Subsidies are available for all biofuels but the allocation should be more towards the best alternatives concerning the full picture scheduled in the table. There are no subsidies available for fossil fuels but in more and more countries penalties in the form of taxes on petrol and diesel are coming into place.

Patent Rights

Patent rights are becoming more and more a threat to the biofuel industry in particular with the newest technologies. (Paragraph 5.4) This is a concern for all new energy techniques since large companies and individuals all are trying to earn money with new energy technology. Governments should be very aware of these developments and react on them actively.

Energetic Balance

The energetic balance of the fuels tells us how much energy we have to put into producing the fuel and how much we gain when burning the fuel. This balance tells us whether it is of use producing the fuel from a certain source. The food and energy crops don't have positive balances and should therefore not be used for fuel, besides the other drawbacks concerned with these fuels. Ethanol from grass and algae, bio diesel and bio hydrogen are energetically seen much better alternatives. This has for a large part to do with the use of land and fertilizers which plays no major role here. In the case of the production of algae diesel the
building and operation of the bioreactors should be taken into account, the influences of this on the positive energetic balance are still part of an ongoing discussion. Solar panels are also positive with regard of the amount of energy used for production and the electricity produced over a thirty year lifespan.

**Total Influence**

When all aspects are taken into account we can make up the total balance. In the comparison bio fuels from food crops have the worst score (red); this is because the social and environmental aspects as well as the energetic balance are negative aspects. Energy crops and fossil fuels follow with an orange score. Bio diesel by energy crops is better than food crops mainly because of fewer effects on food supply and because energy crops can be grown on agricultural land which otherwise would not have been used. Fossil fuels score orange because of the emissions and energy security aspects, on the other aspects fossil fuel have a positive score. Best alternatives which come out of the comparison are ethanol from grass and algae, bio diesel from algae, bio hydrogen from algae and solar power. Most important drawback with these alternatives is in general the price; on the other aspects these alternatives have good scores. The price aspect could disappear when the negative impact on the environment or social side of other alternatives will become visible in the price of for example fossil fuels or bio diesels from food crops.
6.2 Relations of different actors in the bio fuel landscape

The WWF in Germany (2006) has made a report concerning sustainable bio energy in this report bio energy in relation to social and environmental aspects are mentioned. These problems could be covered when bio fuels are being certified on environmental and social basis. This is a good initiative but unfortunately not enough attention is paid to the other relevant aspects in respect to bio fuels, like economics and politics which are very important and intertwined in order to get bio fuels certified and accepted. A schedule with all relevant stakeholders and issues in the bio fuel production and policy needs to be taken into account in order to get an insight into the political process behind the bio fuel discussion and decisions. In the figure below I will try to make a model with all relevant stakeholders and policies in order to make the relations and influence of the stakeholders clear. I have not been able to find such a model with who is influencing who. In this respect I consider this to be important for a solution to the bio fuel dilemma and an addition to the comparison made in table 4. Table 4 can be used in the political process of decision making. In this process all parties will defend their own stakes in order to get a positive result for their supporters. This makes an insight into the process behind the bio fuel debate relevant.

![Diagram of bio fuel landscape and influence of parties on decision making.](image)

Figure 11 Bio fuel landscape and influence of parties on decision making.
The figure shows all parties and how big their influence is on bio fuel decisions and which stakes they have. The different parties have different colours and different sizes. The different parties are in the corner where they have most interests. The figure should be seen as a dynamic whole where parties can grow in importance and shift into a different direction.

The most important actors in the bio fuel discussion are on the one hand the governments and on the other hand the media. Because the government has to balance all the aspects with regard to bio fuels and make decisions in the interest of all people they play a major role in the discussion. Another aspect why the government has such a big stake is because of the legislative power they can execute.

The media is more or less a counterpart of the government. In a true democracy the media criticizes decisions made by the government and balance the information on all different aspects of bio fuels for their viewers. In this way they are able to play a mediating role between civilians and the government and control more or less the way the government acts.

