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Feasibility Study of a Biodiesel Production Plant from Oilseed

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Declaration of Author's Right

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Abstract

The following study is about the feasibility of the installation of a biodiesel plant from oil seeds. As a feasibility study, this dissertation aims to define the requirements for a biodiesel plant and the strategic issues to be considered to assess its feasibility, or likelihood of succeeding. This analysis is useful either when starting a new business, or identifying new opportunities for an existing business. Therefore, it will be extremely helpful for taking rational decisions about the development of a biodiesel production plant.

Biodiesel is an alternative fuel for diesel engines that is gaining attention all over the world. Its primary advantages deal with it being one of the most renewable fuels currently available and it is also non-toxic and biodegradable. It can also be used directly in most diesel engines without requiring extensive engine modifications. Besides, the possibilities of growth of biodiesel business are clearly evident since the EU Directive 2003/30/CE to reduce petroleum dependency in the transport sector has set the use of biofuel in the sector transport at 5.75% for 2010 and 8% for 2020. Similar agreements are set in other countries all over the world.

The purpose of this dissertation is to describe and explain the issues involved in the implementation of a biodiesel production plant. The thesis focuses on the analysis of the technical aspects related to a biodiesel plant such as evaluation of the technology, evaluation of the supply chain, evaluation of the execution alternatives, and evaluation of operating plant issues. Furthermore, biodiesel quality and evaluation of the financial plan are also discussed. In addition, a case study of an actual plant already in operation is discussed. Various analyses, following the approach set out in this thesis, have been carried out and results are shown in the last section of this thesis.

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1. Introduction

This dissertation aims to develop a feasibility study of a biodiesel plant to produce biodiesel from oil seeds.

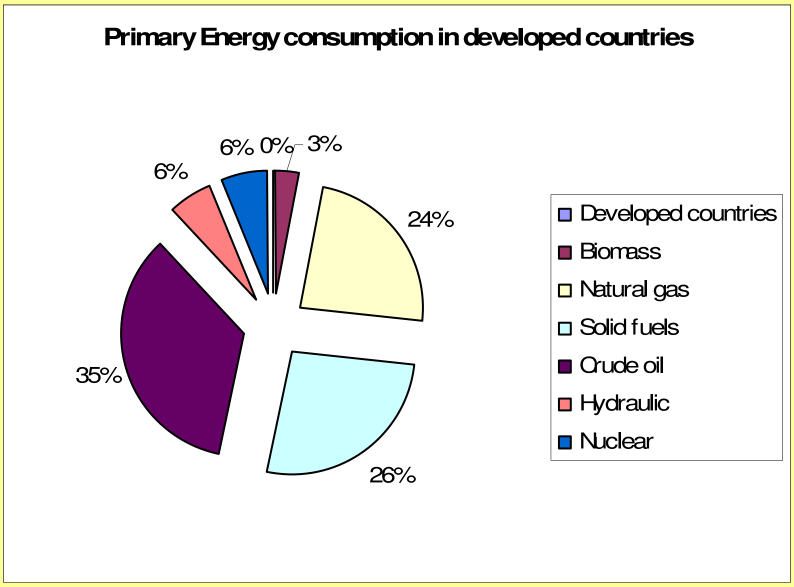
Within this dissertation different possibilities for the implantation of a production plant are discussed. It is not the aim of this dissertation to develop an exhaustive technical analysis of the components and performance of a biodiesel plant, but to develop a methodology to asses the feasibility of developing a new production plant. This methodology is intended to help investors to make a decision about whether or not to invest in a biodiesel plant.

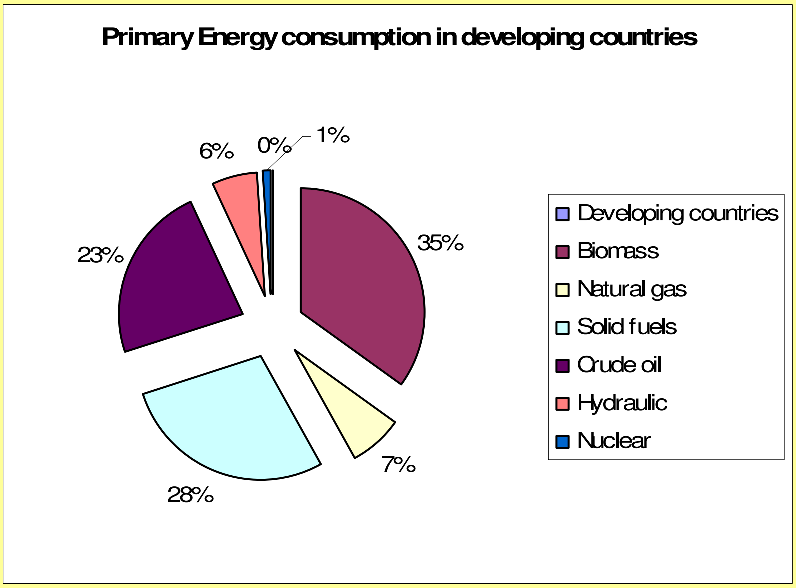
1.1. The context

1.1.1. Energy World

At present, the consumption of primary energy in developed and developing countries is highly dependent on fossil fuels. The figure 1 shows the current energy situation all over the world [9].

Developed countries	
Biomass	3
Natural gas	24
Solid fuels	26
Crude oil	35
Hydraulic	6
Nuclear	6





Developing countries	
Biomass	35
Natural gas	7
Solid fuels	28
Crude oil	23
Hydraulic	6
Nuclear	1

Figure 1- Primary energy consumption in developed and developing countries. Source: Based on data of ICAII-IT 2004 [9]

Moreover, most of the petroleum we use comes from the same sources. The economic dependence of non-producer countries is relevant. It seriously affects local government decisions, social economy and industrial development. Also, as petroleum is widely used on transport, which is a basic economy sector in any country, petroleum prices and supply reliability are really affected, even more in the developed countries.

The situation of world-wide supplying countries is shown in the following figure.

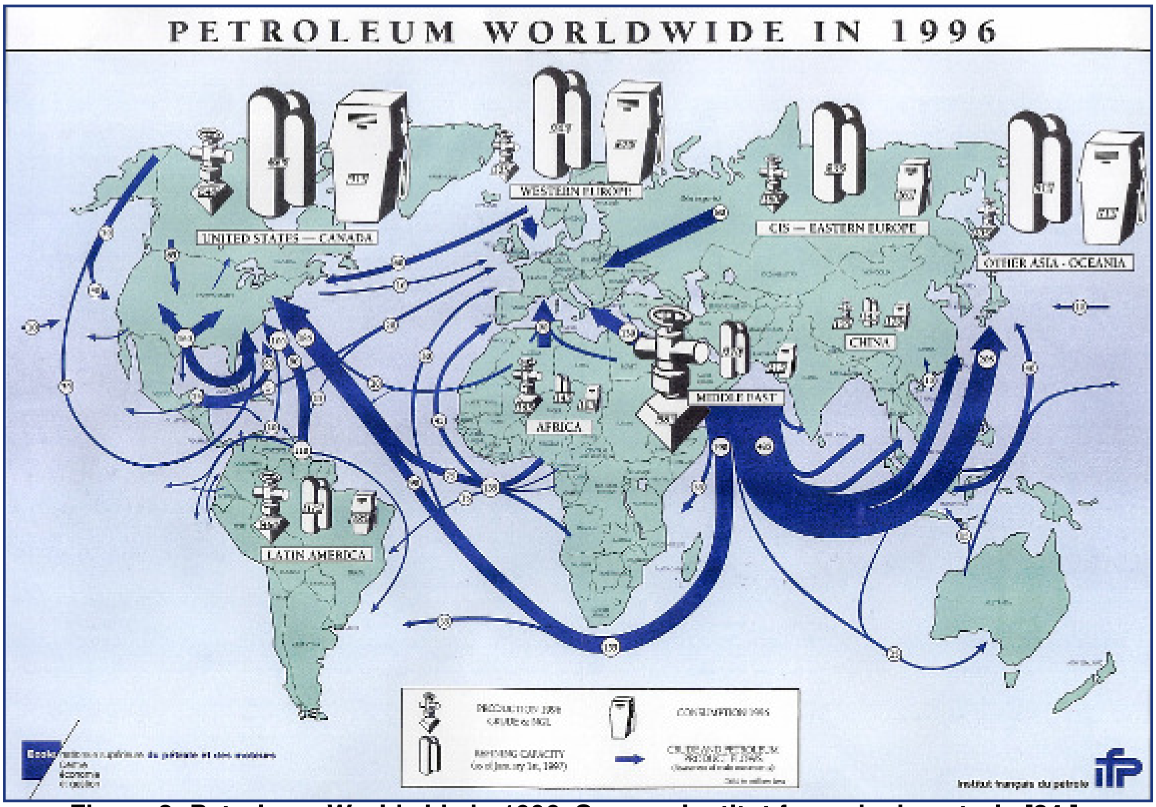


Figure 2- Petroleum Worldwide in 1996. Source: Institut francais du petrole [24]

In order to avoid the current petroleum dependency, it is necessary to develop some other fuel sources. Concerning this idea, biofuels would help.

1.1.2. Biofuels

The biofuels are fuels obtained from biomass. There are different types of biofuels, the most well known ones are bioethanol and biodiesel: bioethanol is produced from seed with a high contain in sugar after having suffered a fermentation process;

meanwhile biodiesel is produced from oil coming from vegetal oil, animal fat o waste grease on an esterifatification process.

In this section, a general approach to biofuel is presented. Different types of biofuel, advantages, applications, history and actual biofuel situation are discussed.

A) DIFFERENT TYPES OF BIOFUELS

The different types of biofuels that already exist in the market are the following ones:

- Bioethanol: It is produced from sugar, starch and residual water dust by a fermentation process. It can be used as replacement or blend for gasoline, and even in high blend percentages in FFV (*Flexible Fuel Vehicles*) vehicles.

- Bio-ETBE: It is produced from a blend of bioethano (45% volume) and isobutileno. It can be used in gasoline engines without any modification on them.

- Biodiesel: It is produced by the vegetal oil and/or animal fat esteritification process. It is similar in some way to the diesel fuel, especially in density and cetane number. Furthermore, its flash point is higher than the diesel one, which means more security on its use.

- Biomethanol: It is produced from methanol, due to the high hydrogen percentage; it could become an interested option for fuel cell propelled cars.

- Biogas: It is mainly produced by anaerobic fermentation of wet biomass.

- Biosynthetic fuels: They are produced from biogas derived from biomass during the Fisher-Tropsch process. Any of these can be produced from single CO and H_2 molecules, so a wide range of fuels of high quality standards can be produced on this basis; however, it is an expensive production process.

- Bio-MTBE: It is similar to Bio-ETBE produced from biomethanol (36% volume) and isobutanol.

- Biodimetileter: It is similar to LPG (liquid petrol gas) in terms of physical characteristics; therefore it can be used as a replacement for GLP, as an addictive of gasoline blends or as a component for other diesel blends.

B) ADVANTAGES

In comparison to fossil fuels, biofuels present some environmental, energetic, and socioeconomic vantages, especially in the transport sector.

- From an environmental point of view, their use helps to reduce the pollutants and greenhouse gas emissions. In detail, biodiesel do not emit Sulphur dioxide what helps to reduce acid rain, and also help to reduce suspension particles concentration on air, heavy metals, carbon monoxide, polycyclic aromatic hydrocarbon and volatile organic components [21].

  Moreover, as biofuels are easily biodegradable, they do not affect soil contamination in a negative way. Besides, they help to eliminate some types of residues, eg wasted oil for biodiesel production.

- From the energetic point of view, biofuels are a renewable and clean energy source. Furthermore, their use help to reduce energy petroleum fuel dependency and they offer a safety global scenery in the global energy market.

- From the socioeconomic point of view, biofuels are a viable alternative for crop lands in decadence. This way, population will come back to rural areas keeping reasonable employment and wealth level, and helping new different agrarian factories to be developed.

C) APPLICATIONS

Focused in applications for internal combustion engines, biodiesel can be blended with traditional diesel or it can be even a replacement for it. Bioethanol can be blended with gasoline in different portions, but it must be considered that above 15% concentration soft modifications on engines must be done.

Generally speaking, biodiesel and bioethanol characteristics are similar to diesel and gasoline respectively.

D) HISTORY

Industrial use of biofuels started on 1880. First public demonstration of operation of a diesel engine was seen in the Exhibition of Paris in 1898, by using oil of a peanut-like fuel. His inventor, Rudolph Diesel, thought that the future of this engine (in contrast with those of steam at the time) will be connected to fuel use coming from biomass, this situation changed on the 1920's, when the industry relegated biofuel to a plane far below.

Later on time, specially due to the petroleum crises of 1973 and 1978, the power policies of the 1980's helped the search of alternative fuels to reduce the dependency on fossil fuels, specially in the US.

E) CURRENT SITUATION

The present perception is that biofuels will not be able to replace fossil fuels totally consumption, but to complement them in forms of different mixtures with the purpose of reducing the dependency with regards to petroleum. This could be done with out seriously engine modifications; unlike other alternatives that are excluding and need certain duplication of the engine system, eg the liquidize gases of petroleum. Furthermore, biofuels can use the same logistical net for distribution as fossil fuels.

On this basis, current fossil dependency is not the same for all products. In detail, the volume of diesel produced in the Spanish refineries is not enough for diesel engines for the present needs. That is why it is necessary to import this product. This is not happening with gasoline which is nowadays exported to other countries. In the figure below, more details of current diesel Spanish situation are shown. Note that most of the imported diesel comes from Italy (26%).

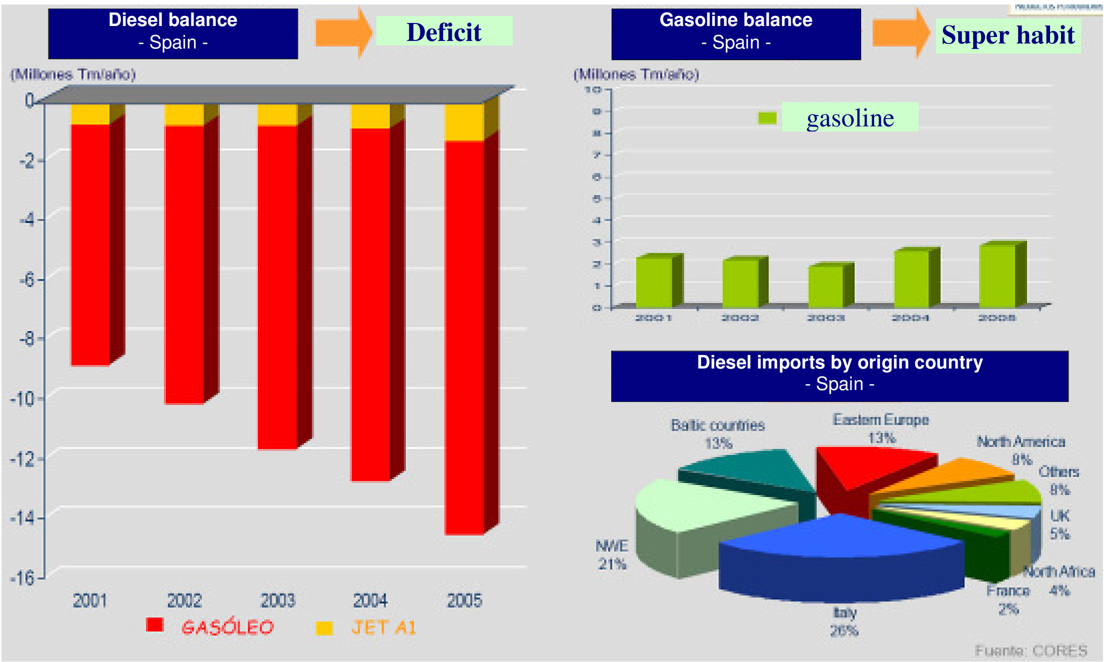


Figure 3- Actual diesel Spanish market situation. Source: CORES [10]

Besides, specially in Spain, the number of registered automobiles has grown quickly in the last years. Diesel engines are more appreciated by customers than gasoline, and this contributes to the increase in the demand of diesel. In the next table figures of gasoline and diesel registered cars are shown. Note that the total car numbers registered in 2006 was 1,500,000 cars.

2006	% gasoline	% diesel
January	29	71
February	30	70
March	31	69
April	31	69
May	31	69
June	30	70
July	29	71
August	29	71
September	29	71
October	30	70
November	30	70
December	31	69
TOTAL	**30**	**70**

Table 5- Gasoline and diesel registered cars. Source: Based on data in ref [2] ANAFC

This represents a problem, not only to reduce petroleum dependency, but also to supply the Spanish market with diesel cars.

1.2. The current status of biodiesel use

1.2.1. What is biodiesel?

A) DEFINITION

Biodiesel is defined as a fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats, called B100.

A mono-alkyl ester is the product of the reaction of a straight chain alcohol, such as methanol or ethanol, with a fat or oil (triglyceride) to form glycerol (glycerine) and the esters of long chain fatty acids.

Biodiesel can be used pure (B100) or as a blend (B %); this will be discussed in following chapters.

B) THE MAKING PROCESS

Although, it will be discussed with more detail, in the next chapters, the manufacture process of biodiesel will be briefly described in this section.

Broadly speaking, the production process starts by refining the oil, just in case the oil is not already refined. Thus, oil is refined, cleaned off impurities, and getting ready to carry out a transesterification process.

The transesterification process is produced by combining the oil with a light alcohol, normally methanol. The reaction leaves glycerine as a remainder product, so that, this can be used by the cosmetic industry, among others.

The oil to be processed can come from different sources, vegetal oil and animal fat, first use or recycled. Market prices and availability are the factors that would help investors to decide which use is the most appropriate. On one hand, in terms of oil coming from seeds, EU biodiesel mainly comes from rape seed, mean US biodiesel from soybean seeds. This is related to the oil yield by hectare on different countries. On the other hand, recycled oils can be a very cheap raw material but the manufacturing process is quite expensive.

C) LIFE CYCLE

The life cycle consider the environmental aspects and potential impacts associated with a product, considering the relevant energy and material inputs and environmental releases, and the environmental impacts associated with identified inputs and releases.

As it is shown in the figure below, the biodiesel life cycle begins with sun energy which is transformed into energy through vegetables to be later transformed and used as a transport fuel. It is assumed than CO_2 emitted on its combustion is reused by other vegetables in the photosynthesis process. So it is considered to be a CO_2 emitter.

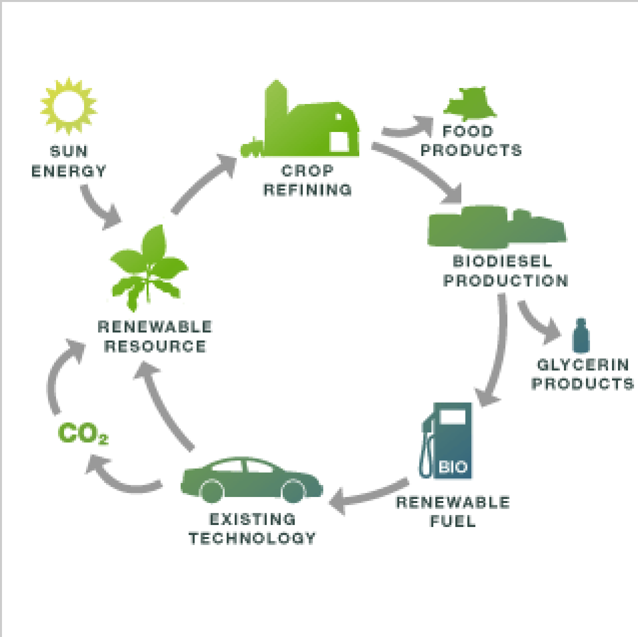


Figure 4- Biodiesel life cycle. Source: www.propelbiofuels.com

1.2.2. Biodiesel compared with other transport fuels

In this chapter, biodiesel will be compared with other transport fuels, especially with diesel, in terms of energy, properties and emissions.

A) ENERGY COMPARISON

There are different ways in which a comparison between conventional road fuels and bio-road fuels can be made. One valuable way is set on the basis of an energy balance, which is the difference between how much energy is created when producing the fuel, and how much is obtained when using the fuel. The approximation considers the energy used to make the plant grow, to produce biodiesel and to distribute it. According to figures of the US Dept of Energy (DOE), the quantity of energy yield by biodiesel is bigger than that used on its production. On the table below, an energy balance of biodiesel production from soybean seeds by transesterification process is shown.

Fuel	Energy IN	Energy OUT	%
Biodiesel	1	3.2	320%
Ethanol	1	1.34	134%
Petro-diesel	1	0.84	84%
Gasoline	1	0.81	81%

Table 6- Energy balance of a the biodiesel production from soybean seeds Source: Based on data of U.S. Dept of Energy (DOE) [12] and U.S. Dept of Agriculture (USDA), 1998 [46].

