Incentives for biodiesel – A European perspective

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Abstract

The share of biofuels in the transport sector is expanding in Europe with the introduction of policies on energy security and environmental protection. Biodiesel (FAME) is the most important biofuel in Europe but in the longer run its consumption is expected to decrease with the introduction of next generation biofuels. New technologies are investigated for the production of second generation biofuels e.g. hydrogenation of vegetable oils, biomass to liquids and pyrolysis of biomass with upgrading of biooils.

1. Introduction

In its report World Energy Outlook from 2006 the International Energy Agency (IEA) predicted that the world energy consumption will increase 50% by 2030 [1]. The total annual energy consumption of the world is presently around 12,000 Mtoe and has been estimated to increase up to more than 17,000 Mtoe by 2030 according to IEA's reference scenario [1]. The portion of EU25 is presently 15%. Even though the energy consumption will increase also in Europe, its share of the world energy use is expected to fall to 11% if no actions are taken.

The transport sector accounts for about 20–30% of the world's total energy consumption [2,3]. In the developed countries the road transport is by far the largest energy user and its share of the transport sector reaches values up to 85% [4]. The number of vehicles is expected to double by the year 2030 [2]. This will increase the energy consumption and CO₂ emissions [2,5]. Unfortunately, only industrialized countries can afford low-emission, modern transportation technologies, and the increase of vehicles in the developing countries will cause serious environmental problems [4].

The driving forces for the introduction of biofuels are energy security and air pollution which is related to climate change. Despite efforts to reduce the consumption of gasoline and diesel produced from fossil raw materials, these fuels are predicted still to be the dominant automotive fuels by 2030. Synthetic biofuels (so-called second generation biofuels) show better performance than traditional fuels. Therefore, the use of these fuels is expected to increase in the future. Synthetic biofuels will gradually replace first generation biofuels e.g. ethanol and vegetable oil esters. The main concerns with traditional biofuels are their sustainability and end-use problems [6,7].

It is expected that in 2030, depending on the policies adopted, alternative fuels will represent 10–30% of the share of transport fuels. However, for synthetic biofuels research is still being carried out to improve the production technologies.

Biofuels can be produced from different sources of biomass like cereal grains, sugar crops, starches, cellulosic material, oil seed-crops, algae and organic waste materials [8]. Several processes are used in the conversion of these raw materials to liquid transport fuels. These include the reaction of methanol with
vegetable oils to produce biodiesel, the hydrogenation of vegetable oils or the gasification of biomass followed by the Fischer-Tropsch synthesis (FT) to produce synthetic diesel, and the production of pyrolysis oil from biomass followed by upgrading to obtain fuels and chemicals. This presentation gives an overview of the policies implemented in the EU concerning biofuels, in particular biodiesel or synthetic diesel, and the existing production technologies. Furthermore, the properties of biodiesel and synthetic biodiesels are compared to conventional diesel.

2. European status

2.1. European policy and legislation

The European Community has long recognized the need to promote the use of alternative sources of energy. In addition to the driving forces mentioned earlier, i.e. energy security and air pollution, the development of a knowledge based industry creating jobs, economic growth, competitiveness and regional and rural development are factors playing an important role in the decision making [9]. The energy consumption in the EU has been higher than the domestic energy production and it is predicted that the EU will continue to depend on imported energy supplies, as presented in Figure 1 [10].

![Energy consumption and domestic energy production in EU25, 1990–2030](image)

Environmental protection including the reduction of green house gases plays an important role in the European energy policy. The amounts of CO₂ emissions coming from the use of fossil fuels are alarming and will continue to increase if no measures are taken. The White Paper "European transport policy for 2010: time to decide" from 2001 expected CO₂ emissions from transport to rise by 50% between 1990 and 2010 [7]. The main sources of CO₂ emissions in EU25 from 1990 to 2030 are presented in Table 1 [10]. Electricity and transport are the major contributors to the total CO₂ released to the atmosphere.
Table 1. CO₂ emissions in EU25, 1990–2030 [10].