Corporations in this model have a medium influence on decisions with regard to bio fuels. Their main focus is in general on technological development based on market principles of supply, demand and prices. They can make a significant contribution to the use of bio fuels but are often dependent on regulations from governments. Therefore corporations have less influence although corporations have a lot of knowledge and capital to invest.

Non governmental organisations (NGO’s) don’t have a large influence but can get in the way when they are able to mobilise the media and consumers. If they team up they can become a party with influence on policy. But if they are just on their own it is not very likely they have a large role in the bio fuel discussion when it comes to decision making. NGO’s are mainly concerned about environmental or social aspects of bio fuels; they are mainly based on one major item or issue.

Consumers have one general interest in the end when it comes to bio fuels: “How much does it cost me?” If bio fuels are more expensive consumers are very unlikely to favour them over regular petrol. Consumers don’t mind driving on bio fuels but don’t want to pay more. In this case they are just followers. Governments play a role in this part by adding taxes or
subsidising favourable fuels. In this way they can stimulate demand and lower prices. After a while the market can support itself.

Universities have as main focus knowledge and technology. In the bio fuel discussion they are a party where research is being done on the effects of bio fuels and which bio fuels are best to use. Corporations make use of universities for their own research purposes and support universities on the financial side. Universities used to have the role of independent knowledge centres but are more and more working in cooperation with governments, corporations and NGO’s to share and gain knowledge. Due to these developments influence of the universities on political decisions is growing in importance. However universities still have a role to fulfil as independent institutions of knowledge.
7. Discussion and recommendations

Below I will discuss the issues regarding bio fuels followed by a set of recommendations.

7.1 Discussion

Bio fuels are widely debated these days with oil prices reaching levels previously expected as impossible. These high oil prices have led to a rapid development of bio fuels. As with all fast developments, bio fuels encounter several problems with regard to the economics, environment, technology and social and ethical aspects which need to be solved in order to become successful on the long run. We need to make a distinction between the different generations of bio fuels in this respect. The first and most developed bio fuels up until now are mainly made out of eatable and energy crops. At first this seemed to be no problem because of overproduction in the agricultural sector, it was a natural way of using the left over stocks. But with rising oil prices and decreasing amounts of stocks and no overproduction, food started to compete with fuel. This has resulted in heated debates between governments and various NGO’s regarding the ethics of using food for fuel, while people are dying in third world countries. Also the perceived CO$_2$ benefits of first generation bio fuels are under fire because of changes in land use, water pesticide and fertilizer use etc. This debate is still going on but it seems economics and energy security are more important than the environmental and ethical aspects up until now.

In the shadow of the debate developments have been going on however, and new generations of bio fuels have been developed or are still under intensive research and development. These are bio fuels made from energy crops, sewage, faeces, agricultural rest products, grassland and algae. How the balances in respect to CO$_2$ reductions are is still object of research and discussion. It is very hard the get a consensus since there are so many variables playing a role in the CO$_2$ balance. Main problems regarding bio fuels from energy crops and waste products are land use and availability of suitable land. With regard to algae there are no problems with land use but here we have problems with continuous production and the price of the products which need to be solved in order to get ready for large scale use. Another concern with algae is the CO$_2$ associated with the building of the algae farms and bioreactors, no extensive calculations which take this into account have been found so far. What stands out however is the fact that newer generations of bio fuels do have better sustainable potential than the first generation when we take all the variables into account. The latest development in the field of
bio fuels is the production of bio hydrogen. This potential future bio fuel is still in testing stages in laboratories and it will take a very long time before production can be started on large scale and become commercially attractive. Whether this is going to be successful on the long term can still be questioned, but it is a road that needs to be explored.

The comparison made in table 4 on all different aspects gives us an insight into the field of bio fuels and where progress needs to be made. Most important aspects we need to make progress on are on the economics in order to make the bio fuels which do not harm the environment more competitive in relation to fossil fuels. Another important aspect we should take into account in order to solve our energy problems are the political aspects. Politics can have a significant influence on major energy decisions, these decisions should be made preferably on world scale. Research on the environmental impact of bio fuels is the field of scientist and consensus should be reached over how to calculate emissions of bio fuels, this would help to make political decisions.