Although the table below shows an efficiency of 320%, different studies show different values depending on the type of raw material used, and the process carried out, thus it is widely accepted that this will be about 220% higher. The difference on figures comes by the fact that it is extremely difficult to clearly identify all steps involved.

C) PROPERTY COMPARISON

According to figures from the IEA (2002), EPA (2002b), the next table shows a property comparison of biodiesel and diesel at low-sulphur content,

The reason to compare those products is based on environmental and performance reasons. Note that nowadays, international efforts are being carried out to reduce emissions as well as air pollution. Therefore, then high diesel sulphur content are tried to be avoid and then extra technical obtaining process are applied on diesel production to reduce sulphur level, and thus to produce diesel at a low sulphur content.

Biodiesel / Diesel Property Comparison		
	Biodiesel	**Low-sulphur diesel**
Cetane number	51 to 62	44 to 49
Lubricity	+	very low
Biodegradability	+	-
Toxicity	+	-
Oxygen	up to 11%	very low
Aromatics	0	18-22%
Sulphur	0	0-350 ppm[a]
Cloud point	-	+
Flash point	300-400°F	125°F
Effect on natural, butyl rubber	can degrade	no impact

Table 7- Biodiesel and diesel properties comparison. Source: Biofuel for transport [21]

Following these figures, comparison can be done on most important properties:

- Cetane number.

  As it has been described in previous chapters, the cetane number measures how easily ignition occurs and the smoothness of combustion. To a point, a high number indicates good ignition, easy starting, starting at a low temperature, low ignition pressures, and smooth operation with lower knocking traits. In the EU a minimum of 49 cetane is normally required, so low-sulphur diesel is sometimes dismissed under this value.

  However, in order to clearly understand the previous table, it is important to note that there is a big difference between petrodiesel and biodiesel with regards to the ignition quality. That is to say, the cetane number must be used rather than the cetane index. To sort this out, the Calculated Cetane Index (CCI) is based on the historical database for the distillation curve of petroleum diesel and is not applicable to biodiesel, primarily due to the lack of a 'distillation curve' for biodiesel.

  So, whereas petrodiesel is comprised of hundreds of compounds boiling at differing temperatures (determined by the petroleum refining process), biodiesel contains only a few compounds- primarily 16 to 18 carbon chain length alkyl esters (determined by the feedstock), which all boil at approximately the same temperature. Biodiesel, therefore, exhibits more of a boiling point than a distillation curve. In addition, the composition of naturally occurring oils and fats is very similar, giving a very tight boiling range for biodiesel regardless of the feedstock. The composition of biodiesel is also the reason for its high flashing point, which is an advantage in enclosed areas such as underground mines.

- Lubricity.

  Better lubricity means lower engine friction.

- Sulphur.

  One important value which is worthy to be considered is the sulphur contents, mainly because it is a basic characteristic in diesel engines, and also because of its negative effect in the environment by measures of acid rain. Thus, in the US and in Europe, legislation tries to take the diesel oil sulphur content, at levels close to zero. Meanwhile no sulphur emissions are produced with the use of biodiesel.

  Therefore, of particular concern are the requirements to reduce the sulphur contents of diesel fuel. Ultra-low sulphur diesel has less than 50 ppm sulphur and new diesel regulations in most IEA countries will bring this level to less than 10 ppm by 2010.

- Lubricity and sulphur content.

  Reducing the sulphur contents also reduces fuel lubricity. That is reason of oil companies must add to diesel some chemical and synthetic additives to mitigate that anomaly. Blending biodiesel can help, since it does not contain sulphur and helps improve lubricity. For example, in France all diesels sold have been added with Biodiesel to 2%, due to the fact that biodiesel is a good lubricant. On the other hand, blending only small quantities of biodiesel with conventional diesel does not bring the average sulphur contents down appreciatively. To reduce 350 ppm sulphur diesel down to 50 ppm, for example, requires a blend of more than 85% biodiesel. At current biodiesel production costs, refiners will likely prefer to cut the sulphur content of conventional diesel at the refinery.

C) EMISSIONS

By using biodiesel instead of petroleum diesel, a contribution to reduce greenhouse gas emissions can be made by nearly 80 per cent, according to the Environmental Protection Agency's 2002 report.

- Biodiesel also substantially reduces particle emissions and PAH air toxins (including benzene) which are hazardous to human health.
- The use and the production of biodiesel exhibit a closed-loop carbon cycle. Unlike petrodiesel, which releases greenhouse gases contained (or sequestered) deep beneath the earth, the emissions released by using biodiesel are equivalent to the amount absorbed by the plant while growing.
- Biodiesel is the first and only alternative fuel to have a complete evaluation of emission results and potential health effects submitted to the U.S. Environmental Protection Agency (EPA) under the Clean Air Act.

Then, although emissions vary with engine design, vehicle condition, and fuel quality, the US EPA (EPA, 2002b) found that, with the exception of NOx, potential reductions from biodiesel blends are considerable relative to conventional diesel, and they increase nearly linearly with increasing blend levels. Reductions in toxic emissions are similarly large (NERL 2000)

Focused on potential emissions reductions, next figure will help.

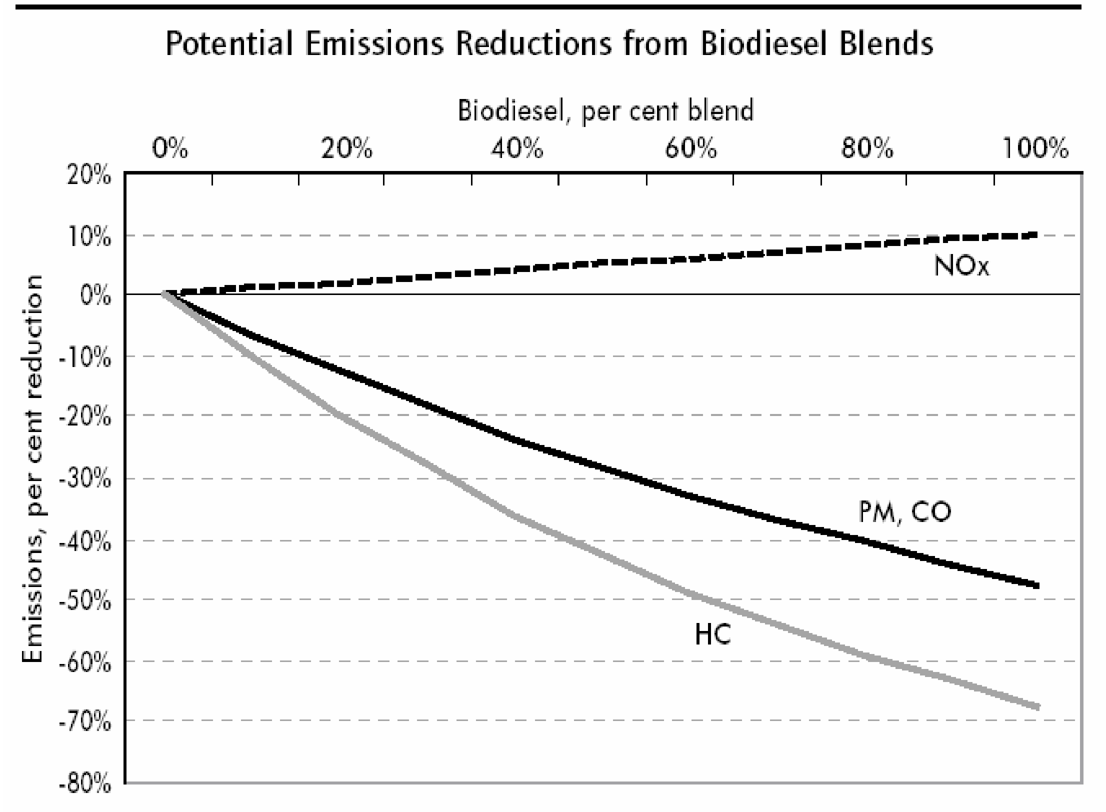


Figure 5- Potential Emissions Reductions from biodiesel blends. Source: EPA (2002b) [39]

According to the figure, by using biodiesel B20, carbon monoxide can be reduced on 13%, hydrocarbons on 11%, particles on 18%.

According to the figure, by using biodiesel B100, carbon monoxide can be reduced on 43%, hydrocarbons on 56%, particles on 55%.

It is considered that total air toxics can be reduced by 0.3% by using B20 or by 1.5% by using B100.

1.2.2. Benefits of Biodiesel

A) ADVANTAGES

Biodiesel is an ecological fuel which has the following characteristics:

- It is obtained from renewable raw materials.

Biodiesel can be produced from vegetal, animal and recycled oils. Among vegetables, although there are more than three hundred types of oil, the most common one in biodiesel production is soybean, rape, sunflower and palm.

The recycled oils come from the collection of sectors such as restaurants, nourishing, domestic kitchens, etc.

- During its combustion it costs smaller amount of CO_2 than the one absorbed on their growth, so that the final balance of CO_2 emissions is positive.

  In fact, it is considered as a CO_2 neutral emissary. Therefore, the combustion of biodiesel does not contribute to the greenhouse effect; it is neutral and it aids to fulfil the protocol of Kyoto. This is extremely important. In detail, according to the European Environment Agency, BAFF, changes (%) in EU greenhouse gas emissions by sector (1990-99) has increased around 20% in the transport sector, so by using biodiesel this value could be decreased.

- Do contain neither benzene nor other carcinogenic aromatic substances, such as aromatic hydrocarbons.

- It is easily biodegradable, and in case of spill and/or accident, it do not put in danger neither the ground nor underground waters.

  Biodiesel is biodegradable in approximately 21 days. The absence of a chemical and synthetic compound makes it innocuous with our environment.

- Is not dangerous merchandise, the flash point is over 110º C.

  Biodiesel flash point is over 110ºC, for that reason it is not classified like dangerous merchandise, which helps on safe storage and safe manipulation.

B) DISADVANTAGES

- At low temperatures, it can begin to solidify and to form crystals that can obstruct the conducts of the fuel.

  Due to its solvent properties, it can soften and degrade certain materials, such as natural rubber and polyurethane foam.

Therefore, sometimes it can be necessary to change some hoses and detents of the engine, specially in old vehicles. Since the 1990's, almost all vehicle manufacturers, specially the German ones, have replaced these conduits by others made of plastic or derived materials, that cannot be dissolved by pure biodiesel. Therefore, in order to use pure biodiesel in a secure way, in cars older than ten years, the rubber conduits must be replaced by plastic ones.

In Spain, biodiesel is sold at a 12% blend at petrol stations, so all vehicles can use it with no problem at all.

- Production costs still can be higher than the cost of diesel itself. It all basically depends on the oil source which has been used.
- Biodiesel performance per litre is about 10% less in terms of energy than the performance of petroleum diesel fuel. That is because 41.92 MJ/Kg diesel is compared to 37.55 MJ/Kg biodiesel energy contents according to figures from IEA, 2004. Biofuels for transport [21].

1.3. Why is any research needed in this area?

According to previous information, it is obvious that biodiesel is a product of great interest for its environmental characteristics.

It is also evident, that there is a latent demand of this product. That is why it is necessary to study the potential market of biodiesel, as well as to make a feasibility analysis for the implementation of a biodiesel production plant.

In the following chapters, the current market situation will be discussed and a feasibility analysis will be carried out for the implantation of a biodiesel plant supplied with oilseeds. It is important to notice that international efforts are being carried out to increase the global biodiesel production and to help biodiesel producers to develop profitable business.

2. Methodology

2.1. Objectives

This chapter aims to describe a methodology for the implementation of a biodiesel production plant from oilseed considering technical, social, and economical aspects.

The methodology has been created in order to assist companies in the selection of appropriate criteria for the implementation of biodiesel.

2.2. Methodology

The methodology is divided into four different parts. The first step is to identify the IDEA of a Biodiesel plant; the second step is to DEFINE what type of biodiesel is going to be produced considering different technologies and supply chain aspects; the third step is to evaluate the IMPLEMENTATION of the biodiesel plant taking into account the execution alternatives, the operative and financial aspects; and the final step is to start up the PLANT after its construction has been finished.

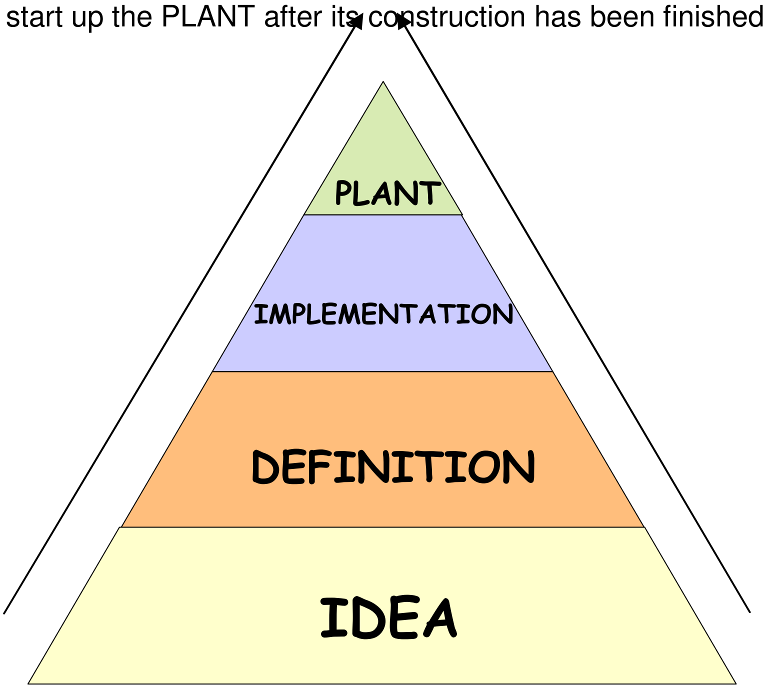


Figure 6- Methodology steps. Source: Self developed.

On this basis, once this methodology has been applied, the following flowchart is obtained where a full feasibility study is described, from the origin of the idea to the final plant being constructed.

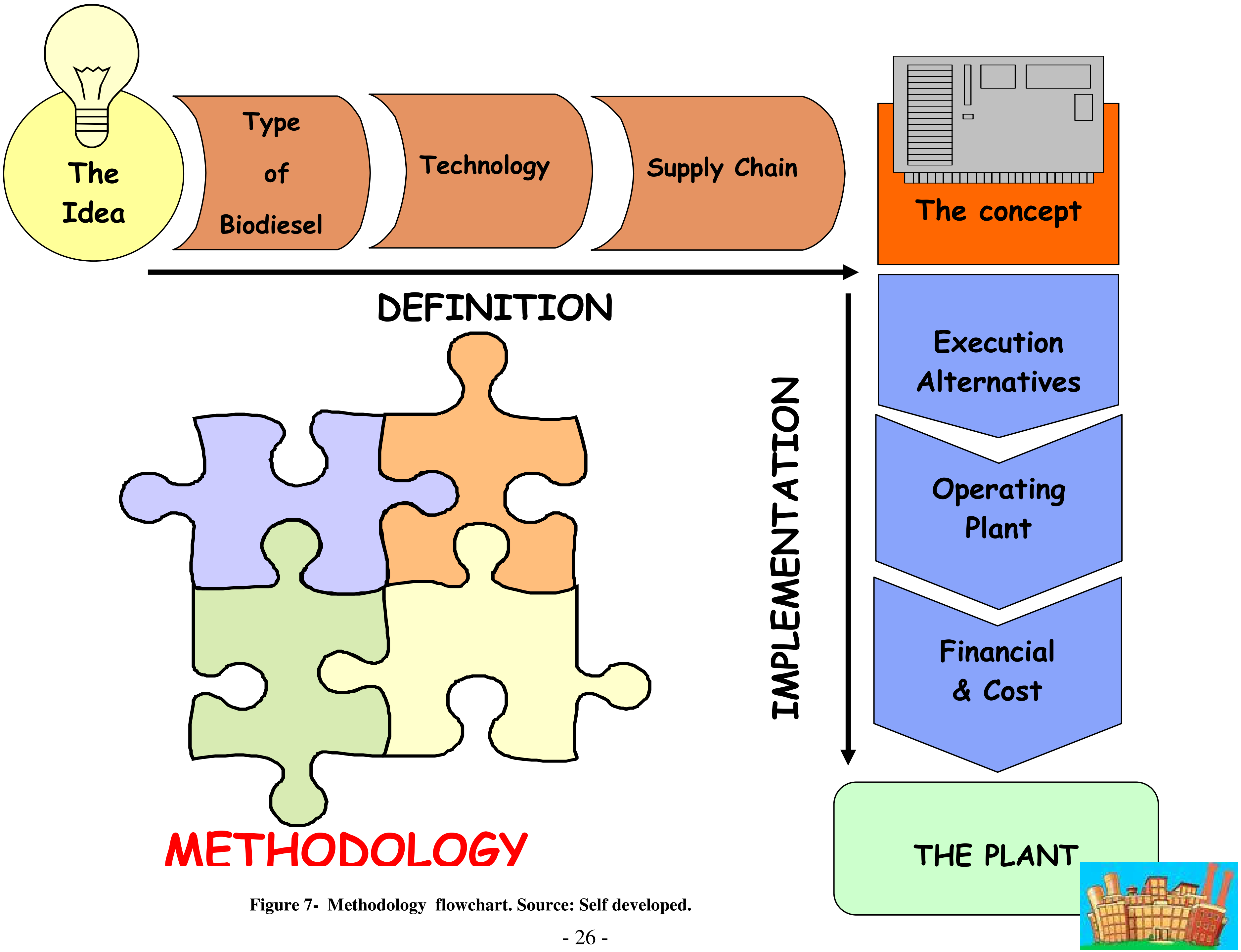


Figure 7- Methodology flowchart. Source: Self developed.

I) THE IDEA

It is important to clarify why to build a biodiesel plant is a good idea. For this, the present and future of the biodiesel market, the relevance compared with other transport fuels, and also the currently existing biodiesel projects and plants must be taken into account. See chapter 3.

II) THE DEFINITION

- Types of biodiesel.

What type of biodiesel is going to be produced? It has to fulfil biodiesel standards, although a several qualities and portions of blends can be used. See chapter 4.

- Technology evaluation.

Which technology has to be used to find the chosen biodiesel type and fulfil the required standards? Different technologies are nowadays being used and therefore different equipment layouts are required. See chapter 5.

- Evaluation of the supply chain.

What supply chain factors have to be taken into account for both the incoming and the outcoming products? Some considerations about the evaluation must be made on raw materials, specially on the election of oilseeds, but also in the election of methanol. The same considerations have to be made out of by-products such as wash water and glycerine. See chapter 6.

III) THE IMPLEMENTATION

- Evaluation of Execution alternatives.

Once the concept of the biodiesel plant appears to be clear, some technical aspects must be considered. Schedule, site location, plant components, and layout design among other factors must be clearly described. See chapter 7.

- Evaluation of operating plant alternatives.

  Different operating plant alternatives can be applied to a biodiesel production plant. This will depend on many factors including the company strategy and the availability of human resources. See chapter 8.

- Evaluation of financial and operating costs.

  Finally, a detailed analysis of the financial aspects must be carried out. There is a wide range of financial options already available in the market; the choice will depend on companies and on the market situation. Operating costs must also be planned to consider the profitability of the business. See chapter 9.

IV) THE PLANT

As the final part of the process, the biodiesel production plant from oilseed must be built and run in a profitable way. In this dissertation, a case study of a biodiesel facility is shown featuring a discussion about it. A thorough analysis of the plant is done from both the technical and cost perspective, considering such aspects as the quality of the biodiesel product, the technology involved in the process, all the supply chain aspects, the possible execution choices, and the operating plant alternatives as well as financial plant and operating cost issues.

I. THE IDEA

3. Literature review

3.1. Present and future of biodiesel

At the present time, recent researches indicate that the use of biofuel has moved to a world-wide scale market, emerging from countries like Brazil, the US, EU or China. However, there are some barriers to this development; most of which have to do with cost reasons.

Nowadays, international present policies for the introduction of biofuel, specially in the transport sector, are improving this situation thus helping the biodiesel market.

According to the Ministry of Industry, Tourism and Trade of Spain, in the EU the power consumption of the transport sector represents 45% of the total demand of petroleum derivatives, within an annual growth of 2%.

According to the Interdisciplinary Centre for Comparative Research in the Social Sciences- ICCR, 98% of the energy consumed in the transport sector comes from fossil fuels. Also, with respect to the polluting emissions, the transport sector is responsible for 87% of the CO emissions, 66% of the NOx, 60% of CO2 and 5% of SO2.