<table>
<thead>
<tr>
<th>Year</th>
<th>CO₂ emissions (Mt)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1990</td>
</tr>
<tr>
<td>Source</td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td>1200</td>
</tr>
<tr>
<td>Transport</td>
<td>850</td>
</tr>
<tr>
<td>Industry</td>
<td>700</td>
</tr>
<tr>
<td>Households</td>
<td>510</td>
</tr>
<tr>
<td>Energy</td>
<td>150</td>
</tr>
<tr>
<td>Tertiary</td>
<td>200</td>
</tr>
<tr>
<td>Total</td>
<td>3610</td>
</tr>
</tbody>
</table>

EU efforts also focus on the reduction of energy consumption. The Green Paper on Energy Efficiency (2005) proposes a 20% reduction from the present level by 2020 [11]. In 2006 the member states were required to draw up a national plan on energy saving, supply and distribution of electricity, natural gas, urban heating, and other energy products including transport fuels [12].

In the energy policy issued in January 2007 the European Commission proposed to reduce the GHG (green house gas) emissions in the EU by at least 20% by 2020. Furthermore, a binding target of 20% for renewable energy by 2020 was planned. This also included a binding minimum target for biofuels of 10%. In May 2007 the EU leaders committed themselves to the proposed policy and stated that the characteristics of the biofuel such as sustainability and availability of second generation biofuels should also be addressed. In January 2008 the Commission presented a new directive proposal on renewable energy [13]. The statements of the previous directive were reasserted and new renewable energy targets were set for the member states.

In 2003 the Directive on the promotion of the use of biofuels or other renewable fuels for transport was issued [14]. Already in that document the minimum proportion of biofuels and other renewables in all petrol and diesel for transport purposes, calculated on the basis of energy content, was set to 2% by the end of 2005 and 5.75% by the end of 2010. That directive also gave the definitions of various biofuels.

Despite the existing legislation on the promotion of biofuels for transportation purposes, the introduction of these fuels is slow and the indicative targets set by 2005 were not reached. For EU25 only an average share of 1% was achieved [9,15]. The share of biofuels strongly varied between countries as presented in Table 2. The largest consumers of biofuels in 2005 were Germany and Sweden.

Table 2. Use of biofuels in some EU countries in 2005 [9].

<table>
<thead>
<tr>
<th>Country</th>
<th>Share (%)</th>
<th>Country</th>
<th>Share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweden</td>
<td>2.2</td>
<td>Poland</td>
<td>0.48</td>
</tr>
<tr>
<td>Germany</td>
<td>3.8</td>
<td>UK</td>
<td>0.18</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>0.05</td>
<td>Finland</td>
<td>0.1</td>
</tr>
<tr>
<td>France</td>
<td>1.0</td>
<td>Malta</td>
<td>0.5</td>
</tr>
<tr>
<td>Spain</td>
<td>0.44</td>
<td>Total share in EU25</td>
<td>1.0</td>
</tr>
</tbody>
</table>

In 2007 the total consumption of biofuels in the EU was approximately 7.7 Mtoe representing 2.6% of the energy content of the road transport fuels [16]. Biodiesel (FAME, fatty acids methyl esters; definition from
the Directive 2003/30/EC [14]) is the most important biofuel for transport in Europe. In 2007 the EU production was 5.7 Mt for biodiesel and 1.7 Mm$^3$ for bioethanol. Germany is the largest producer of biodiesel in the EU followed by France, Italy and Austria. If the EU targets are met, the consumption of biofuels in 2010 will be 17.5 Mtoe. Even though the targets for biofuels have been decided, the debate continues. Especially the increase in food prices has raised strong questions concerning the effectiveness of biofuels in the fight to reduce greenhouse gases. It is to be seen whether the targets for the use of biofuels will be lowered or at least postponed.

2.2. European R&D on energy

2.2.1. Funding schemes in the EU

In the EU R&D funding is mainly channeled through the framework programmes managed by the Directorate General of Research. The overall amount of EU financial participation in the 7th Framework Programme for R&D (FP7) is € 50.521 billion for the whole seven year period (2007–2013). In FP7 the maximum funding for Energy Research (in the Cooperation Programme) is € 2.35 billion [17].

European Technology Platforms were a new concept in Europe from 2004 onwards for academy and industry research and innovation cooperation targeting more intensive economical growth of Europe than the R&D Framework Programmes were able to create. Since then forty European Technology Platforms have been formed, among them the European Biofuel Technology Platform, Road Technology Platform, Forest-based Sector Platform, Sustainable Chemistry Platform and Plants for the Future (“green” biotechnology) [18]. Six platforms have reached a Joint Technology Initiative status. These Initiatives are joint undertakings structured as legal entities and they are obliged to open calls independently from the Commission. One of them is Fuel Cells and Hydrogen Joint Technology Initiative (FCH JTI) [19].