The conclusions of the comparison are; food crops should not be used for fuel, ethanol from waste products has good potential, algae should be further investigated and developed in order to make large scale production possible and last but not least, solar energy should be a part of the energy solution. Eventually a mix of bio ethanol from waste products, bio diesel from algae and electricity from solar panels can secure a large part of our energy needs by renewable energy sources.

In order to become less dependent on foreign oil, bio fuels are however only a part of the solution of the problem and can not be expected to be the ultimate solution. Production of more and different fuels is solving the problem from the supply side. The demand side should be taken into account as well. The demand problem should be acknowledged in order to make real changes in the energy problems possible. Our booming population and even more extraordinary rise in energy consumption should be halted and decimated in order to solve our energy problems. Therefore world population growth should be stabilized, consumption patterns should be changed and when we consume, the appliances available should be as energy efficient as possible. Even in this case it can be questioned whether the energy problem will be solved on the short term. In the end a solution will be a mix of different (renewable) energy and (bio) fuel types, population control, high energy effectiveness and last but not least global policy on energy and climate issues.
7.2 Recommendations

As mentioned in the paragraph above it is going to be important to formulate a global energy and climate policy, control population growth and change consuming patterns. In this way we can make a swift transition from a fossil fuel economy to a more sustainable economy and way of life. This is not going to be easy and without geopolitical tensions because world leaders will need to set aside their personal disputes and priorities in order to achieve a consensus on energy policy and create a higher goal for all. Besides world politicians other stakeholders like NGO’s, corporations, universities and consumers should be heard. Research needs to continue to aim on sustainable energy solutions which do not harm the environment. In particular energy from waste products, algae and the sun should be further developed. Eventually the sun will be the major sustainable energy source to aim for, since this is the earth’s only energy source if we go back to the roots of energy. Besides the supply side we should take firm action on the demand side as well, since a lot of energy is still being spilled.

We will need to set aside our disputes in order to make energy solutions possible and keep our world liveable and prevent a collapse of our energy dependent societies on the long run. To solve this extremely challenging social dilemma a world wide accepted institution which takes all different aspects and perspectives on energy into account regarding economics, environment, politics, energy consumption and world population needs to be created, a so called world government.
Appendix

Calculations of MJ, $ per MJ and gCO₂ per MJ

**MJ per square metre solar panels**

Insolation 1300 kWh per m² (Average 1700 for southern Europe and 900 for the Netherlands) and a solar panel efficiency rate of 15%. Results in 1300 * 0.15 = 195 kWh per m² solar panels on average 195 * 3.6 MJ = 702 MJ per m² solar panels.

**$ per MJ**

Diesel $3.27 per gallon / 4.6 = $0.71 per litre / 38.6 MJ = 0.0184

Solar electricity 21.32 $ct per kWh

0.2132 $ per kWh / 3.6 MJ = 0.0592 $ct

1 kWh = 3.6 MJ

**Emissions per MJ**

*Diesel* 2.63 kg per litre direct + 0.51 kg per litre indirect = 3.14 * 1000 / 38.6 MJ = 81.3 gCO₂ per MJ

*Petrol* 2.32 kg per litre direct + 0.41 kg per litre indirect = 2.73 * 1000 / 34.8 MJ = 78.4 gCO₂ per MJ

**Solar energy**

Solar cells emissions per kWh on average over thin film technology and mono crystal produced in the USA with low insolation and high insolation. Conversion rate of 15% used for the solar panels. Electricity by gas 450 gCO₂ per kWh / 3.6 MJ = 125 gCO₂ per MJ. Electricity by coal 850 gCO₂ per kWh / 3.6 MJ = 236 gCO₂ per MJ. This means 180 gCO₂ per MJ when assumed 50/50 production of electricity by gas and coal.