Due to this, it is evident that non petroleum producing countries all over the world should be worried about the reduction of their strong dependency on these fuels. It is also obvious that the transport sector becomes most directly affected by this petroleum dependency.

For that reason, the European Union has established in the directive EU 30/2003, some strategies to reduce petroleum dependency, specially focusing attention on the sector transport. Available at European Union Website [14].

3.2. How does biodiesel fit in with other transport fuels in Spain and other countries?

A) INTERNATIONAL AGREEMENTS

All over the world, countries have developed different biofuel targets. More details are shown in the following lines, according to data extracted from APPA- Asociación productores de Energías Renovables [6].

- European Union: Use of biofuel in the transport sector of 5.75% for 2010 and 8% for 2020.
- The United States: Use of biofuel in the transport sector of 4% for 2010 and 20% for 2030.
- Brazil: 25% of obligatory mixture of bioetanol in gasoline.
- Canada: According to the region, 7, 5%-10% of obligatory mixture of bioetanol in gasoline.
- China: 10% of obligatory mixture of bioetanol in gasoline in several provinces.
- Argentina: 5% of obligatory mixture of bioetanol for the next five years.
- Colombia: 10% of obligatory mixture of bioetanol for the greater cities.
- Thailand: 10% of obligatory mixture of bioetanol in the powerboats of Bangkok.

In detail, the 2003/30/CE directive to reduce petroleum dependency in the transport sector, considers various fuels to be promoted. More details are shown in the table below.

Year	Biofuel (%)	Natural Gas (%)	Hydrogen (%)	Total (%)
2005	2	---	---	2
2010	5,75	2	---	7,75
2015	7	5	2	14
2020	8	10	5	23

Table 8- European Plan. Source: Extracted from Inega institute [23].

According to the European commitment, the consumption of biofuel in 2005 is still 1% of the Communitarian objective of 2%. The production capacity forecast for the end of 2006 will be approximately a little bit ahead of one fourth of the total needs to fulfil the objective of the 5. 75% for 2010. Following the current trend, just a 1.7% of diesel will be replaced by biodiesel in Spain [6].

This means a problem, not just to reach the proposed European target, but also in terms of the fuel supplying of diesel cars in Spain.

In detail, Directive 2003/30 on the promotion of biofuel, in EU sets a target of 2% market penetration in 2005, which means 5,500 tonnes, and 5. 75% in 2010, this means 17,600 tonnes of biodiesel.

In Spain, the order in council R.D. 1700/2003, 15 of December, sets that the 5, 75% of total fuel consumption in the transport sector must be replaced in 2010 by biofuel. This would mean 2,200 thousands of biodiesel tonnes.

This improvement is helped by some economic advantages, i.e. the EU administration helps biodiesel producers by reducing government taxes. That is stated in the Directive 2003/96/CE, where a reduction on government taxis for a 10-year period is set.

Nowadays, in Spain, diesel and biodiesel blends are available at petrol stations at similar prices. This is because the Spanish Law 53/2002 reduces biodiesel taxes. According to Acor, biodiesel is 0.269 € per litre reduced calculated on the basis of diesel being 41.92 MJ/Kg, and biodiesel 37.55 MJ/Kg.

B) BIODIESEL PRODUCTION CAPACITY

- EU: Biodiesel has been produced on an industrial scale since 1992, mainly in response to positive signals from the EU institutions.

In 2000, a total amount of 700 thousands of biodiesel tonnes was produced in Europe, mainly in France, Germany, Italy and Austria. In 2003, the biodiesel production reached 2,315 thousands of biodiesel tonnes, which means a 30% increase.

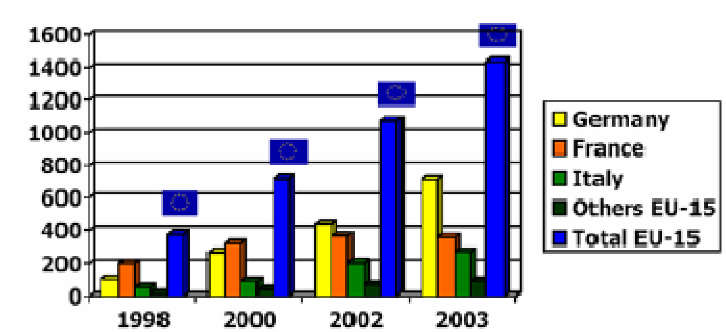


Figure 8- Biodiesel production in member states in the EU (0,000 t).
Source: European Biodiesel Board [15]

The biodiesel production is mainly distributed through Germany, France, Italy, UK and Austria. The table below shows the biodiesel production in tonnes in the EU countries from 2003 to 2006. Note that the 2006 value is estimated and no real figures are already available in the market. The total biodiesel production reaches a 35% growth.

(thousands of tonnes)	2003	2004	2006
Germany	715	1088	2100
France	357	502	800
Italy	273	419	550
United Kingdom	9	15	250
Austria	32	100	150
Poland	0	0	120
Spain	9	70	80
Slovaquia	0	15	80
Check Republic	70	48	70
Others	42	58	65
TOTAL	1507	2315	4265

Table 9- Biodiesel production in member states in the EU (0,000 t).
Source: Based on data of EBB (European Biodiesel Board) [15] and USDA (U.S. Dept of Agriculture) [46]

Some interesting remarks on the following countries:

- Germany: It is the main biodiesel producer in the EU, with about 45% of the total EU biofuel production in 2006. Germany, as the main car manufacture in the world, is demanding from local car manufacturers to produce their cars in technical situations so that they can be supplied with biodiesel blends, and with pure biodiesel for trucks. It is possible to find pure biodiesel at German petrol stations.

- France: France is the second biodiesel producer in the EU, with about 15% of EU the biodiesel production in 2006. The legal problems in France in relation to taxes in biofuel are well known. In fact in 2000, BP took legal action against the French subsidy for biofuel, due to the fact that BP considered that this was damaging their business. At this time, the European Court of Justice accepted BP's argument against the tax break. However, at the present time, the EU agreements have put France back to the situation that existed seven years ago.

- Austria: Austria is the fifth biodiesel producer in the EU, with about 3% of the total EU biodiesel production in 2006. However, this means a high percentage according to Austria cropland area. Also, Austria has been pioneer country in establishing a bioenergy program, which was started up in 1991 by the first biodiesel production plant in the world.

- Spain: Spain is the seventh biodiesel producer in the EU, with about 1.5% of the total EU biodiesel production in 2006. It is not a high figure compared to the Spanish cropland area. This can be explained because Spain has invested heavily in the development of its bioethanol industry, instead of biodiesel. In fact, Spain is now producing around 400,000 tonnes of ETBE which are available at petrol stations all over Spain. However, big efforts are being taken nowadays in Spain to improve the production of biodiesel and many biodiesel plants are being installed in Spain. In the following table, an estimated production of biodiesel according to EU targets is shown.

Estimated Biodiesel consumption

(million tonnes)	2005	2006	2007	2008	2009	2010
Estimated consumption	23.93	25.84	27.9	30.1	32.54	35.14
EU target	2	2.75	3.5	4.25	5	5.75
Diesel quantity to substitute	0.47	0.71	0.97	1.28	1.62	2.02

Table 10- Estimated biodiesel consumption in Spain. Source: Based on data of ACOR

3.3. *Current biodiesel projects*

Nowadays there are many biodiesel production plant projects in the world. The list of companies in the biodiesel business is changing rapidly, and the information just older than four to six months may be out of date. In particular, this chapter is set in the Spanish context.

- The greatest world-wide agreement of the biodiesel production.

  Repsol YPF has recently announced the greatest world-wide agreement of biodiesel production that the company has subscribed with Acciona, to put more than a million tons of this product before 2010 in the market, which turns it into one of the greatest world-wide producers of biofuel. This agreement, with an overall investment over € 300 million, involves the construction of up to six biodiesel producing plants that will be operative between the first semester of 2007 and the second of 2009 [April 2006].

- The biggest biodiesel project in Spain.

  The Ministry of Industry, Tourism and Trade, through CDTI (Centre for the Industrial Technological Development) has granted a subvention of more than € 22 million to a group of companies led by Repsol YPF, for a great research and development project regarding biodiesel with a four-year duration. The project Biodiesel ZENITH will allow to develop the technology required to produce biodiesel. Its objective is to contribute to the introduction of biodiesel in the national market by means of a program of R+D oriented to the reduction of production costs and the increase of the availability of necessary local raw materials for the biofuel. Repsol YPF leads to this initiative along with other fourteen Spanish companies leading in their respective sectors: Acciona Biofuel, Biogas Cell Fuel, Bonior, Elcogas, Iberian Facet, Guascor, Koipesol Seeds, I.Q. Lasem, Robert Bosch Spain, Reunited Sacyr, Suescum Industries, Techniques, Tiffel, and Agricultural Cooperative 26 Valparaiso [27].

  Besides, Repsol has announced the construction of up to six plants which will be operative between the first semester of 2007 and the second of 2009 [36].

- The biggest biodiesel production plant in Spain.

  In Madrid, on the 21 November, the manager of the capital risk company, Giuliani Sage, announced that it participates in association with Interdin Corporate Advisory, in the creation of the greater Spanish project of biodiesel manufacture through the Becco Spain company. This project will construct in Spain two plants located in Burgos and Madrid. The annual industrial targets for these plants in the short term are estimated in the 150,000 tons of fuel, with the intention of reaching the 500,000 tonnes in the mid term [13].

- The highest number of biodiesel production plants concentrated in a particular region.

  In the North West of Spain, in Galicia, the most Spanish ambitious plan for biodiesel production is been carrying out. In detail, 5 biodiesel production plants are projected to be set in this area. See table below.

Company	Production (thousands tonnes per year)	Location
Entaban	100	Ferrol
Forestal del Atlántico	100	Mugardos
Repsol y Acciona	200	A Coruña
Diesel Energy	150	Unknown
Infinita renovables	300	Vigo

Table 11- Biodiesel plants projected in Galicia, North West of Spain. Source: Based on data of different sources.

3.4. Current biodiesel production plants

Today, there are several biodiesel production plants all over the world.

In the US, in 2006 there were more than 50 biodiesel suppliers representing 1,300 millions litres of production capacity and more than 50 additional plants were announced for construction [32].

In the EU, currently, approximately 120 plants are producing up to 4,000 million litres of biodiesel annually. These plants are mainly located in Germany, France, Italy, and Austria.

In Spain, the figures are not so high. The current Spanish producers mainly use fried as a raw material for the biodiesel production. In the following table, biodiesel plants both in operation or under project are shown. Further information on the type of oil used as a raw material is shown. EHN Caparroso biodiesel plant is the only producer of biodiesel from oilseeds. It is deeply studied in chapter 4 of this dissertation.

	Company	Situation	Production (tonnes per year)	Oil origin
In operation	Stocks del Valles	Barcelona	6,000	Recycled
	Bionor	Álava	30,000	Recycled
	Bionet Europa	Tarragona	50,000	Recycled
	IDEA-UCE	Madrid	5,000	Recycled
	EHN Caparroso	Navarra	35,000	Oilseeds
In project phase	Biocarburante Almaden	Ciudad Real	21,000	Oilseeds
	Bionorte	Asturias	5,000	Recycled
	Biocarburante Cataluña	Tarragona	100,000	Imported
	Gebiosa	Cantabria	150,000	Imported
	Biocombustibles de Cuenca	Cuenca	42,000	Imported
	Biodiesel C.L. Mancha	Toledo	13,000	Recycled
	Grup Ecologic	Baleares	7,000	Recycled
	ACOR	Olmedo	65,000	Oilseeds
	Entaban	Ferrol	100,000	Oilseeds
	Forestal del Atlántico	Mugardos	100,000	Oilseeds
	Repsol y Acciona	A Coruña	200,000	Oilseeds
	Diesel Energy	Unknown	150,000	Oilseeds
	Infinita renovables	Vigo	300,000	Oilseeds

Table 12- Biodiesel plants both in operation or under project

3.5. The Production of Biodiesel in the US and EU in 2000

In the following table, some figures of production of biodiesel in the US and EU in 2000 are shown. These figures prove that in spite of the US being the highest cropland area, the European Union has produced all the biodiesel 2000.

In the present, total values have been increased on portion similar for both US and the EU.

	Biodiesel US	Biodiesel EU-15	Notes
Total cropland area of all major crops (million hectares)[a]	133	49	Includes all major field crops, excludes orchards and grazing land
Crop types currently used for biofuels production and approximate shares	soy 100%	rape 70% sunflower 30%	EU production varies by country; see Chapter 1.
Cropland area used for crop types used to produce biofuels (million hectares)	30.1	4.1	
Actual cropland area devoted to making crops for biofuels (million hectares) and average yield estimates	0.0	0.6	Estimate is based on total production of biofuels
Per cent of cropland area for relevant crops actually used to produce biofuels	0.2%	14.1%	
Per cent of total cropland area, all crop types	0.0%	1.2%	
Average crop yield (metric tonnes/hectare)	2.5	2.9	Weighted average for current crop types used to produce biofuels
Total crop production (million metric tonnes)	75	12	
Avg. biofuel yield (litres per metric tonne of crop)	212	427	Weighted average for current crop types
Avg. biofuel yield (litres per hectare)	530	1 230	Weighted average for current crop types
Actual biofuel production (billion litres)	0.0	0.7	IEA estimates (note US biodiesel production was 20 million litres, which rounds to 0.0 billion litres)
Biofuel production, gasoline/diesel equivalent (billion energy-equivalent litres)	0.0	0.6	Adjusted for lower volumetric energy content of biofuels (ethanol = 0.67 of gasoline, biodiesel = 0.87 of diesel)
Year 2000 consumption of relevant (gasoline/ethanol, diesel/biodiesel) transport fuel (billion litres)	173.3	146.0	US and EU data
Biofuel share (volume basis) of relevant road transport fuel	0.0%	0.5%	
Biofuel share (energy basis) of relevant road transport fuel	0.0%	0.4%	

[a] Total cropland estimate based on total planted hectares of grain, sugar and oil-seed crops; total available agricultural land is higher and includes fallow and reserve lands, orchards and pastureland.
Sources: United States: USDA, Economic Research Service; except ethanol conversion efficiency from Wang (2001a); European Union: DG Agriculture (crop yields adjusted on the basis of Table 6.3); biofuel production data from F.O. Lichts (2003).

Table 13- Biodiesel comparison production of US and EU in 2000. Source: extracted from IEA- BIOFUELS FOR TRANSPORT. April 2004

II. THE DEFINITION

4. Evaluation of Types of Biodiesel

4.1. Biodiesel standards

The quality of biodiesel depends on two main factors. One is the type of oil used as a raw material, which can be refined oil, dry or neutral; and the other one is the degree of correct production. Due to this, the importance of having a standard regulation which fulfils the international basic quality parameters comes out as a real need. So this biofuel must guarantee a good performance on petrol engines.

There are already very tight quality standards. The most well known are CEN 14214 for the EU, and ASTM standard for the US. The most important one is the ASTM PS 121/1999 "Provisional Specification for Biodiesel Fuel (B 100) Blend Stock for Distillate Fuels" for the US; ASTM D 6751:2002 "Standard Specification for Biodiesel Fuel (B-100) Blend Stock for Distillate Fuels." for the US; and the pr ENN 14214/May 2001 "Automotive fuels - Fatty acid methyl esters (FAME) for diesel engines - Requirements and test methods." for the EU countries.

Other countries are also developing own standards as Argentina is doing with the IRAM 6515-1 standard, based on the Resolution N° 129/2001 of the State Energy Secretary.

In more detail:

- European and Spanish standards

  The fatty acid methyl ester (FAME), called biodiesel, is produced from vegetal or animal products. The Spanish commercial biodiesel is determined in terms of its composition and quality in the Spanish Normative EN14214, with the exception of the Iodine value, established in 140 units as maximum. Note: consider CEN Specs (EN 1424 and revision EN 590)

Consequently, biodiesel is regulated by the Spanish government in the Order in council (Real Decreto) 61/2006, of the 31 January, in which gasoline, gas oils, fuels and liquid gases from the petroleum are regulated, and therefore their uses.

The blends which are commercialized, following the Spanish law, fulfil all the specifications determined on the Automotive Gas-oil Spanish Normative (EN-590), and also follow the EU Diesel normative where it says that containing up to 5% biodiesel is considered diesel at all effects and is covered by normal diesel standard EN 590.

- US standards

In the US, the standards on biodiesel are different from the European way. In the States, the standard is framed as a set of property specifications measured by specific ASTM test methods. The standard for biodiesel is ASTM 6751-02.

In detail, the ASTM D 6751 – 02 standard, sets forth the specifications that must be met for a fatty acid ester product to carry the designation of biodiesel fuel or B100 or for use in blends with any petroleum-derived diesel fuel. Those for use in blends must be defined by ASTM D 975, Grades 1-D, 2-D, and low sulphur 1-D and 2-D.

According to this, nowadays some quality programmes for the insurance and certification of the biodiesel quality are coming out, most known of which is the BQ9000 accreditation programme.

BQ9000 is a cooperative and voluntary program for the accreditation of producers and marketers of biodiesel fuel. It is mainly developed in the US and it is created after various ISO 9000 type programmes (International Standards Organization, responsible for the ISO 9000 and other international quality standards; in detail ISO 9000 is a generic name given to a family of standards developed to provide a framework around which a quality management system can effectively be implemented)

This certification is awarded by the National Biodiesel Accreditation Commission (NBAC or the Commission) which was formed by the National Biodiesel Board to administer BQ9000. Pointing that the NBAC is an autonomous committee of the National Biodiesel Board (NBB) that works independently in all matters directly relating to BQ 9000.

As a conclusion, the objective of BQ9000 is to promote the commercial success and public acceptance of biodiesel by recognizing biodiesel producers and marketers who prove compliance with acceptable quality standards.

4.2. Evaluation of biodiesel quality

The critical items to attend for the determination of biodiesel quality are:

- Complete reaction to the mono alkyl esters.

  The standard developed to address this quality assurance is based on the conversion of the fat or oil to mono alkyl esters measured through measurement of the total.

- The elimination of free glycerine.

  The standard developed to address this quality assurance is based on the measurement of glycerine, which includes all mono-, di-, and triglycerides as well as free glycerine.

- The elimination of residual catalyst.

  The standard developed to address this quality assurance is based on the removal of the catalyst measured through the measurement of the ash content.

- The elimination of reactant alcohol.

  The standard developed to address this quality assurance is based on the removal of the alcohol and it is ensured through measurement of the flash point.

- The absence of free fatty acids.

  The standard developed to address this quality assurance is based on the absence of fatty acids measured through measurement of the acid number.

In more detail, considering the EN 14214 (European norm) a deep analysis of the generally applicable requirements and test methods can be applied.

EN 14214 (October 2002) specifies the requirements and test methods for marketed and delivered fatty acid methyl esters (FAME) to be used either as automotive fuel for diesel engines at 100% concentration, or as an extender for automotive fuel for diesel engines in accordance with the requirements of EN 590. Note that 100% concentration is applicable to fuel for use in diesel engine vehicles designed or subsequently adapted to run on 100% FAME [14].

On the next table generally applicable requirements and test methods can be displayed. A consideration must be done on Iodine value, which is set on 140 units as maximum at the EN 14214 as exception that can be shown in the following table.

Property	Unit	Minimum method [a]	Maximum	Test
Ester content [a] 14103	% (*m/m*)	96,5 [b]		prEN
Density at 15 °C [c] 3675 EN ISO 12185	kg/m^3	860	900	EN ISO
d				
Viscosity at 40 °C 3104	mm^2/s	3,50	5,00	EN ISO
Flash point 3679 [e]	°C	120	–	ISO/DIS
Sulphur content ISO 20884 Carbon residue distillation residue) [f] Cetane number [g]	mg/kg % (m/m)	–10,0 –0,30 51,0		prEN ISO 20846 prEN- EN ISO 10370 (on 10 % EN ISO 5165
Sulphated ash content	% (m/m)	–	0,02	ISO 3987
Water content	mg/kg	–	500	EN ISO
12937 Total contamination [h]	mg/kg	–	24	EN 12662
Copper strip corrosion stability, 110 °C	Rating Hours	Class 1 EN ISO 2160 (3 h at 50 °C) Oxidation 6,0 –		prEN 14112
Acid value	mg KOH/g		0,50	prEN
14104 Iodine value	120		prEN 14111 Linolenic	
acid methyl ester	% (m/m)		12,0	prEN
14103				
Polyunsaturated (>= 4 double bonds)	% (m/m)		1 methyl esters [i]	
Methanol content	% (m/m		0,20	prEN
14110 Monoglyceride content	% (m/m)		0,80	prEN
14105 Diglyceride content	% (m/m)		0,20	prEN
14105 Triglyceride content [j]	% (m/m)		0,20	prEN
14105				
j				
Free glycerol 14105 prEN 14106 Total glycerol	% (m/m) % (m/m)		0,02 0,25	prEN prEN 14105
k				
Group I metals (Na+K) 14108 prEN 14109	mg/kg		5,0	prEN
Group II metals (Ca+Mg) [l] 14538 Phosphorus content 14107	mg/kg mg/kg		5,0 10,0	prEN prEN

A See standard for more detail
B See standard for more detail

c Density may be measured by EN ISO 3675 over a range of temperatures from 20 ^{0}C to 60 ^{0}C. Temperature correction shall be made according to the formula given in Annex C. See also 5.5.2

d If CFPP is –20 °C or lower, the viscosity measured at -20 °C shall not exceed 48 mm^2/s. In this case, EN ISO 3104 is applicable without the precision data owing to non-Newtonian behaviour in a two-phase system.
E See standard for more detail
f ASTM D 1160 shall be used to obtain the 10% distillation residue.

G See standard for more detail
h See standard for more detail
i Suitable test method to be developed
J See standard for more detail
k See standard for more detail
l See standard for more detail

Table 14- Generally applicable requirements and test methods.
Source: EUROPEAN STANDARD. prEN 14214. October 2002. ICS 75.160.20. [7]

Main characteristics are discussed on the following lines:

- Flashing Point.

  The flashing point parameter is used to limit the level of un-reacted alcohol remaining in the finished fuel. The flashing point also has an important connection with the legal requirements and safety precautions involved in fuel handling and storage. It is normally specified to meet insurance and fire regulations. The flashing point specification for biodiesel is intended to be 100℃ minimum. Typical values are over 160℃.

- Viscosity.

  This is specially important on engines. For some engines, it may be advantageous to specify a minimum viscosity because of power loss due to injection pump and injector leakage, and also because sulphur emissions. Maximum allowable viscosity, on the other hand, is limited by considerations involved in engine design and size, and the characteristics of the injection system. The upper limit for the viscosity of biodiesel is 5.0 mm^2/s at 40 ° C and the minimum is 3.5 mm^2/s at 40℃.

- Sulphated Ash.

  Ash-forming materials may be present in biodiesel in three forms: abrasive solids, un-removed catalysts, and soluble metallic soaps. Abrasive solids and un-removed catalysts can contribute to injector, fuel pump, and engine deposits. These unwanted materials can also lead to premature piston and ring wear. Soluble metallic soaps have little effect on wear but may contribute to filter plugging and engine deposits.

- Sulphur.

  Sulphur is being extremely controlled by international standards in order to reduce the greenhouse effect and for other environmental reasons. Therefore, sulphur fuel can also affect the performance of the emissions control systems. On the other hand, the effect of sulphur content on engine wear and deposits appears to vary considerably in importance and depends largely on operating conditions. BIOO is essentially sulphur free, although some biodiesel produced from used cooking oils has been shown to have as much as 30 ppm sulphur.

- Copper Strip Corrosion.

  This test serves as a measure of possible difficulties with copper and brass or bronze parts of the fuel system. The presence of acids or sulphur-containing compounds can tarnish the copper strip, thus indicating the possibility for corrosion.

- Cetane Number.

  The cetane number is a measure of the ignition quality of the fuel and influences white smoke and combustion roughness. The cetane number requirements depend on engine design, size, nature of speed and load variations, and on starting and atmospheric conditions. It is important to subscribe that substantiating data to support the calculation of cetane index with biodiesel or biodiesel blends does not exist. See next chapter for more details.

- Carbon Residue.

  Carbon residue analysis measures the carbon depositing tendencies of a fuel oil. While not directly correlating with engine deposits, this property is considered an approximation. Although biodiesel is in the distillate boiling range, most biodiesel boils at approximately the same temperature and it is difficult to leave a 10 % residual upon distillation.

- Phosphorus Content.

  Phosphorus can damage catalytic converters used in emissions control systems and its level must be kept low. Catalytic converters are becoming more common on diesel powered equipment as emissions standards are tightened. Therefore, low phosphorus levels will become increasingly important.

- Density.

  The density of biodiesel meeting the specifications EN14214 falls between 0.86 and 0.90 g/m^3, with typical values falling between 0.88 and 0.89. Since biodiesel density falls between 0.86 and 0.90, a separate specification is not needed. The density of raw oils and fats is similar to biodiesel; therefore, the use of density as an expedient check of fuel quality may not be as useful for biodiesel as it is for petrodiesel.

4.3. Biodiesel pure or blended

Biodiesel can be used as "biodiesel fuel" or "B100" or in a blend with petroleum diesel. As it was described in previous chapters, a blend of 20 % biodiesel with 80 % petrodiesel, by volume, is termed "B 20". A blend of 2 % biodiesel with 98 % petrodiesel is " B 2", and so on; so B100 means a pure biodiesel called neat biodiesel. Properties of these blends are different in every blend and are moved in between maximum and minimum levels described in previous chapters.

Thus, applications of blends depend:

— Neat biodiesel: specially used in big engines such as marine applications and trucks. Major environmental reductions are obtained, but some technical problems could appear, as described earlier in this dissertation, with some components of all cars, specially Buna rubbers.

— B20 to B50: those are the most common blends used in the markets. Environmental reductions depend on biodiesel content. Blends help to reduce the economical impact of biodiesel use.

— B02: biodiesel is also used as an additive from ranges to 0.25 to 2% content. It is used as a lubricant.

In detail, for OECD countries, different biodiesel blends are currently on the market.

⇒ In France biodiesel is often blended at 5% in standard diesel fuel and at 30% in some fleet applications

⇒ In Spain and Italy, it is commonly blended at 5% in standard diesel fuel (EU,2001).

⇒ In the US, the most common use is for truck fleets, and the most common blend is B20.

⇒ In Germany, Austria and Sweden, it is used as a pure fuel (100% biodiesel) in some trucks with only minor fuel system modifications.

5. Technology Evaluation

There are different technologies currently used in biodiesel production in the market. Depending on which type of biodiesel this technology is going to be used, the energy efficiency and productivity results could vary from a wide range.

By using an advanced system for the biodiesel production from soybeans seeds, the output results from the productive process may reach values around 70% of efficiency, and around 53% of greenhouse gas reduction as it can be seen on table below extracted from IEA- Biofuels for transport.

The biodiesel efficiency production value is far from 91% which is obtained in the diesel production process. However, current researches are intended to increase this figure.

Estimates of Energy Use and Greenhouse Gas Emissions from Advanced Biofuels from the Novem/ADL Study (1999)

			Well-to-tank		Well-to-wheels	
Fuel	Feedstock / location	Process	Process energy efficiency (energy in/out)	Percent efficiency	CO_2-equivalent GHG emissions g/km	GHG% reduction v. gasoline/diesel
Diesel	petroleum	refining	1.10	91%	198	
Biodiesel	rapeseed (local)	oil to FAME (transesterification)	1.60	62%	123	38%
Biodiesel	soybeans (local)	oil to FAME (transesterification)	1.43	70%	94	53%
Diesel	biomass - eucalyptus (Baltic)	HTU biocrude	1.47	68%	79	60%
Diesel	biomass - eucalyptus (Baltic)	gasification / F-T	2.35	43%	-16	108%
Diesel	biomass - eucalyptus (Baltic)	pyrolysis	3.31	30%	72	64%
DME	biomass - eucalyptus (Baltic)	gasification / DME conversion	1.78	56%	22	89%
Gasoline	petroleum	refining	1.20	83%	231	
Gasoline	biomass - eucalyptus (Baltic)	gasification / F-T	2.71	37%	-10	104%
Ethanol	biomass - poplar (Baltic)	enzymatic hydrolysis (CBP)	1.94	51%	-28	112%
Ethanol	biomass - poplar (Brazil)	enzymatic hydrolysis (CBP)	1.94	51%	-28	112%
Ethanol	biomass - poplar (local with feedstock from Brazil)	enzymatic hydrolysis (CBP)	1.94	51%	-3	101%
Ethanol	corn (local)	fermentation	2.25	45%	65	72%
Hydrogen	biomass - eucalyptus (Baltic)	gasification	2.41	42%	11	95%
CNG	biomass - eucalyptus (local)	gasification	1.69	59%	39	83%

Table 15- Estimates of Energy Use and Greenhouse Gas Emissions from Advanced Biofuels from the November/ADL Study (1999). Source: Biofuels for transport [21].

5.1. The Process Techonology Selection

Biodiesel from fatty acid methyl esters (FAME) can be produced by a variety of esteritification technologies. The production of biodiesel, or methyl esters, by esteritification is a well-known chemical process that has been used for decades in the soap and detergent industry. First the oil is filtered and pre-processed to remove water and contaminants. If free fatty acids are present, they can be removed or transformed into biodiesel using pre-treatment technologies. The pre-treated oils and fats are then mixed with an alcohol (usually methanol) and a catalyst (usually sodium or potassium hydroxide). The oil molecules (triglycerides) are broken apart and reformed into esters and glycerol, which are then separated from each other and purified. The resulting esters are biodiesel.

An extremely easy way for anyone to be able to produce biodiesel at home can be done by following the next steps: Add some soda, and medical alcohol to a one-litre olive oil bottle, hardly shake it several times; as a result glycerine will appear at the bottom of the bottle, and biodiesel and soda will appear at the top. This is a Batch process which needs to be shaken for a long time, undertook by an organic reaction not a kinetic one.

By this time, there are three basic chemical routes to produce methyl esters from renewable oils and fats:

- Base catalyzed transesterification of oil with methanol.
- Direct acid catalyzed esterification of oil with methanol.
- Conversion of the oil to fatty acids, and then to methyl esters with acid catalysis.

The election of these chemical routes will determine the technology process to be used, so that an election on those must be taken extremely carefully. This can be carried out basing on the following aspects:

- Economy of Scale (Size of Plant) Comparisons.
- Batch vs. Continuous Technology.
- Existing vs. Developing Technology.
- Capital and Operating Cost Differences.
- Product Yields and Quality from Various Feedstock.

Nowadays, most of the methyl ester producers use the base-catalyzed reaction called transesterification, and a batch process. This is mainly for economical and operational reasons whose justification is based on the fact that it is easier to handle variations in raw material quality in a discontinuous process.

The main characteristics of the transesterification process in comparison to others, according to Biodiesel Production Technology report of January 2004, are the following:

- Low temperature about 71-82 ºC.
- Low pressure about 103 Pascal to 206 Pascal.
- High yields conversion around 98% with minimal side reactions when low free fatty acid feed stocks are used.
- No exotic materials are required for construction.

5.2. The transesterification

5.2.1. Chemical Reaction

Transesterification is a base-catalyzed chemical reaction process. Almost all the biodiesel is produced by using a base-catalyzed transesterification process, as it is the most economical process for it only requires low temperatures and pressures. In the reaction, 100 parts of a fat or oil is reacted with 10 parts of methanol in the presence of a base catalyst to produce 10 parts of glycerine and 100 parts of methyl esters (biodiesel). Normally, the methanol is charged in excess to assist in quick conversion and the excess is recovered for reuse. The catalyst is usually sodium or potassium hydroxide that has already been mixed with the methanol. On the figure below a typical transesterification reaction is shown, a triglyceride reacts with methanol through a base catalyst to produce biodiesel methyl ester and glycerine.

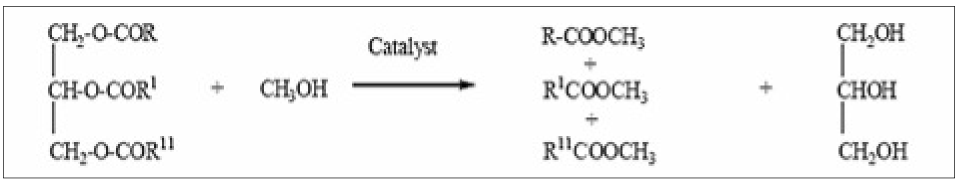


Figure 9- The transesterification reaction. Source: Technology Information, Forecasting.

5.2.2. Production Process

According to information extracted from the Biodiesel Production Technology source [47], the transesterification process, in general, consists of the following steps.

Nº	Operation	Description
1	Oil Feedstock pre-treatment	The oil feedstock is pre-treated by caustic refining to remove any free fatty acids. A growing number of companies are utilizing additional de-gumming of the incoming feedstock to improve downstream processing,. Some biodiesel producers are etherifying the fatty acids with a strong acid, neutralizing the acid with a strong base, and then feeding the mixture to the transesterification process. Using the acid esterification pre-treatment step requires a more expensive processing equipment, but may be the best choice if oil feedstock includes waste oils and greases.
2	Catalyst Preparation	The catalyst is produced by reacting sodium hydroxide or potassium hydroxide with methanol. The catalyst is dissolved in the methanol using a simple mixing process. Some care must be taken to ensure the potassium or sodium hydroxide does not absorb water in storage. This could cause the formation of large clumps which are hard to dissolve; additionally, the water has an adverse impact on the downstream processing.
3	Reaction	The methanol catalyst mix is then charged into a reactor, either continuously or batch, and the oil is added. The reaction mix is kept at approximately 170 for one to eight hours. Excess methanol is normally added to

		ensure high levels of conversion of the fat to methyl esters. The catalyst will first react with any free fatty acids present in the oil making soaps, which can form emulsions and hamper separation and catalyze the reaction. Increased catalyst costs and emulsion formation are the key reasons why low free fatty acid feedstocks are desirable.
4	Methanol Recovery	In some biodiesel processes, the excess methanol is removed at this stage via a simple flash process or vacuum distillation. In other processes, the methanol is removed after the glycerine and esters have been separated. In either case, the excess methanol is recovered and distilled using a conventional distillation equipment to remove any water. Some care must be taken to ensure no water accumulates in the recovered methanol stream. There must be enough catalyst added to neutralize any free fatty acids in the oil feedstock
5	Product Separation	Once the reaction is complete and the methanol has been removed, two major products exist: glycerine and methyl esters. Due to the density difference between glycerine and methyl esters, it is easy to separate both in a gravity separator. The crude glycerine is simply drawn off the bottom. In some cases, a centrifuge is used to separate the esters from the crude glycerine. The esters float to the top of the settler and are pumped to the wash column.
6	Methyl Ester Washing	Once separated from the glycerine, the methyl esters are gently washed with warm water to remove the residual catalyst and soaps. The esters are vacuum dried, and sent to storage. The product is typically 98.5% methyl ester and it is ready to be sold as biodiesel. In some cases, the esters are distilled under vacuum to achieve even higher purity and can be sold in the chemicals commodity market.

7	Glycerine Recovery	The co-product, crude glycerine, contains water, residual base catalyst and fatty acid base soaps. The crude glycerine is acidulated with an acid (usually hydrochloric or phosphoric acid), which converts any soaps back to fatty acids and ionic salts. The fatty acids usually are separated from the crude glycerine by gravity separation and each phase is sent to storage. Any catalyst remaining in the glycerine (sodium hydroxide or potassium hydroxide) is neutralized by the acid creating a sodium salt, which is simply left in the glycerine. The glycerine is typically 80-88% pure and ready to be sold as salt crude glycerine. In some cases, when using potassium hydroxide for the catalyst and phosphoric acid acidulation, the salt formed (potassium phosphate) is recovered and sold for fertilizer.

5.3. Equipment layouts

A flowchart of a transesterification process is shown below. Displayed numbers represent the different production process phases which were used in the previous section

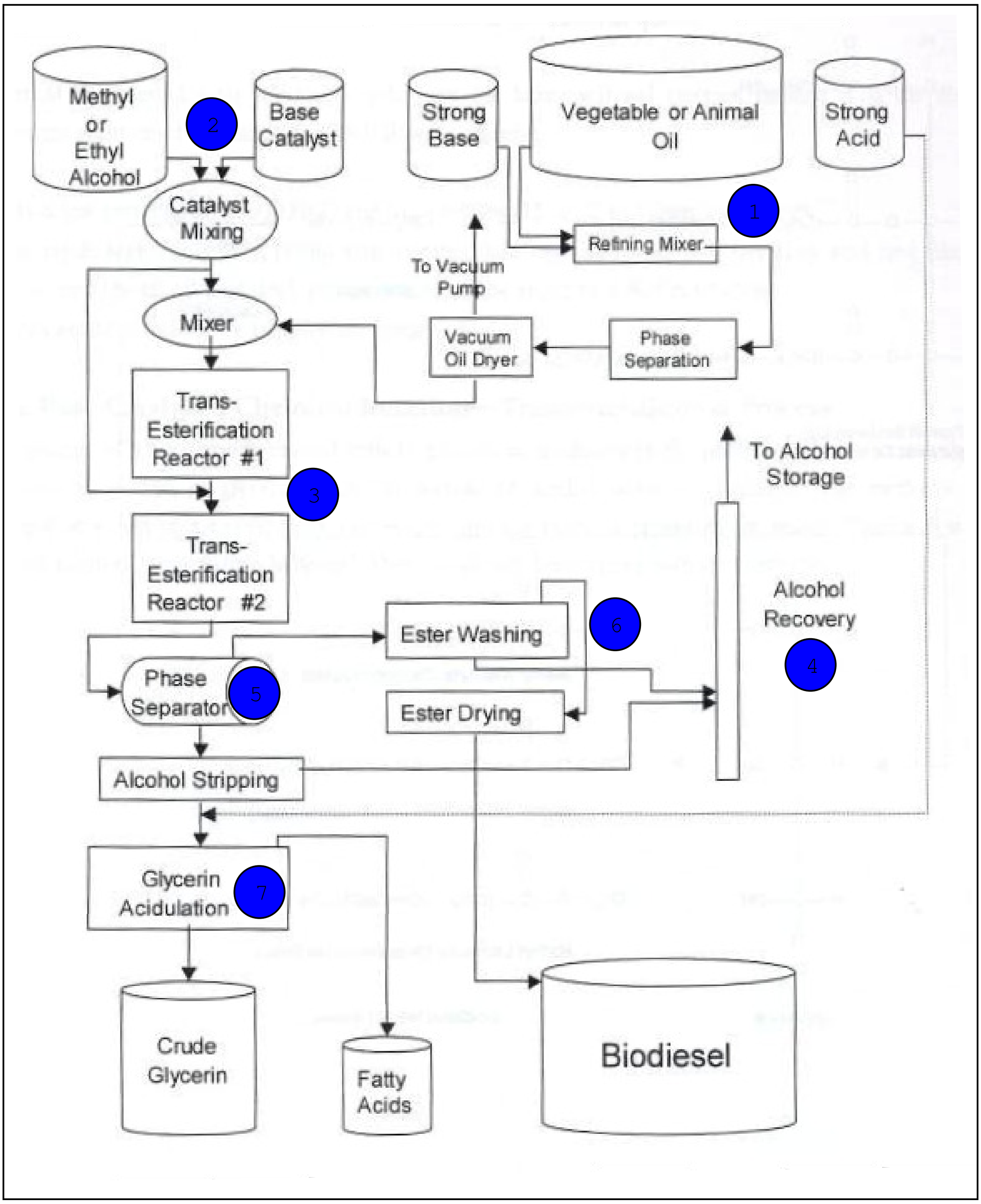


Figure 10- Typical transesterification flowchart. Source: Extracted from Asociación productores de Energías Renovables [6]

A typical layout is shown below. This may vary very few from real industrial schemes.

A) OIL FEEDSTOCK PRE-TREATMENT

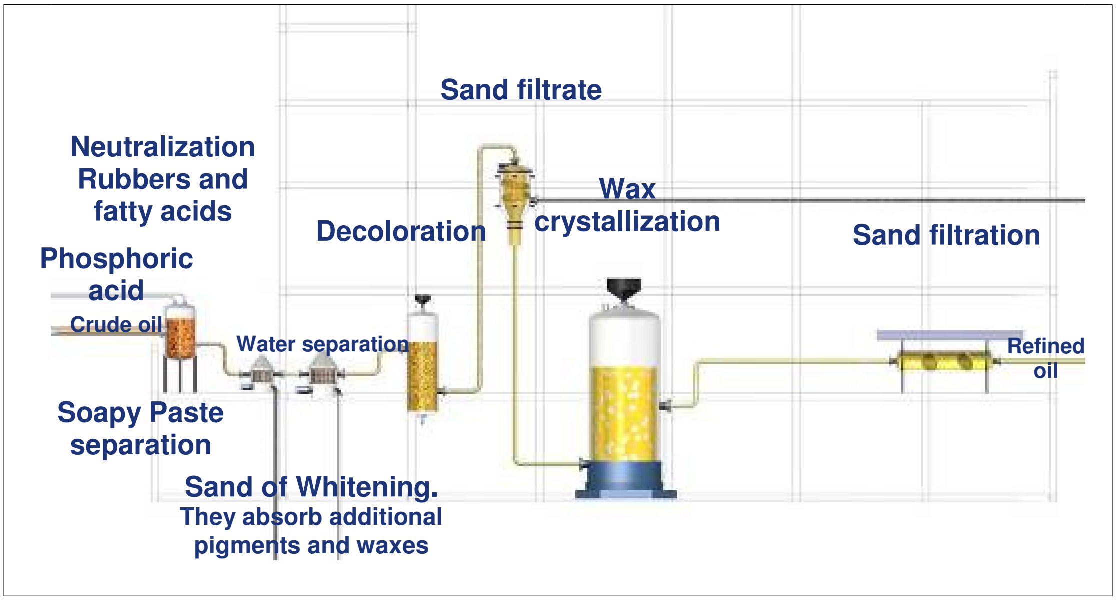


Figure 11- Typical transesterification layout, oil feedstock pre-treatment. Source: Extracted from Asociación productores de Energías Renovables [6].