**Production Thin Film Technology (EU) 75 kgCO₂ per m²**

*Low insolation* 900 * 0.15 = 135 kWh per m² per year * 3.6 = 486 MJ per m² per year * 30 years = 14580 MJ a lifetime per m²

(75 kgCO₂ / 14580 MJ per m² = 5.4 gCO₂ per MJ) - 180 gCO₂ per MJ for avoided electricity produced by gas or coal = -174.6 gCO₂ per MJ a lifetime per m²
Medium insolation $1300 \times 0.15 = 195 \text{ kWh per m}^2 \text{ per year} * 3.6 = 702 \text{ MJ per m}^2 \text{ per year} * 30 \text{ years} = 21060 \text{ MJ a lifetime per m}^2$

$\frac{75 \text{ kgCO}_2}{21060 \text{ MJ per m}^2} = 3.56 \text{ gCO}_2 \text{ per MJ}$ - $180 \text{ gCO}_2 \text{ per MJ for avoided electricity produced by gas or coal} = -176.4 \text{ gCO}_2 \text{ per MJ a lifetime per m}^2$

High insolation $1700 \times 0.15 = 255 \text{ kWh per m}^2 \text{ per year} * 3.6 = 918 \text{ MJ per m}^2 \text{ per year} * 30 \text{ years} = 27540 \text{ MJ a lifetime per m}^2$

$\frac{75 \text{ kgCO}_2}{27540 \text{ MJ per m}^2} = 2.72 \text{ gCO}_2 \text{ per MJ}$ - $180 \text{ gCO}_2 \text{ per MJ for avoided electricity produced by gas or coal} = -177.3 \text{ gCO}_2 \text{ per MJ a lifetime per m}^2$

Production Mono Crystal (USA) $314 \text{ kgCO}_2 \text{ per m}^2$

Low insolation $900 \times 0.15 = 135 \text{ kWh per m}^2 \text{ per year} * 3.6 = 486 \text{ MJ per m}^2 \text{ per year} * 30 \text{ years} = 14580 \text{ MJ a lifetime per m}^2$

$\frac{314 \text{ kgCO}_2}{14580 \text{ MJ per m}^2} = 21.5 \text{ gCO}_2 \text{ per MJ}$ - $180 \text{ gCO}_2 \text{ per MJ for avoided electricity produced by gas or coal} = -158.5 \text{ gCO}_2 \text{ per MJ a lifetime per m}^2$

Medium insolation $1300 \times 0.15 = 195 \text{ kWh per m}^2 \text{ per year} * 3.6 = 702 \text{ MJ per m}^2 \text{ per year} * 30 \text{ years} = 21060 \text{ MJ a lifetime per m}^2$

$\frac{314 \text{ kgCO}_2}{21060 \text{ MJ per m}^2} = 14.9 \text{ gCO}_2 \text{ per MJ}$ - $180 \text{ gCO}_2 \text{ per MJ for avoided electricity produced by gas or coal} = -165.1 \text{ gCO}_2 \text{ per MJ a lifetime per m}^2$

High insolation $1700 \times 0.15 = 255 \text{ kWh per m}^2 \text{ per year} * 3.6 = 918 \text{ MJ per m}^2 \text{ per year} * 30 \text{ years} = 27540 \text{ MJ a lifetime per m}^2$

$\frac{314 \text{ kgCO}_2}{27540 \text{ MJ per m}^2} = 11.4 \text{ gCO}_2 \text{ per MJ}$ - $180 \text{ gCO}_2 \text{ per MJ for avoided electricity produced by gas or coal} = -168.6 \text{ gCO}_2 \text{ per MJ a lifetime per m}^2$

Average CO$_2$ emission per MJ per m$^2$ per Year

$2.72+3.56+5.4+21.5+14.9+11.4 \div 6 = 9.9 \text{ gCO}_2 \text{ per m}^2 \text{ per Year average over Thin Film and mono Crystal with different insolation.}$
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