B) TRANSESTERIFICATION

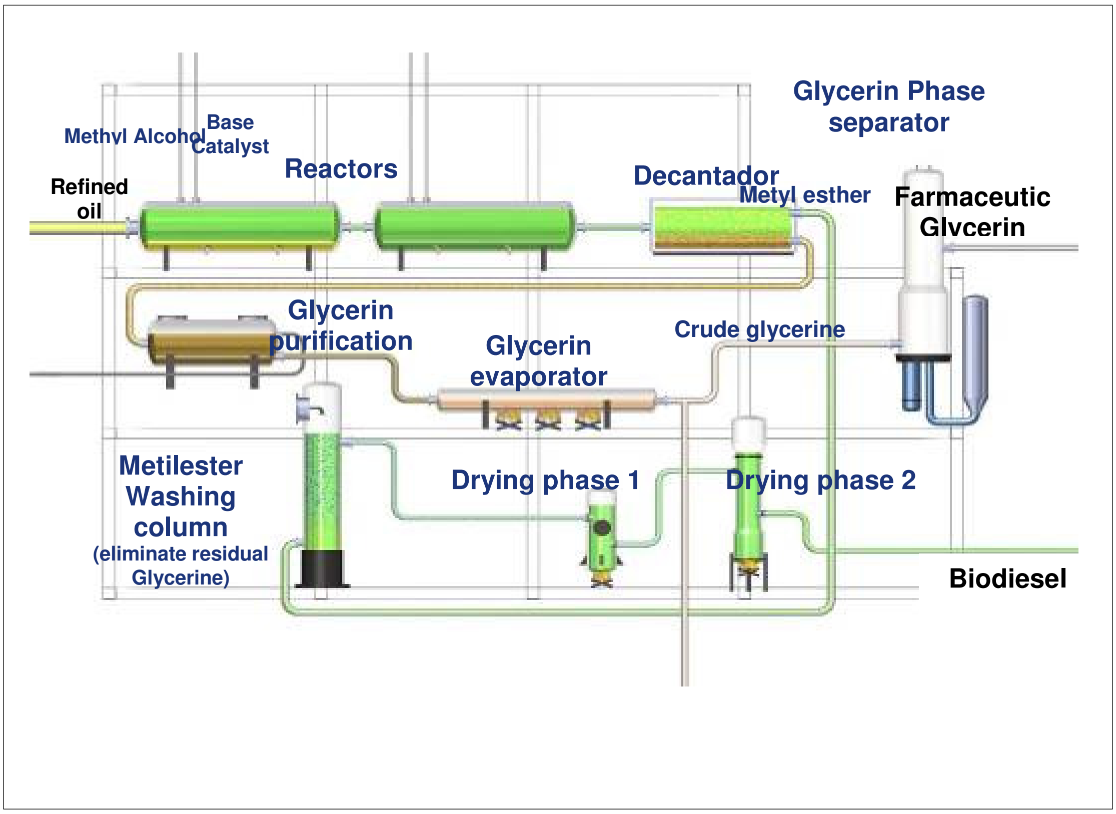


Figure 12- Typical transesterification layout, reaction. Source: Extracted from Asociación productores de Energías Renovables [6]

6. *Evaluation of The Supply Chain*

Biodiesel can be obtained from different types of oils and fats:

- Oilseeds: rape, soy, sunflower, palm, castor, seed of thistle, and others,
- Recycled or waste oils and grease.
- Animal fats.

Broadly speaking, in most countries in the world, including Spain, biodiesel is produced from oilseeds, mostly sunflower and rape in Spain and the EU, and soybean in the US.

In the following chapters, different possibilities and aspects in the supply chain of the production of biodiesel will be evaluated; incomings and output products will be discussed taking into consideration different aspects involved in their uses.

6.1. Considerations for the evaluation

For the election of the biodiesel feedstock, there are many factors that must be taken under consideration: the cost, the quality, the reliability of the incoming supply, the technology requirements, and the finished product.

Mainly, cost is the single most important determinant of material choice; but this must be followed by the quality of the oil incoming, and the reliability of the supply.

The main products involved in the biodiesel production are:

- Raw Materials: The oil used to produce biodiesel is the most important cost factor in biodiesel production. The higher the cost of the feedstock, in general, the higher the production cost of biodiesel. There are two different types of oil considering the origin:
    - Oil from seeds (further detailed in following chapters).
    - Recycled or Waste Oils and grease: Oils coming from a food cooking or a processing operation have high levels of impurities such as moisture and free fatty acids which can be found on these oils. So

additional operations must be carried out to remove these impurities. Specially, cooking and frying oil may contain some amount of waste vegetable oils (usually hydrogenated or partially hydrogenated so they act more like animal fats) as well as animal fats from cooking operations.

Commercially, recycled cooking oils are called yellow grease. The colour of the biodiesel obtained is normally darker, but the biodiesel can meet quality standards with an appropriate technology selection.

- Alcohol: methanol or ethanol. Further detailed in following chapters.
- Sub-products: Glycerine is the most commonly used commercial name in the world for products whose principal component is glycerol. Glycerine is a very versatile and valuable chemical substance; it is used mainly in the cosmetic industry but also in lower proportion in countless other products.

6.2. Oil from oilseeds

6.2.1. Types Of Oilseeds

It is extremely important to determine the type of oilseed to be used. This will determine the technology to be applied, and the alcohol, sub products, and final product obtained.

There are around 300 types of oilseed in nature, however in the market the most usually used for biodiesel production are the following ones:

- soybean (Glicine max):
- rape (Brassica napus)
- rice (Oriza sativa)
- sunflower (Helianthus annuus)
- peanut (Arachis hipogaea)
- castor (Ricinus communis)
- pinion (Jatropha curcas)
- avocado (Persea americana)
- coco (Cocos nucifera)
- palm (Elaeis guineensis)

The current vegetable oil being used in the EU is rape seed oil, while soybean seed is used in the US. These oils also have good low temperature flow characteristics. Therefore, the European studies generally focus on rapeseed methyl ester, while the US studies look at both rape and soy-based biodiesel. It is remarkable to point out that rape is being called canola in Canada.

6.2.2. Oilseed Election

For the election of oilseed some aspects must be taken under consideration:

- Free Fatty Acids (FFA)

  This is the amount of free fatty acids contained in the product. Fats and oils are compounds containing three fatty acids each chemically connected to oxygen on a glycerine molecule, called triglycerides. Free fatty acids are those structures that are no longer connected to the glycerine. They are a degradation product and a measure of the quality of the fat. A high quality fat has a low FFA level.

- Moisture, Insolubles, Unsaponifiables (MID)

  MID is a measure of the remaining compounds in the oil that are not fatty acids or triglycerides. Generally, the lower the MID level, the higher the quality of the oil and the easier it is to process it into biodiesel. It is considered a measure of quality.

- Suspended solids (SS)

  SS is defined as the dry weight percent of hexane insoluble materials retained on an lOO-micron filter. The lower suspended solids, the best quality.

- TITER

  This is the solidification point of the fat or oil (Celsius degrees), and it is a rough measure of the saturation level of the oil or fat. The higher the titer, the more saturated the fat or oil. Titer is an important characteristic, due to the fact that the highly saturated oils and fats make biodiesel to gel quicker in a fuel tank.

Therefore, the free fatty acids (%FFA), moisture (%MIU) and Suspended Solids (%SS) are important characteristics to be taken into account in the election of the oilseed, i.e. a typical value for soy seeds is 2.5% on FFA and 0.25 on %MIU.

Some oils samples can be seen in next table.

FROM OILSEEDS	SOYBEAN	RAPE	PALM	PEANUT
				
FROM RECYLED	**COOKING**	**ANIMAL FAT**		
				

Table 16- Oil samples. Source: Photos extracted from APPA-Asociación productores de Energías Renovables [6].

The benefits of biodiesel also depend on the type of oilseed used. There is a wide range of values from biodiesel net energy savings, oil savings and well-to-wheels GHG emission impacts from using biodiesel from different types of oilseeds. Some values are shown in the following table.

Estimates from Studies of Biodiesel from Oil-seed Crops

	Feedstock	Ethanol production efficiency (litres/tonne feedstock)	Fuel process energy efficiency (energy in/out)	Well-to-wheels GHG emissions, compared to base diesel vehicle (per km travelled)	
				Fraction of base vehicle	Percent reduction
GM *et al.*, 2002	rape	n/a	0.33	0.51	49%
Levington, 2000	rape	1.51	0.4	0.42	58%
Levelton, 1999	canola (rape)	n/a	n/a	0.49	51%
Altener, 1996	rape-*a*	1.13	0.55	0.44	56%
Altener, 1996	rape-*b*	1.32	0.41	0.34	66%
ETSU, 1996	rape	1.18	0.82	0.44	56%
Levy, 1993	rape-*a*	1.18	0.57	0.56	44%
Levy, 1993	rape-*b*	1.37	0.52	0.52	48%
Levelton, 1999	soy	n/a	n/a	0.37	63%

Note: Where a range of estimates is reported by a paper, "*a*" and "*b*" are shown in the feedstock column to reflect this.
n/a: not available.
Source: All studies from CONCAWE (2002), except GM *et al.* (2002), and Levelton (1999), cited directly.

Table 17- Estimates from studies of Biodiesel from Oil-seed crops. Source: Biofuel for transport, April 2004 [21]

According to figures, biodiesel from rape seeds can get a 66% reduction on GHG emissions compared to a base diesel vehicle per km travelled, and a 63% reduction can be obtained by using soybean seeds.

On the other hand, the production of biodiesel is not as extended as required. World biodiesel production and capacity in 2002 is shown in next table. As it can be seen, the EU is the biggest biodiesel producer in the world; whereas Spain is one of the EU countries where biodiesel production is lower.

Biodiesel Capacity, 2002 (million litres)	Biodiesel	
	Biodiesel production capacity[a]	**Typical use**
United States	70	blends <25%
Canada		
IEA North America	**70**	
Austria	32	blends <25%
Belgium	36	
Denmark	3	
France	386	mainly 5% blends
Germany	625	100% biodiesel; some blends
Italy	239	blends <25%
Spain	9	
Sweden	17	blends <25%
UK	6	
Other EU		
EU	**1 353**	
Poland	80	
IEA Europe	**1 433**	
IEA Pacific (just Australia)[b]		
Latin America (just Brazil)		
Asia (just China)		
World	**1 503**	

Table 18- Biodiesel capacity 2002. Source: IEA report Biofuel for transport and Self developed

6.2.3. Land Productivity

Typical yields by region and crop, based on litres per hectare of cropland, are shown on table below.

Typical Yields by Region and Crop, circa 2002
(litres per hectare of cropland)

	US	EU	Brazil	India
Biodiesel from:				
Sunflower seed		1 000		
Soybean	500	700		
Barley		1 100		
Rapeseed		1 200		

Sources: Averages estimated by IEA, based on 2000-2002 data and estimates from USDA (2003), EC-DG/Ag (2001, 2002), Cadu (2003), Johnson (2002), Macedo *et al.* (2003), Moreira (2002), Novem/Ecofys (2003).

Table 19- Typical yields by region and crop, circa 2002.
Source: Extracted from IEA for transport, April 2004 [21]

On the basis of these figures, it is estimated for the EU that meeting the 2010 EU target of 5. 75% about biofuel production would mean the occupation of the 4% and the 13% of total arable land of the EU-25 depending on the election of the crop and the technology development. Source: Peder Jensen (2003) extracted form Biofuels for Transport [21].

6.2.4. Economical aspects in oilseed production.

Oilseed agriculture for biodiesel production is often versus basic agriculture for food. Besides, there is a historical and traditional culture in most of the countries of the world to protect own crops to ensure the basic levels of food for the country, which will help not to depend on commodities prices and will keep the rural structure of the country healthy.

Thus, countries are doing efforts to adapt arable land to oilseed for the production of biodiesel. In fact, some governments, i.e. the US and the EU, are developing certain programmes to compensate farmers for set-aside land; besides, if this land could be used to grow crops for Biofuels in an eco-friendly manner that preserves this often sensitive land, then farmers would get subsidies targeted towards more productive activities. I.e. in EU, Common agricultural policy (CAP).

Good examples of these actions in the EU are the CAP policies. The CAP policies were created after the Second World War to ensure the basic agrarian productive sector in Europe. This sector was terribly damaged by the recent war and it was not able to provide cities with basic food. Because of that the EU took the increase of total production instead of the productivity of the sector as a main objective.

Later in time, when this situation was overcome, the CAP policies suffered two of the biggest reforms on their history, one in the 1990's, and another one in the 2000's. These reforms corrected the situation of excess of production which generated some side economical problems. This changed the CAP mentality, preferring a sustainable development target to one based just on productivity.

Nowadays, in the last year, a different type of compensation to farms came out. This is regulated in Europe by the (CE) 1782/2003 from the EU council, of the 29 September 2003. Then, farmers will receive some economic aid based on the area of land the farmer owns, without taking into account if this land is being cultivated or not.

Besides, to this minimum basic paid, farmers will receive different economic aids depending on the type of cultivation.

For energy crops, this aids mean 45 €/Ha and year, considering that all EU energy crops will not reach 1.500.000 Ha; in this case this value would be proportionality reduced by extra Ha added.

According to this, figures published by the Agronomic service ACOR, rape crops show that farmers will get around 150 €/ha for wet and dry lands, in Spain.

6.3. Evaluation of raw materials: methanol

6.3.1. Election of the Alcohol.

The alcohol to be used can be methanol or ethanol, and the election will modify some technology aspects.

On the alcohol election, there are some aspects to be taken into account, the most important of which is the cost:

- Cost of reaction: In organic chemistry, a basic alcohol rule stands that the shorter the carbon chain length is, the more reactive the alcohol. Therefore, methanol (CH_4) seems to be more used than ethanol (C_2H_8). Consequently, it takes 1.8 proportions of ethanol to produce 10 proportions of biodiesel versus 1.0 proportion of methanol to produce 10 proportions of biodiesel.

- Raw Material cost: Generally, but always depending on market fluctuations, the cost of methanol is about 35% - 50% of the cost of ethanol. Note than ethanol is also used for another Bioethanol.

- Recovery cost: Only 95% of the water of the ethanol can be distilled. The remaining 5% of the water has to be removed by other, more expensive mechanisms.

Other aspects are:

- Reliability of the supply: Both, methanol and ethanol, are used as building blocks on other chemicals such as solvents and fuels. This will impact their availability and obviously their price.

- Time for the supply: the closer the biodiesel plant location is to the alcohol supplier, the lower the transportation lasts, and this has an important influence on the time and the side risks.

6.3.2. Processing the alcohol.

The excess of alcohol can be recycled in the process or returned to the supplier for re-processing. These aspects may be considered when designing the plant.

Nowadays, current producers usually recover and purify their excess methanol. This is because the costs of returning the excess of alcohol used in the manufacturing of biodiesel to the supplier is very high, mainly for staging and for transporting it (by moving on public roads and railroads, the risk of accidental spill or explosion increases).

6.4. Evaluation of the by-products

6.4.1. Wash Water

The use of water in process is a must, but what to do with this wash water after the process becomes a problem for producers. In fact, over the past twenty years, environmental sensitivity has risen within the chemical process industry, and this has led to improved chemical process designs in order to become more energy efficient and cause a lesser pollution.

Consequently, wash water must be processed to become fat and grease free. This mainly can be done in two different ways:

- Sending wash water from the productive process directly to the sewer.

  This will become very costly, mainly, because most Public Owned Treatment Plants (POTPs) are charging some additional fees for wastewater treatment based upon Fats, Oils and Grease (FOG) and Biological Oxygen Demand (BOD).

- Sending wash water to a wastewater pre-treatment system.

  Initially, this means an important investment, but after a while, this becomes more cost effective. Nowadays, , there are different technologies available for wastewater pH control and for the removal of fats, oils and greases (FOG) in the market. This pre-treat wastewater is close to the factory so that they can also recover the used water.

6.4.2. Glycerine

Glycerine is the name given to a very high concentration of glycerol. This can be produced via a synthetic way or as a purified product recovered from triglycerides.

Glycerine can be obtained:

- From fats and oils during soap and fatty acid production and by transesterification, in biodiesel production.
- From petrochemical building blocks via several processing steps.

Nowadays, glycerine has many end uses. It is mainly used in cosmetics, personal care, drugs, toiletries, and food products. Also, glycerine is highly stable under typical storage conditions, and it also has no negative environmental effects.

There are different options for glycerine in a biodiesel process: to get a poor quality glycerine as a final normal product or to improve its quality and to get a high quality crude glycerine to sell in the crude glycerine market.

However, the answer to these options is not clear. The glycerine industry is very difficult to predict. This market does not wok as with the typical supply and demand behaviour, so it becomes hard to understand and to predict. Consequently, prices of crude glycerine are varying daily.

Currently, it is happening that the price of glycerine is getting lower and less predictable because of the increase of biodiesel production.

So, while most feasibility studies take positive credit for crude glycerine sales, it occurs that some factories producing biodiesel (specially small plants), so that glycerol is not of a high quality standard, are finding that they cannot sell it and they are being forced to give it away, mainly to farmers who would use it as a fertilizer or in other cases to pay disposal costs.

Therefore, a decision must be made: to produce a high quality glycerine crude to be sold or to be ready to pay for taking away poor quality glycerine from a biodiesel production process.

III THE IMPLEMENTATION

7. Evaluation of Execution alternatives

After the description given in previous chapters, where the biodiesel quality standards was described, as well as the different types of applied technology and the products and sub products of the process, it is time to describe how the producing plant should be built. So, this chapter will describe some different execution alternatives that may be used in the construction of a biodiesel plant.

7.1. Schedule

As usual, all projects need to be clearly planned. The success on the execution of the project directly depends on the plan and therefore on the execution of it.

As it is shown in the following graph, the key project phases and major activities are mainly: a feasibility study, a conceptual idea, a project definition, the design, the construction, and finally starting it all up.

Obviously, the duration of each phase will depend on how many resources and efforts are assigned to each phase.

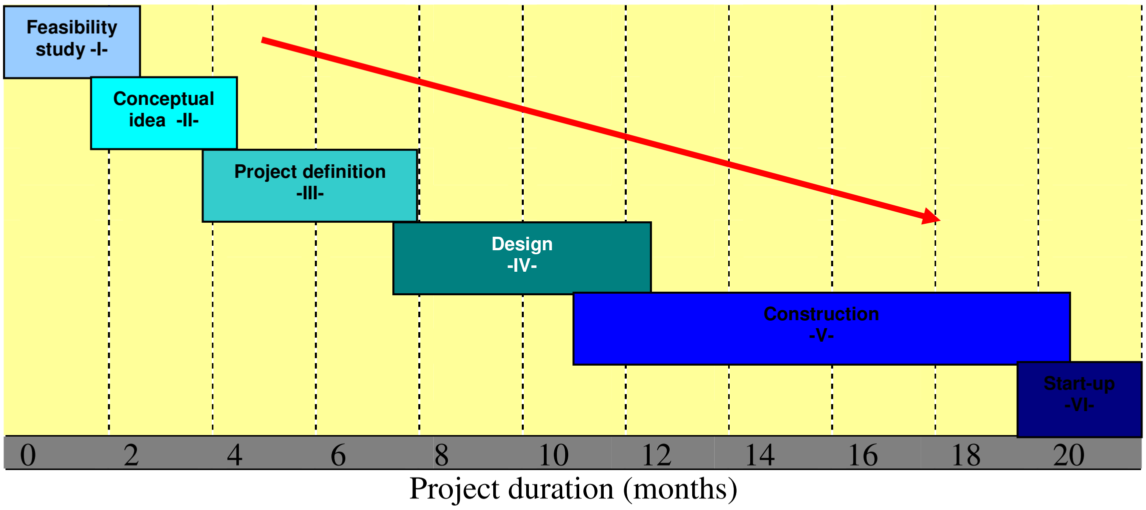


Table 20- Project duration in months. Source: Self developed.

I. Feasibility study.

In this part of the project the technical and economical feasibility is analysed.

This phase must take into account:

⇒ To initiate the feasibility study by defining the opportunity.

⇒ To develop and evaluate different technology options and select the right one.

⇒ To develop different supply chain options including products and sub-products.

⇒ To develop execution alternatives.

⇒ To develop basis for business.

⇒ To define funding strategy.

II. Conceptual idea.

To accomplish the business objective, the best approach to the conceptual idea must be considered. This phase must take into account:

⇒ To make an effort on defining the conceptual business idea.

⇒ To clearly define the technology option, the operation method and the supply chain which are going to be used.

⇒ To evaluate costs.

⇒ To put down an execution plan on schedule and to define milestones.

III. Project definition.

The basis for the design that will be used by the engineering contractor will be developed on the project definition. The details of the plan to be executed will also be defined. The project definition will set the basis to build the plant , so it is required to develop a detailed guideline for the design process. To reach this, it is important:

- ⇒ To develop a detailed scope.
- ⇒ To create the Project Execution Plan.
- ⇒ To prepare the basis for the design.

IV. Design.

Clearly, the project execution begins here. In this phase, the engineers from the Contractor Company start to design the details of the execution phase, then the team starts to build according to the design. To reach this, it is important:

- ⇒ To use resources on design management.
- ⇒ To define installations based on safety considerations. Due to the flammability of methyl and ethyl alcohol, and to the corrosive nature of the acids and bases, biodiesel plants are considered hazardous chemicals plants. Because of that, a safety zone must be designed to allow the emergency response forces and the security personnel access to the facility.
- ⇒ To access the equipment to build and to test.

V. Construction

The project executions mainly take place in this phase. So, engineers from the contractor company execute the plan following the detailed project design. To reach this, it is important:

- ⇒ To use resources on construction management.
- ⇒ To develop a detailed Start-Up plan, including a training plan.

VI. Start-Up

The execution project, finally ends in this phase. To reach this, it is important:

- ⇒ To define a Start-Up team
- ⇒ To execute the Start-Up details
- ⇒ To evaluate the final implantation of the detailed instructions
- ⇒ To evaluate the final performance of the factory and final capacity obtained.

7.2. Site location study

For the election of the site location, it must be taken into consideration mainly:

- The feedstock supply.
- The biodiesel distribution.

7.2.1. Feedstock Supply

As it was described in previous chapters, some factors around the feedstock supply vary in a wide range according to the different types of oilseeds used, the countries and the prices of the market.

Therefore, the location of the biodiesel plant is extremely important in order to reduce transports and costs. Due to this, most of the biodiesel facilities in the world are located near the feedstock source.

7.2.2. Biodiesel Distribution

Once, the biodiesel is produced according to the quality standards described in the previous chapters, the distribution phase appears as a big issue to be attended.

For sale and distribution, it is important to distinguish between pure biodiesel B100 or a blend.

For blends, in the Spanish market, the Order in council (RD) 1700/2003 must be take into account. In fact, the RD 1700/2003, art. 7.1, determines the level of blend that a biofuel can contain to be sold, so that values above those permitted cannot be marketed.

- Transport, storage and distribution.

  As it is known, every country has its own service of transportation and distribution of oil petrol products.

In Spain, there is a common logistic system for the transportation and distribution of oil petrol products. This system is formed by petrol ducts, refineries, and storage tanks. These resources are managed by a company named CLH (Compañía Logística de Hidrocarburos) which distributes around 85 % of all the diesel and the gasoline sold in Spain. The rest is distributed by minor companies.

Biofuel blends can be done by two different ways: by sending the biodiesel to refineries where the mix will be made, after which it will be distributed by CLH; or by sending the biodiesel directly to CLH tanks and doing the mix there. Nowadays, there is not a clear line to process these aspects but some work must be done to adapt CLH installations to the near biodiesel production.

- Selling biodiesel to customers.

Biodiesel is sold on petrol stations. However, nowadays there are just a few petrol stations within the EU, where the final customer can find biodiesel. A slight improvement of this situation occurs in the American petrol stations.

7.3. Plant components

In this chapter, main components of a biodiesel plant will be discussed. So, reactors, pumps, centrifuges and distilling columns are studied. Note that there is additional equipment which is also necessary for the production plant work but which is not important to describe as it is just a normal kind of equipment, such as tanks, ducts etc.

7.3.1. Reactors

In chemistry, following an English dictionary, “a Reactor is a large container, as a vat, for processes in which the substances involved undergo a chemical reaction. Due to this, the reactor is the only place where a chemical conversion occurs in a biodiesel plant”.

The Reactor must be designed to maximize net present value for the given reaction, then designers must make sure that the reaction proceeds with the highest efficiency towards the desired output, at the time of producing the highest yield of product while requiring the least amount of money to purchase and operate with them.

In reactors key process variables include the measurement of:

- volume (V), temperature (T), and pressure (P)
- residence time (τ, lower case Greek tau)
- concentrations of chemical species (C1, C2, C3, ... Cn)
- heat transfer coefficients (h, U)

There are three main basic models used as reactors:

- Batch reactor model.
- Continuous stirred-tank reactor model (CSTR)
- Plug flow reactor model (PFR)

A) Batch.

It is a discontinuous process reactor, in which all the reactants are loaded at once. Its is preferred because by leaving the reactant in the reactor for long periods of time, it is possible to get high conversion levels. However, it conveys the disadvantages of high labour costs per batch and also the difficulty of large scale production.

It is necessary to use external agitation to mix separate feeds initially and to enhance heat transfer, and so the reaction takes place.

Batch reactors are widely used by chemicals industries, because they have good flexibility in regards to reaction time and due to the types and quantities of reactions that can be performed. As a summary, the characteristics of a batch reactor include the total mass of each batch being fixed, each batch being a closed system, and the reaction time for all elements of fluid being the same.

B) Continuous stirred-tank reactor model (CSTR)

A CSTR model is a continuous reactor, in which one or more fluid reagents are introduced into the tank reactor equipped with an impeller while the reactor effluent is removed. The impeller stirs the reagents to ensure proper mixing by dividing the volume of the tank by the average volumetric flow rate on the residence time. Often, it is economically beneficial to operate several CSTRs in series or in parallel. It is economically useful in chemistry industries where high needs are required.

C) Plug flow reactor (PFR)

A PFR is a continuous reactor in which the fluid passes through in a coherent manner, this fluid is known as a plug, so that the residence time is the same for all fluid elements. It is assumed that as a plug flows through a PFR, the fluid is completely mixed in the radial direction but not in the axial direction, therefore, each plug of differential volume is considered as a separate entity as it flows down the tubular PFR.

Generally speaking, the most important aspects to be taken into account in a reactor are the conversion, which is the extent of reaction of the reactants; and the selectivity, which is the selectivity of the reaction of the desired products.

Current batch reactors have many positive features that are mixing characteristics, relative ease of handling homogeneous catalysts, and good flexibility with respect to reaction time. Due to this, as it was discussed earlier in the previous chapters, the reactor which is currently most used in biodiesel plants is the batch reactor. Note that batch reactors can be turned into a continuous mode by using multiple reaction vessels sequenced.

In the transesterification process, it must be taken into account that methanol, due to the fact that it is an alcohol that can easily become gas, and at the reaction it is in a liquid phase step, the pressure in the reactor must be maintained at a level that should keep the methanol in the liquid phase. To achieve this, as the reaction temperature is increased, the pressure must also be increased. Besides, it must be taken into consideration that to increase the conversion in a reactor is necessary to increase the time of the reaction; therefore for a given temperature, conversion is going to increase as the reaction time increases.

7.3.2. Pumps

According to an English dictionary, "a pump is an apparatus or machine for raising, driving, exhausting, or compressing fluids or gases by means of a piston, plunger, or a set of rotating vanes".

Nowadays, in the chemical industry, the most common type of pump which is being used is a centrifugal one.

It is basically built by a rotodynamic pump that uses a rotating impeller to increase the pressure of a fluid. Therefore, the fluid enters the pump impeller along or near the rotating axis and it is accelerated by the impeller. So, the fluid is flowing radially outwards into a diffuser, from where it exits into the downstream piping system. Due to this, centrifugal pumps are commonly used to move liquids through a piping system.

However, in biodiesel plants, the shear created by a centrifugal pump can create emulsion problems for the product stream from the biodiesel reactor. To sort this out, by using a positive displacement pump it is possible to reduce the amount of fluid shear imparted by the pump.

Nowadays, in the market there are several different types of positive displacement pumps including gear pumps and lobe pumps.

- Gear pumps can be external or internal. The difference between both of them is related to the teeth number and to the position in relation to the gears. Internal gear pumps have one larger gear with internal teeth and a smaller gear with external teeth; meanwhile external gear pumps have two gears with equal number of teeth located outside the gears.

  Basically, the liquid is moved by the action of being carried between the gear teeth followed by displacement as the teeth mesh.

- Lobe pumps in normal work time conditions have impart less shear to the fluid than gear pumps. In general, these pumps are best for handling fragile and high viscosity fluids at low pressures; this is mainly due to the fact that lobe pumps are designed for no contact with the fluid. On the other hand, for these reasons high amounts of slip can occur if the fluid has a low viscosity.

The election on the different types of pumps depends on different parts of the process and on the design engineers. By using the information given above some orientation can be obtained. However, some attention must be paid in terms of cavitation because in general, positive displacement pumps it is more difficult to cavitate than in centrifugal pumps.

7.3.3. Centrifuges

According to an English dictionary, "a centrifuge is an apparatus consisting essentially of a compartment spun about a central axis to separate contained materials of different specific gravities, or to separate colloidal particles suspended in a liquid".

Centrifuges are typically used to separate solids and liquids, but they can also be used to separate immiscible liquids of different densities, so this will be helpful in a biodiesel process. However the separation can also be made by a settling tank.

Centrifuges work using the sedimentation principle, where the centripetal acceleration is used to separate substances of greater and less density. Therefore the performance of a centrifuge depends on the characteristics of the mixture to be separated, but product quality specifications must be taken into consideration, in order not to damage the fluid by selecting wrong centrifugation speed. Besides, the centrifuge size has some important implications, e.g. higher viscosity fluids are more difficulty to handle.

7.3.4. Distillation

According to an English dictionary, “distillation is the purification or concentration of a substance, the obtaining of the essence or volatile properties contained in it, or the separation of one substance from another, by such a process”.

This is another way to separate chemicals in a fluid mixture, by exploiting the differences in boiling points between the chemicals. Therefore, this is useful in a biodiesel plant for sub-products recovery such as it happens with water and biodiesel according to what was described in previous chapters.

Distillation can be done by applications including both batch and continuous fractional, vacuum, azeotropic, extractive, and steam distillation. The degree of the separation that can be achieved depends on the relative volatilities of the chemicals to be separated, and also on the number of trays or the height of the packing, and finally on the reflux ratio.

7.4. Layout design

The layout design may vary in a wide range depending on many factors, but mainly on resources to be used and the availability of land. The main resources are:

- Plant Utilities.

  The cost and availability of these utilities can have an influence on the site location and the technology selection. While the exact amounts of each utility required will vary depending upon the size of the operation and the technology, it is a good idea to make sure the price availability, and capacity of each of these utilities. The following are the most common utilities needed for biodiesel production

  - Electricity-power for motors, controls, lighting, and HVAC.
  - Natural Gas and/ or Fuel Oil- fuel for boilers to generate steam.
  - Steam - generally low pressure for process heating and vacuum systems.

- Compressed Air- to operate control devices and controllers.
- Cooling/ Chilled water- cooling for process fluids and equipment.
- Wash Water- cleaning for separated fluids.
- Sewer- local municipality or plant pre-treatment for liquid discharges.
- Inter Gas (Nitrogen) – may be required for process storage tank blanketing.

- Transportation Facilities.

  The facilities for the reception of raw materials and shipment of finished product are a key component to any facility. Most plants will find tank truck to be the best choice, but rail or barge may be more economical. The design and layout for roads and railroad trucks, including the load out facilities, must provide adequate flexibility and expandability.

- Other Facilities.
  - Sewers for discharge of liquid waste.
  - Roads and rail track for access to the plant.
  - Steam, water, electric power availability to the site.
  - Fire protection equipment in the form of city fire mains and emergency equipment.
  - Fencing and security systems, including gates to accede the plant and for the security staff.

- A valid Plant Layout

  A good example of a layout of a biodiesel factory is shown in the figure below.

  These installations contain the items previously described. Planned works for the building of the biodiesel plant will include basically the following issues:

  - Building for offices and laboratory.
  - Building for process machinery and control, a small workshop will be allocated in this area.
  - Building for utilities: steam generation, nitrogen, compressed air…
  - Storage area: raw materials, sub-products, final products.
  - Loading and unloading area for trucks.

The plant could occupy about 23,850 m^2 . Roadways, parking areas and general services are included in this area.

Figure 11 shows the layout of a biodiesel plant, while figures 12 and 13 show some detailed parts.

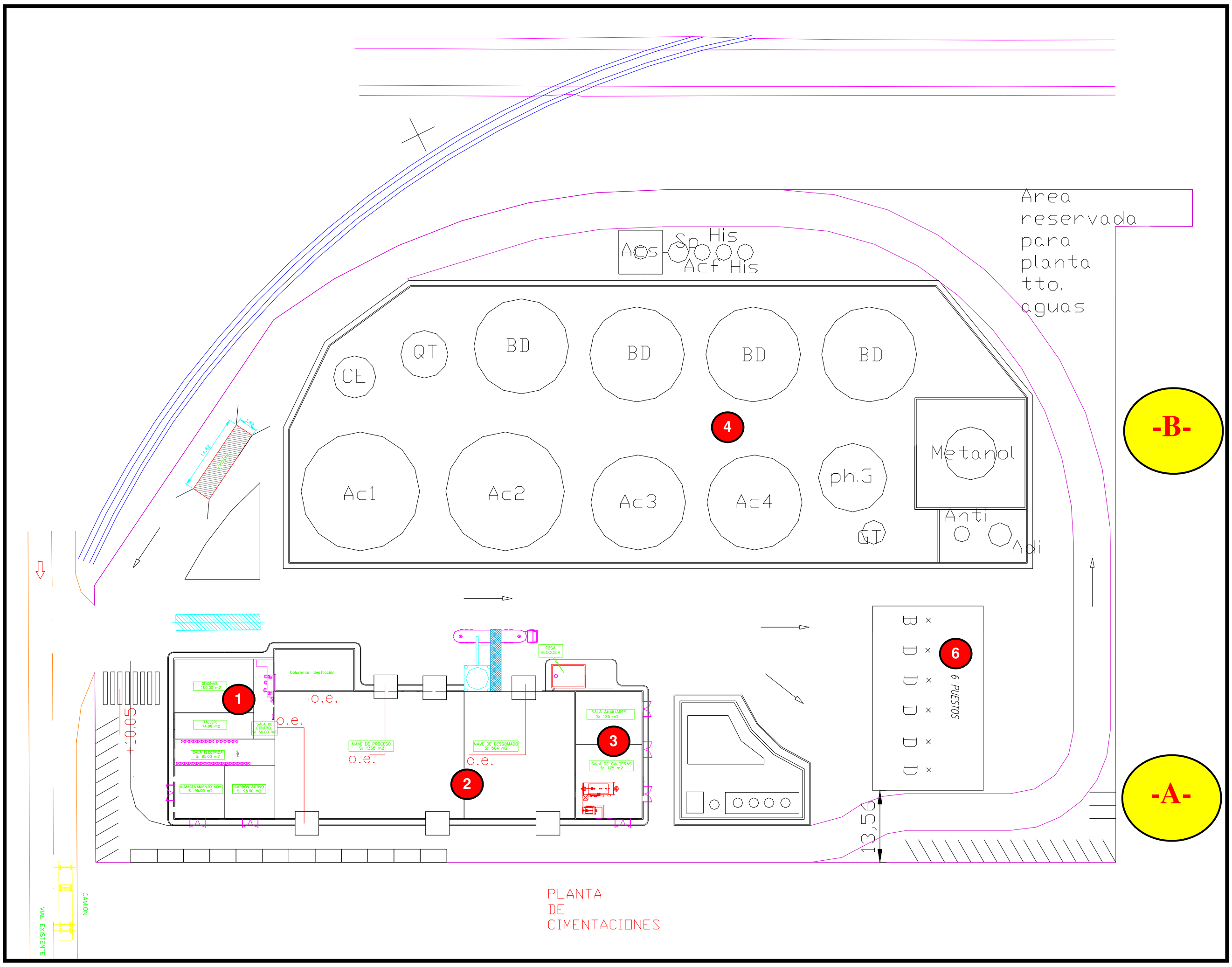


Figure 13- Layout of a biodiesel plant. Source: Self developed.

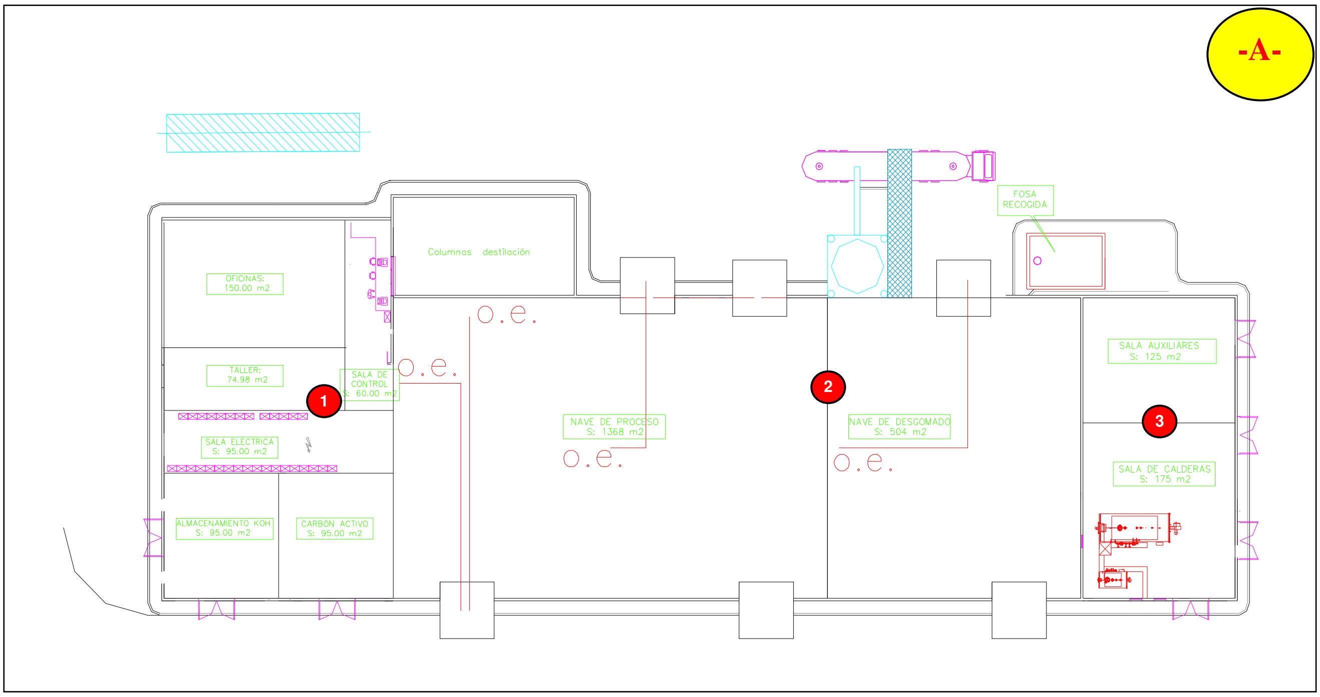


Figure 14- Detail of the layout of a biodiesel plant, part 1. Source: Self developed.

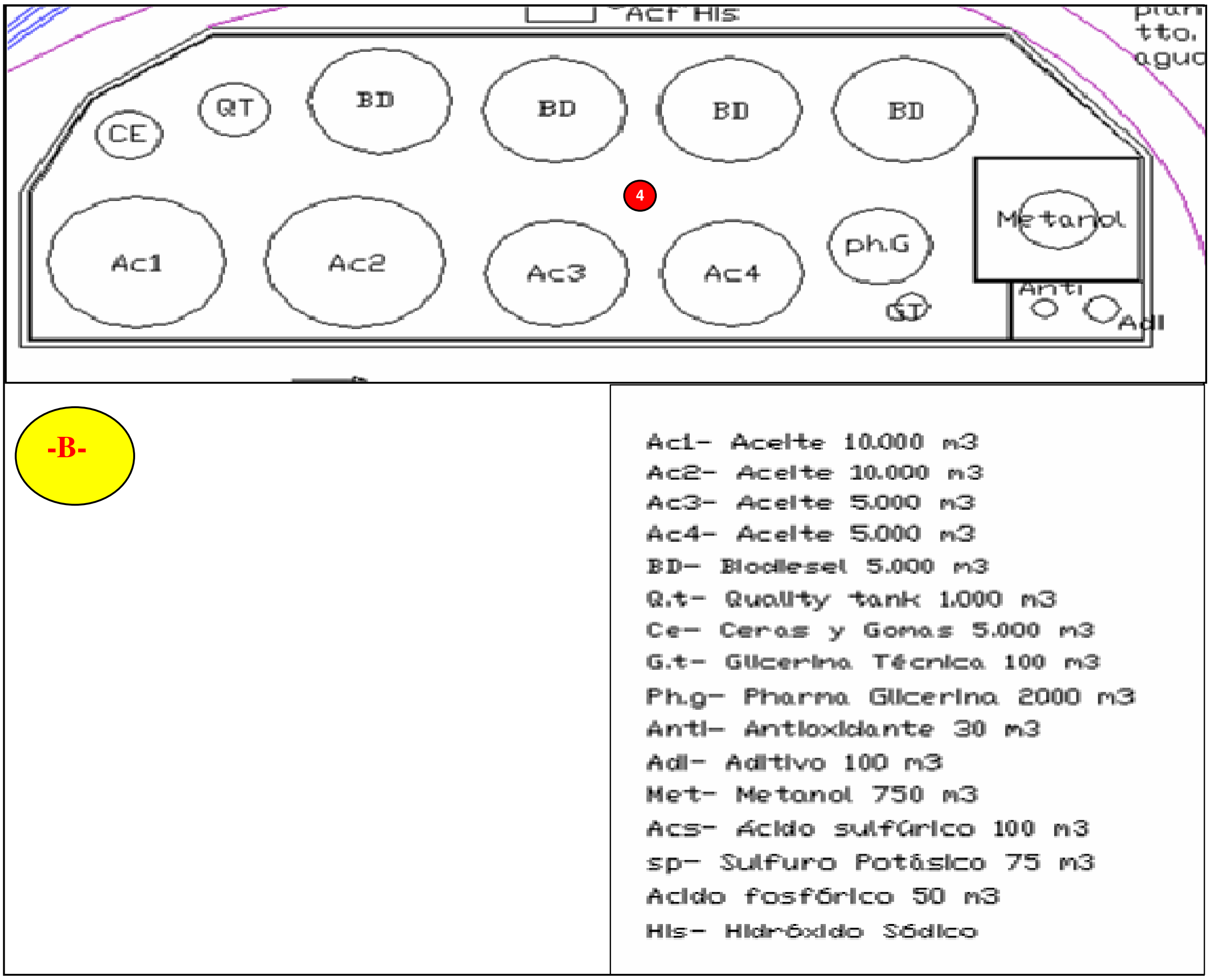


Figure 15- Detail of the layout of a biodiesel plant, part 2. Source: Self developed.

7.5. Other factors to be considered

7.5.1. External Impacts

Although a biodiesel production plant is one of the safest and least intrusive chemical operation facilities found in the chemical industry, it may happen that some people may not be supporting the idea of a near-by implantation. The most important reasons that may trouble the neighbours could be:

- Sound impact. In the process of a biodiesel plant many electric motors, pumps, control valves, blowers, and a huge different types of other equipment will be used. Besides, transportation equipment bringing in raw materials and taking finished product from the plant will also appear. All this devices cause a strong noise. Therefore, there will always be some sound impact attached to the installation of a biodiesel plant.

- Light Impact. There are a lot of lights in a biodiesel plants. In fact, it is very important to have well lit process areas, tanks, and parking areas to increase the employees and visitors safety.

- Odour Impacts: All chemical plants cause nasty smells. In the developed countries, odours must be monitored and they are often controlled by the government to guarantee healthy values for the population. It is difficult to describe the smell, but it goes from fresh baking bread to rotting fish.

7.5.2. Required Permits

The permits will depend and vary in every part of the country. Normally, biodiesel plants must fulfil some international agreements, states agreements, and local regulations. To fulfil all the required permissions it is an extremely important part of the project, so it is necessary to take some time and efforts to accomplish with all permissions before starting up on the schedule.

Some controls from the environmental point of view would address:

- To the water quality permits, measurements for quality and flow.
- To the storage tank design, registration and spill protection.
- To the waste treatment handling procedures.
- To the projected throughputs, ratings and capacity of equipment.
- To the odour emissions.
- To the projected smoke stack emissions.
- To the state fire marshal inspection

Some controls from the local permissions point of view would address:

- To the building permit.
- To the plant operating permit.
- To the POTW pre-treatment approval and discharge permit, or sewer permission.
- To the industrial waste disposal permit.
- To the boiler operating permit and license.
- To the environmental impact assessment.

8. Evaluation of Operating Plant Issues

8.1. Method Of Operating The Plant

To determine the method of operating the plant, the following factors must be taken into consideration: capacity of production, shift works, number of employees, and maintenance and several inspections.

- Capacity of production.

  Initially, the production volume should match the initial demand, but the capacity must be designed to make it easily possible in case a future spreading of the aforementioned capacity is needed due to an increase in the demand. For such a reason, it is important to design a process that could be easily spread in order to accomplish higher demands, and also to produce for the current demand at good economic production rates. As it was previously discussed the discontinuous batch process matches these requirements.

- Shift works.

  The production capacity depends on the operating schedule. Current biodiesel plants work by using a variable production schedule in order to match the plant production capacity to the demand.

  By using a discontinuous process, factories can be run on a 1, 2, or 3 shift or a 7 day-production schedule, depending on the demands.

- Number of employees.

  In much business all over the world, employee costs represent the highest annual costs in the final business administration annual audition. Due to this, it is necessary to evaluate the possibility of using a high technology process so highly automated plants that it requires as few employees as possible, always searching for higher skilled operators and mechanics; a low technology process which require complex operations, but lower skilled people so less cost salary can also be considered. Eventually a decision between the two models must be made. Holidays and seasonal weather changes must also be taken into consideration.

- Maintenance and several inspections.

  In addition to the whole production process, maintenance as a routine must be done to keep the equipment in optimum conditions. Besides, safety inspections on personal, standards and equipments are required in order to match local regulations and health, safety and security standards.

8.2. Start-Up

It is important to consider the following aspects:

- Start-Up team.

  It is necessary to employ a start-up team responsibility to design and to construct the biodiesel plant under the considerations described in this dissertation, including operating and maintenance standards.

- Employee Training.

  Training is an important issue to be dealt with a successful result. Therefore, the training responsibility should be established early in the project and a training Coordinator must coordinate trainers and trainees to allocate them on time for the training processes in order to run the factory in a satisfactory way.

  Training will be different depending on different positions and works. eg vendors, labours, engineers…

  It is highly important that the start-up team is involved in engineering training, due to the advanced technical knowledge required for engineering works and controls.

- Sales and Marketing Team.

  Nowadays, the sales and marketing staff is becoming perhaps the most important part on the biodiesel operation, because they are responsible to sell the output from the factory and to tell the production staff about next demands.

These days, some companies are hiring their own staff, while others are using existing biodiesel marketing companies to sell their fuel. In both cases, the success of the factory hardly depends on their performance.

- Safety.

  The current legislation force factories to have a high standard quality process in terms of Health, Safety and Security stands. Due to this, it is compulsory to select someone in charge for the adherence to process and personnel safety. This role must be identified and must be involved from the beginning of the project.

  Besides, due to the hazardous chemical materials involved in a biodiesel plant, some procedures are compulsory:

  - Analysis of all the systems and procedures must be completed under the Safety point of view. Safety training must be established to all worker prior to start-up.

  - All training process must include some safety aspects integrated into a specific programs.

  - Extreme precautions in the start-up process must be taken because of the fact that new equipment is being used.

- Quality Assurance

  The current market forces factories to have a high standard quality process in terms of biodiesel quality stands. Due to this, it is compulsory to select someone in charge of making sure that all the process need to guarantee quality. This role must be identified and must be involved from the beginning of the project.

  Moreover, this role must identify the needs on training people to work on factory, and also of those responsible for the test quality according to local regulations and standards test methods as seen in previous chapters, e.g. ASTM D 6751 test methods in the US.

It must also identify which analytical procedures will be performed by their own staff and which must be done by certified standard laboratories, e.g. Cetane Number.

9. Evaluation of Financial Plant & Plant Operating cost

9.1. Production costs

In IEA countries liquid biofuels production costs currently higher than the cost of petroleum fuels.

However, just to consider biodiesel price is not a reasonable way to measure biodiesel benefits. In fact, by increasing the use of Biofuels the global energy supply security can be improved, the greenhouse gas and pollutant emissions can be reduced, and also the rural economy can be improved. This is clearly understood by well developed countries which have established some policies to enhance biodiesel production by reducing local taxes, as it was early discussed in this dissertation.

In detail, research has shown that diesel prices typically range between $0.17 and $0.23 per litre, depending on world oil price. In opposition to biodiesel from rape seed oil via transesteritification process which range between $0.80 and $0.50 per litre in most of the production scenarios [21].Note that US dollars are considered in the present figures due to the fact that the petroleum market is referenced on this currency. Biodiesel saves about 10% of energy in relation to petroleum diesel fuel.

In the following paragraphs a deep analysis of biodiesel costs is shown.

Biodiesel production costs are highly dependent on feedstock prices, as it was discussed in previous chapters; this means a high percentage of inputs in the process.

An estimate on production costs can be made based on the technology and the type of the raw material used. According to figures from the IEA, production costs for 6 European biodiesel factories converted to diesel-equivalent litres, may vary from $0.80 to $0.35 per diesel-equivalent litre, considering that costs for production via continuous process are lower than for batch. Note that these cost estimates include, the value of side product sales, such as glycerine. More details are shown in table below.

Biodiesel Cost Estimates for Europe (US dollars per diesel-equivalent litre)			
Scenario	Rapeseed oil price	Conversion costs	Final cost
Small scale, high raw material price	0.60	0.20	0.80
Small scale, low raw material price	0.30	0.20	0.50
Large scale, high raw material price	0.60	0.05	0.65
Large scale, low raw material price	0.30	0.05	0.35

Source: IEA (2000d), with conversion to diesel-equivalent litres.

Table 21- Production costs for 6 European biodiesel factories converted to diesel-equivalent litres. Source: Extracted from IEA for transport, April 2004 [21]

Some important aspects must be considered on the production cost analysis.

- Production cost from oilseeds
    - In the US.

      Nowadays, in the US, biodiesel production relies mainly on soybean oil and production facilities are small scale sized.

      Thus, it is estimated that US biodiesel production costs range from about $0.48 to $0.73 per diesel-equivalent litre.

      This is based on soybean oil costs of $0.38 to $0.55 per litre of biodiesel, production costs in the range of $0.20 to $0.28 per litre, and a glycerol input of about $0.10 per litre [20].

    - In the EU.

      At the present time, in the EU, the biodiesel production relies mainly on rape oil, also production facilities are large scale sized.

      According to this, it is estimated that the current cost of producing biodiesel from rapeseed ranges from $0.35 to $0.65 per conventional diesel-equivalent litre of biodiesel. Important attention must be taken in the fact that these values could rise by an additional $0.10 if the price of glycerine falls [20].

- Production cost from recycled oils.

  The cost of the biodiesel output from recycled oils is lower than the one from oilseeds, due to the fact that the cost of the feedstock is lower. This could clearly lead biodiesel producers to prefer recycled oil plants, but there is a problem since the quantities of biodiesel from these sources are limited.

  Thus, the costs for biodiesel from recycled oils could be around $0.25 per litre, in cases where the feedstock is refined and free or it has a negative price, this happens when companies pay to remove waste oil from their installations. Or biodiesel cost could range from $0.30 to $0.40 per litre, in the rest of the cases, when additional processing before introducing it into the transesterification process is needed and it is produced in a typical small scale production plant [20].

- Glycerine cost.

  On one hand, glycerine is a key by-product for biodiesel that is widely used in several industrial process; on the other hand glycerine markets are limited. Thus, it could happen that for a large scale biodiesel production, an excess of glycerine in the market could cause that no customers were interested on paying for it and it would become non profitable.

  However, these days, glycerine is a valuable by-product of a biodiesel production plant. Assuming that glycerine is produced at a ratio of 1:10, the incoming of glycerine is in the order of $0.05-$0.10 per litre of biodiesel. E.g. in the glycerine case it is produced in a range of $500 to $1,000 per tonne [46].

- Cost by technology options.

  Nowadays, biodiesel production by means of a transesterification process is costly than diesel. Besides, on the market, new types of biodiesel technology are coming out and could be used for the production of biodiesel and also some types of synthetic biodiesel are developed. For example, hydrothermal upgrading (HTU) process and biomass gasification followed by Fischer-Tropsch conversion to synthetic diesel. But, again production costs are higher than with conventional diesel.

It is obvious that these prices would fall under scenarios of large scale production plants and technology improved process. However, in the long term, estimations show that crop prices could also become higher and glycerine cost could fall down. Thus, feasibility studies of biodiesel production costs are discussed on the basis of its price which will be higher than that of diesel. Note that current analysis are developed on the base that the biodiesel is produced in developed countries, however it could become cheaper in developing countries. No research is found on this basis due to the lack of data.

9.2. A Plant Operating Cost Example

All aspects described before in this dissertation, and those related to business administration must be considered. A typical Plant Operating Cost Worksheet is shown in the table below.

PRODUCT		UNITS		Average cost		Cost per litre
Feedstock						
	Seed prize		x		=	
	Transportation cost		x		=	
	Pre-treatment cost		x		=	
Total Feedstock cost						
Reactives						
	Methanol		x		=	
	Hydrochloric acid.		x		=	
Energy resources						
	Electric Power		x		=	
	Steam		x		=	
	Cooling Water		x		=	
Administration costs						
	Sales and Administration				=	
	Number of Employees		x		=	
Maintenance (% of capital cost/litre)			x		=	
Insurance (% of capital cost/litre)			x		=	
Cost before Interest, Depreciation & Glycerine Credit					=	
Crude Glycerine			x		=	
Cost per litre before Interest & Depreciation					=	
Interest & Depreciation					=	
Biodiesel Transportation Cost					=	
Total cost per litre					=	

Table 22- Plant Operating Cost Worksheet. Source: Self developed.

9.3. Financial Plan

A financial plan is required in any project. It must include the following key assumptions.

9.3.1. Market Considerations

The following aspects must been considered:

- Local, Regional, National and International Markets.
- Historic and Projected Markets.
- Customer Product and By-Product Specifications.
- Transportation Cost Analyses.
- Feedstock and Off-take Agreements.
- Retail, City, State and Government Fleets.

9.3.2. Financial Considerations

Nowadays, there are different options in the market. The most common ones are the following:

⇒ Equity financing: Equity funds can come from personal investment and outside investment, such as individual stockholders. This includes Venture Capital groups, which are usually shareholders, secured by share value and legal agreements.

⇒ Long-term debt financing: it is classified as a fixed income security. For this, it depends on terms which refer to the time for which the money, in a secured loan, is required and also the period over which the loan repayment is scheduled.

It must also be considered:

- State Subsidies.
- Expansion and Production Subsidies.
- Debt and Equity Options.
- Return on Investment Projections.

IV THE PLANT

10. The Plant- Case study

This case study aims to set up the concepts presented in this dissertation and to help investors to apply those figures to any specific idea they want to evaluate.

Therefore, this section applies the developed methodology to a real biodiesel production plant. Thus, some figures have been obtained directly from the source, while others have been calculated under estimations and rates discussed early in this dissertation. This way, on one hand the methodology will be tested, and on the other hand a real case study will be discussed.

10.1. Methodology

As described in chapter 2, the methodology is divided into four different parts: the IDEA, the DEFINITION process, the IMPLEMENTATION process, and the final result, the PLANT.

In the figure below extracted from section 2, the main steps on the methodology process are shown.

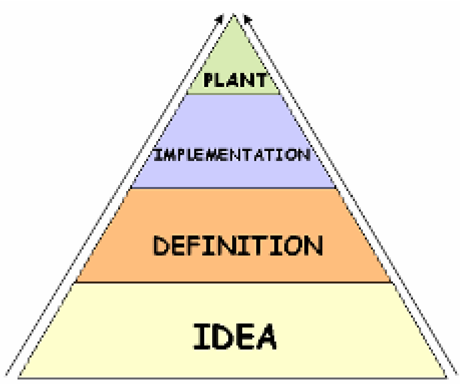
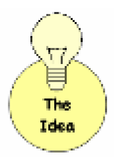


Figure 7- Main steps on methodology. Source: Self developed.

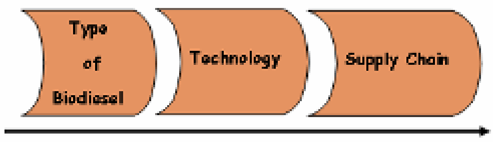
10.2. The idea



According to the figures shown in previous chapters, it is obvious that there is a potential high demand on biodiesel fuel. Besides, local governments are helping companies to develop biodiesel production plants and there is some biodiesel fuel taxes help to make it a competitive product for customers. Therefore, a feasibility analysis for the implementation of a biodiesel plant could be done.

On this base, EHN (Acciona Group) has developed a plant for the production of Biodiesel. This study is applied to this facility.

10.3. The definition



In this section, important decisions must be taken in order to identify the type of biodiesel related to the oil source, to evaluate the technology which should be applied, and to clearly identify the different supply chain issues. Further details are shown in next sections.

10.3.1. Type of Biodiesel

The Biodiesel obtained in this factory is produced from vegetable oil coming from oilseeds. This can come from non used crude and refined oils, such as sunflower, rapeseed, soy bean, palm, among other oils.

Fulfilling biodiesel standards is an essential issue which must be accomplished in order to be able to sell this product in the market. Due to this, EHN has developed some experience on biodiesel control quality before running this Caparroso's factory; in fact EHN has been producing biodiesel in an experimental laboratory since 2003.

Therefore, the Caparroso facilities match quality standards. Thus, this factory output complies with the twenty-six quality parameters required by the European standard EN 14214, and they also fulfil the Spanish law in Decree RD1700/2003.

10.3.2. Technology

The process of the biodiesel plant will pass through the following stages:

A) RECEIVING THE OIL

The oil received at the plant can be refined-oil, which is sent directly to the transesterification unit, or crude-oil , which must be pre-treated before the transesterification process begins.

Thus crude oil will pass through the following stages:

- Neutralising, to eliminate fatty acids.
- Whitening, to eliminate phosphates and colour pigments.
- De-waxing: to eliminate waxes.
    - First, the oil is neutralised to eliminate phosphates. For this, a different range of chemical products must be used, for which purpose a separation process and a centrifugal cleaning system are needed.
    - Second, the oil is whitened to eliminate the remains of phosphates, soap, and oil pigments. This will be done by filtration and by dragging the oil.

B) TRANSESTERIFICATION REACTION

Once the oil is in the transesterification unit, the transesterification reaction takes place. Thus, the refined oil reacts with methanol and it is converted into methyl ester. This reaction is started by using a catalyst.

After the reaction, two products are obtained: the methylester and the glycerine water.

The methylester is used to eliminate any remains of methanol, glycerine or catalyst of the mix, and after this is vacuum-dried to finally obtain biodiesel.

The glycerine water is conducted to a desalination column. There under an evaporation effect, the methanol is recovered and it is re-circulated into the process. This water is sent to be evaporated in two evaporation stages, until the final product gets a 90% of glycerine content. Finally, glycerine is distilled and whited, by utilising active carbon, until pharmaceutical grade (99%) glycerine is obtained. This

Figure 16- A transterification reactor. Photo extracted from Infoenviro Caparroso plant report [22]

process is carried out in a double reverse-flow distillation column, and eventually in a filter to purify its colour and thus eliminating the pigment that could remain.

10.3.3. Supply Chain

A) RAW MATERIALS

According to the figures obtained from the Plant Report, the following raw materials are consumed in the process as it is shown in table below. Note the importance of water reaching more than 50% of tonnes of raw material required.

Raw materials	Tonnes /day	%
Vegetable oil	110	33.70%
Methanol	10	3.06%
Sodium methoxide	2.5	0.77%
Alkali 50%	2	0.61%
Hydrogen chloride 30%	1	0.31%
Phosphoric acid 80%	0.5	0.15%
Citric acid 50%	0.2	0.06%
Additives	0.2	0.06%
Water	200	61.27%

Table 23- Raw materials and tonnes per day. Source: Extracted from Infoenviro Caparroso plant report [22]

Note that it is necessary to use more than 33.000 Ha of oilseeds crops to reach the 110 tonnes per day required. This oil mainly comes from rape and sunflower seeds.

B) PRODUCTS

According to the figures obtained from the Plant Report, the following products are obtained in the process as it is shown in the table below. Note that this process has a high efficiency due to the fact that more than 90% of the final product is Biodiesel.

PRODUCTS	Tonnes /day	%
Pharmaceutical glycerine	9.4	8.18%
Glycerine 90	0.5	0.44%
Biodiesel	105	91.38%

Table 24- Products and tonnes per day. Source: Extracted from Infoenviro Caparroso plant report [22]

10.4. The implementation

10.4.1. Execution Alternatives

A) SITE LOCATION STUDY

Caparroso is a small town, 2,602 inhabitants in 2006, situated in Navarre in the North of Spain. It is very well road connected just at 56 Km from Pamplona (the local capital).

Figure 17- Caparroso view.

Caparroso has always been an agriculture village. Lately, it is becoming of industrial interest because of the new Industrial Park. Hence, some multinational companies are setting activities there as it is the case of Rockwool or EHN (Acciona Energy Group) which is the one who promoted the biodiesel plant discussed in this chapter.

In the figure, the Caparroso village is shown; note the importance of the River Aragón which supplies water for population needs, and agriculture and industrial requirements.

B) PLANT COMPONENTS

In the following figures, the transesterification plant, and the oil refining and the distillation glycerine plants are shown. In those photos, details from main important components are shown. Note that those are installed in the same building, and it is formed by two modules of metal structures 30x10 m and 20x10 m in size, respectively, and both 20m height.

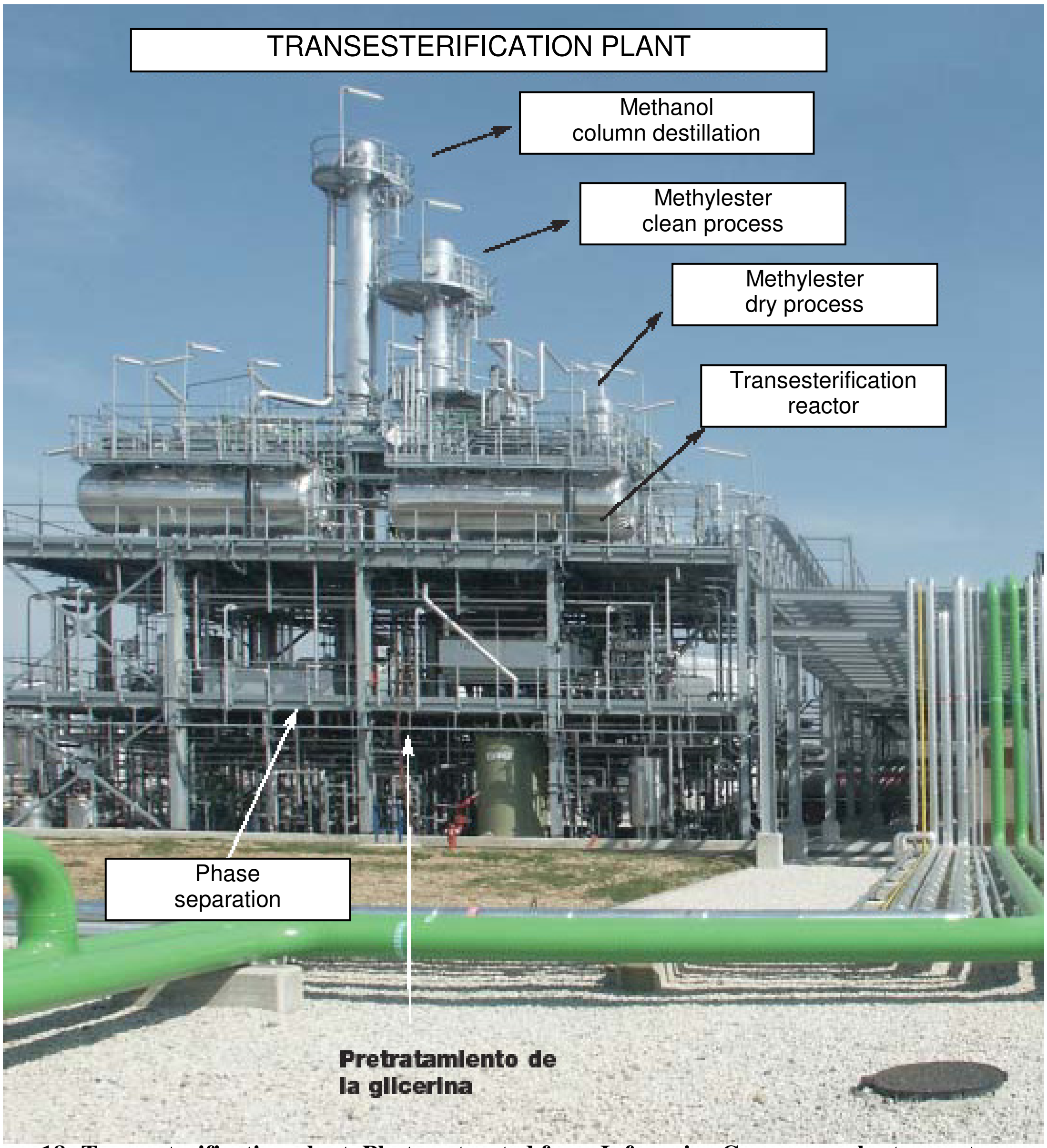


Figure 18- Transesterification plant. Photo extracted from Infoenviro Caparroso plant report [22]

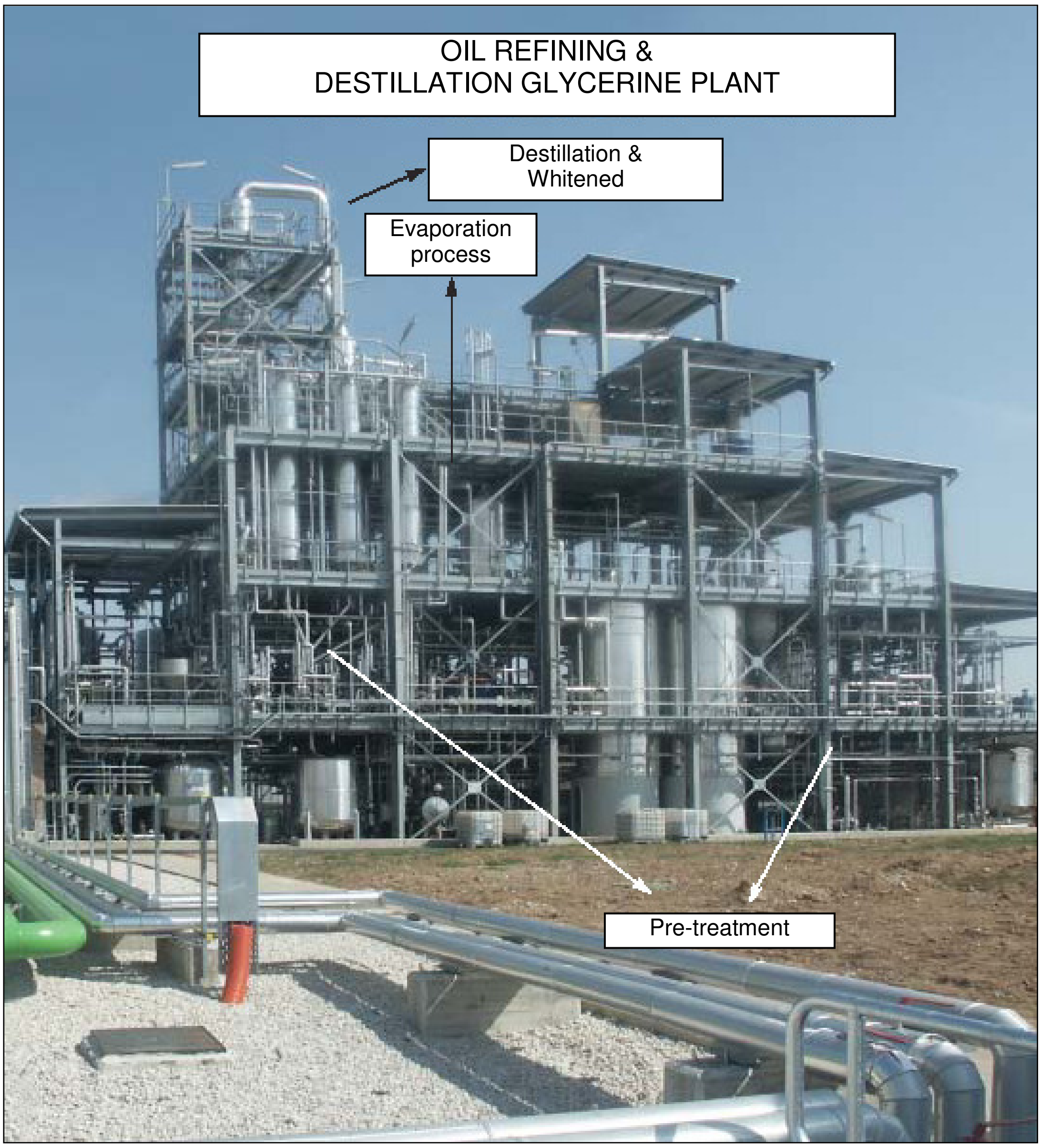


Figure 19- Oil refining & distillation glycerine plant. Photo extracted from Infoenviro Caparroso plant report [22]

C) STORAGE TANKS

On the store tanks, as it is shown in the figure on the right and also in table below, the raw materials, various components and end products are stored. There is a total of thirty-five storage tanks installed, nine of which are destined for oil, eight for biodiesel, six for glycerine and the rest for other required materials; half of the total capacity is used to store crude and refined oil, and three quarter parts are used for storing biodiesel. The rest is used for other products.

Figure 20- Storage tanks. Photo extracted from Infoenviro Caparroso plant report

These tanks have the following capacity:

TANK	CAPACITY (m3)	%
Crude and refined oil	6000	52.63%
Biodiesel	4500	39.47%
Methanol	200	1.75%
Methoxide	40	0.35%
Glycerine	300	2.63%
Chemical reactive agents (alkali, phosphoric acid and hydrogen chloride)	70	0.61%
Soapy paste and fatty residue	250	2.19%
Additives	40	0.35%

Table 25- Deposit tanks. Source: Extracted from Infoenviro Caparroso plant report [22]

D) LAYOUT DESIGN

The Caparroso plant is different from other typical factories due to the fact that there are two truck-tank loaders installed.

Thus, the main unit is used to unload oil, methanol, methoxide and additives and after that to load the biodiesel produced. The other unit is used to load glycerine and other by-products and, after the process, to unload the chemical reactive required.

It is also important to note that the plant has the following auxiliary sections:

- Water treatment plant: this is used for the processing of water and also for wastewater purification.
- Medium-voltage transformer plant, and low-voltage power transmission station.
- Steam-raising system.
- Compressed-air production system, and nitrogen distribution network.
- Fire detection and extinguisher system.

10.4.2. Operating Plant Issues

According to the figures obtained from the Plant Report, the plant will operate 8,016 hours/year; being able in full operation to produce 35,000 tonnes/year of biodiesel and 3,100 tonnes/year of pharmaceutical-grade glycerine.

10.4.3. Financial Plant & Plant Operating Cost

According to the figures obtained from the Plant Report, the plant involves an investment of 25 million Euro.

A valid financial plan for this €25 million could be carried out thorough different options, equity financing or long-term debt financing at different rates.

According to this, it is estimated that the current costs of producing biodiesel from rapeseed ranges from $0.35 to $0.65 per conventional diesel-equivalent litre of biodiesel. Also, assuming that glycerine is produced at a ratio of 1:10 biodiesel, the incoming of glycerine is on the order of $0.05-$0.10 per litre of biodiesel produced [46].

10.5. The plant

As a result, the plant submits to the following issues:

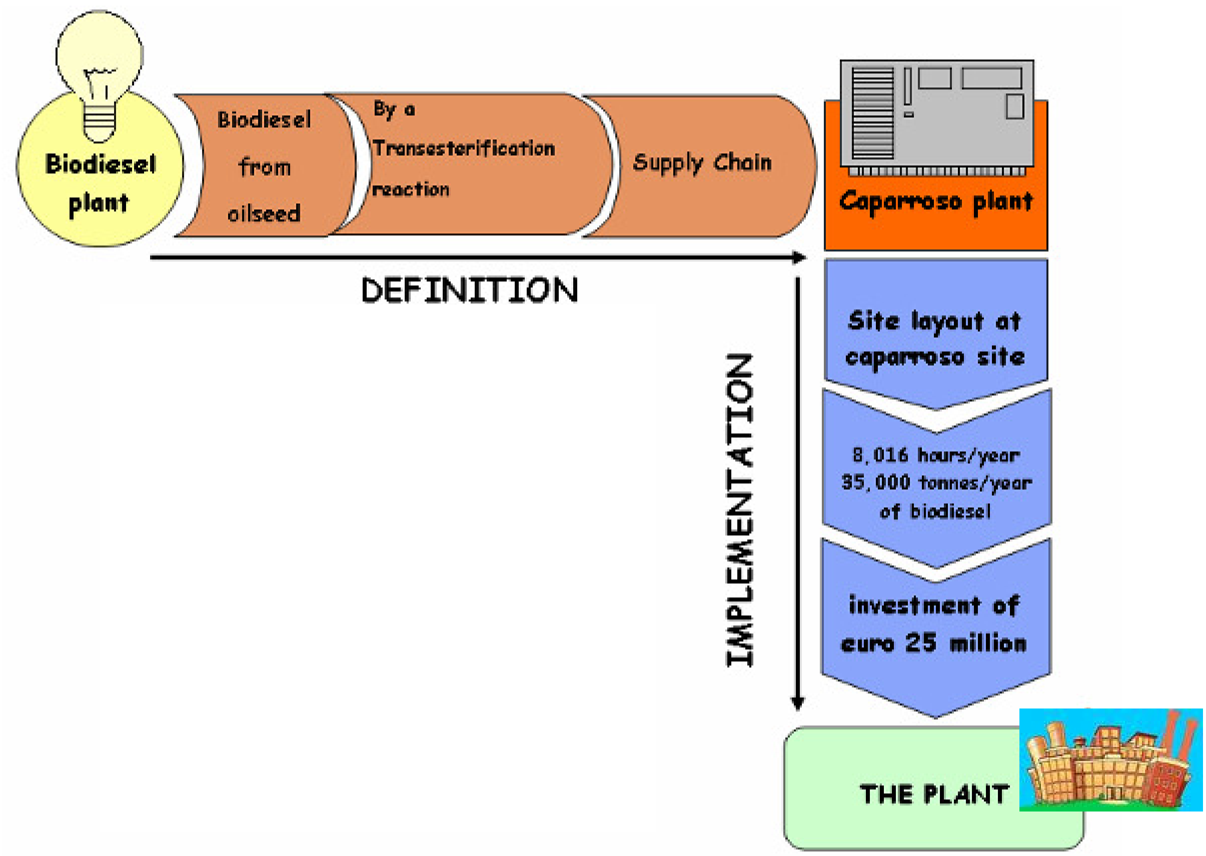


Figure 21- Methodology flowchart for Caparroso plant. Source: Self developed.

11. Conclusions

As it has been presented on this thesis, there is an urgent need to reduce petroleum dependency. Countries all over the world, are developing strategies to help the biodiesel market grow. Special attention must be paid to the EU directive 2003/30/CE to reduce petroleum dependency in the transport sector, in which the EU countries have proposed to use the 5.75% of biofuel in transport at 2010 and 8% at 2020.

On this dissertation, it has been shown that the production of biodiesel from oilseeds can be successfully carried out, but only after having taken into consideration all the technical, social and economical aspects.

- From the technical point of view, nowadays some technologies are available in the market, but the most widely used are large scale factories producing via a transesterification process. Some improvements are under studies, but previsions are that the technology will not be able to reduce in a significant range biodiesel production costs due to the fact that they are highly dependent on feedstock prices; also the efficiency of the production process is around 70% for biodiesel production plants in comparison to 90% in diesel petroleum facilities.

- Looking at the social aspect, it is shown that biodiesel coming from vegetable oils contributes in a significant way to the sustainable power provision, and to reduce the dependency of petroleum; to increase the security and diversity in the provisions; and to increase the socioeconomic development of the rural area, and thus the conservation of local environments.

- From the economical point of view, at least in IEA countries the liquid biofuels production costs are around three times higher than the cost of petroleum fuels. No data has been found for any IEA countries. Current diesel prices range between $0.17 and $0.23 per litre, in opposition to biodiesel from rape seed oil via transesteritification process which range between $0.80 and $0.50 per litre.

The following figure shows that the biodiesel production is more costly than the petrol diesel production. However, biodiesel has other many benefits that are considered in other non-economic issues, and which have been previously debated on this dissertation. All these aspects have been clearly understood by developed countries and different policies to enhance biodiesel production have came out.

As a conclusion, it appears clearly that the desired growth of biodiesel in the world, especially in the EU, depends on a number of technological factors and economical aspects that deeply depend on the setting-up of adequate government measures to support the growth of biofuel production. i.e. taxes discounts.

12. Areas for Further Research

Some important areas for additional research into biodiesel are outlined below.

- Potential land required.

  Although, it has been discussed early in this dissertation, it is obvious that due to the high importance that feedstock has on the production of biodiesel; there is an important need to do much more research in this area. In particular, it is important to determine the potential land required, the distribution around the word, the competition with food crops, and eventually the different prices and market balance for a truly global analysis.

- Current Agricultural technology.

  Besides, current studies consider potential land required by current land production technology; no considerations under potential technology improvements are being taken, for example ethanol, electricity and feed grains from cellulose crops. So, opportunities for improving farmers and agricultural technology could make land more efficient and so get costs down.

- Agricultural Policy and Biofuels Production

  As it has already been discussed, most IEA countries, particularly in the EU, have complex agricultural policies. These policies have an impact on crop prices, agricultural subsidies, and the net social welfare, but this is not clearly understood yet.

  So, it is necessary to implement a clear EU Agricultural policy to really improve the production of biodiesel as a social development factor. Thus, there are already some subsidies that encourage farmers not to plant, thus not helping to keep crop price levels. With some variations, it will change into subsidies that encourage farmers to improve the production of crops for biodiesel.

- Benefits and costs of biodiesel.

  It seems obvious, that the production of biodiesel cannot be subsided for ever. Therefore, it is important to assess the real benefits and costs of biodiesel. These benefits have been considered in terms of economical considerations, but other benefits early discussed in this thesis, have been ignored up to now. Some research is required to exactly determine these benefits and their economical and social effects.

13. Glossary

Alcohols - A class of organic compounds of the general formula R-OH where R is any alkyl or substituted alkyl organic group. All alcohols contain the hydroxyl (-OH) group, which as the functional group determines the properties characteristic of the organic family. Common primary alcohols are:

ASTM: American Society for Testing and Materials (ASTM)

Azeotrope - A liquid mixture that is characterized by a constant minimum or maximum boiling point which is lower or higher than that of any of the components.

Biodiesel: n/ a fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats, designated by B100.

Biodiesel blend: n/ a blend of biodiesel fuel with petroleum-based diesel fuel. In the abbreviation, BXX, the XX represents the volume percentage of biodiesel fuel in the blend. For example, a fuel comprised of 20% biodiesel and 80% diesel is called B20.

Equity - Equity is typically generated from personal resources, financial institutions, and from investors. These funds are normally unsecured and have no registered claim on any of the assets of the business, freeing those up to be used as collateral for debt financing.

Esters - Esters are a family of organic compounds that are known as functional derivatives of carboxylic acids. The ester derivative is formed when the -OH (hydroxyl group) is replaced with a OR' (where R' is an alkyl or aryl organic).

FFA - Free Fatty Acid content of a feedstock.

Leverage - This is the relationship of debt financing to equity financing (leverage or debt-to-equity ratio). Some analysts may only wish to use long-term debt-to-equity rations. Lenders vary on what ration they wish to see, but may want a 1 to 1 ration for new businesses.

Long Term Debt - Long-term debt is classified as a fixed income security. "Term" refers to the time for which money (a secured loan) is required and the period over which the loan repayment is scheduled.

Methyl Ester - A methyl ester is an organic compound (organic salt) that has a methyl group attached to the carboxyl carbon of a fatty acid.

Short Term Debt - Short-term loans usually take the form of operating term loans (less than one year) and revolving lines of credit.

Transesterification - class of organic chemical reactions that refers to the esterification of a fatty acid by an alcohol. The reaction is catalyzed by a strong acid or a strong base. Transesterification is an equilibrium reaction. The equilibrium is shifted to form esters by using a high excess of the alcohol.

Triglyceride - The organic classification of fats and oil.

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