Technology is vital for reaching energy and climate change objectives. Therefore the Commission presented the European Strategic Energy Technology Plan (SET Plan). Its main goal is to accelerate the development and implementation of these technologies [19]. One of the priorities is to analyze the bioenergy pathways which bring a significant contribution to the EU renewables and biofuels objectives, based on clear assumptions concerning feedstocks and policy framework.

2.2.2. European Biofuels Technology Platform

The Biofuels Research Advisory Council (BIOFRAC) was established by the Commission to make a concrete proposal for the establishment of a European Technology Platform for Biofuels. The mission of BIOFRAC was to develop a vision and outline strategy, with emphasis on RTD&D (research, technology, development & demonstration), to increase the production and use of biofuels in the EU. The Strategic Research Agenda and Strategy Deployment Document were launched in January 2008 [20].

The current debate in the Biofuels Technology Platform focuses on recent biofuels policy developments in the EU and its Member States, especially the 10% target for 2020, sustainability certification, the food versus fuel debate, and biofuels related calls in FP7.

2.2.3. European Institute of Innovation and Technology
The Strategic Energy Technology Plan [21] also recalls a new governance structure for Europe in the energy sector. Already in 2005 the idea of a new governance structure was under development. The European Institute of Innovation and Technology (EIT) was the first European initiative to integrate the three sides of the "Knowledge Triangle" (Higher Education, Research, and Business Innovation) and create a new governance and collaboration model between academy and industry and all relevant stakeholders. The EIT will be set up by several Knowledge and Innovation Communities (KICs), distributed all over Europe, carrying out their activities in strategic trans-disciplinary areas. The EIT Governing Board was elected in the Spring of 2008. The Governing Board will prepare the first call for proposals for the two or three KIC's on the target area apparently of Renewable Energy, Environment and ICT. A budget of € 308 million for the 2008–2013 period has been set up by the Commission [22].

3. Routes to biodiesel

Biodiesel is produced by the transesterification of vegetable oils such as rapeseed (mainly in the EU), soy bean (mainly in the US), palm oil or animal fats with methanol which is usually derived from fossil fuels. The process yields glycerol as byproduct. A better alternative to fossil methanol is to perform the transesterification with bioethanol to obtain ethyl esters. The biodiesel production can be homogeneous or heterogeneous depending on whether the catalyst used in the process is liquid or solid [23,24,25,26].

The chemical composition of the transesterification product differs depending on the raw material. Thus, the properties of the final product also differ and blends of several oils are needed to obtain an acceptable product [4]. The interest in precluding the use of food crops in the production of biodiesel is growing, and therefore jathropha, lignocellulosic and algal feedstocks are investigated as raw materials [27].

The biodiesel production in the EU is now moving from small plants to large scale production. This is the result of ongoing development and more experienced technology providers. There are a large number of plants either operational or planned throughout Europe. The main manufacturers of biodiesel in the EU are: Verbio AG, Cargill, Biopetrol, Gate, Saria Bio, Lurgi, AT Agrar-Technik and Petrotec from Germany, Diester Industrie and Axens from France, Ital green oil and Novaol from Italy, BDI from Austria, Desnmet Ballestra from Belgium, and Greenergy and D1 Oils from UK [16,28].

The main technical difficulty with homogeneous processes is the separation of the catalyst, and large amounts of waste waters are generated in the cleaning and separation of catalyst and products. Therefore, it is expected that these processes will be replaced with more environmentally friendly heterogeneous processes [25].

The advantage of the heterogeneous process for the production of biodiesel is that the separation of the catalyst is simple. Furthermore, the amount of waste water is smaller than for the conventional process [25]. Axens (entirely owned subsidiary of IFP) is leading the implementation of the heterogeneous production of biodiesel. This company has installed Esterfip-H units in France (2006) and Sweden (2007). Six units are reported to be under construction [28,29].

3.1. Applications of glycerol

The quantity and quality of the glycerol obtained as byproduct should be taken into consideration in the production of biodiesel. Glycerol is not suitable as a fuel component due to its water solubility, immiscibility
in hydrocarbons, and high viscosity. In addition to its multiple applications as a chemical, a possible fuel application of glycerol is its etherification with isobutene to produce mono-, di-, and triethers. These components have boiling points and octane numbers in the range of gasoline. Therefore, they can be used as oxygenates in gasoline [30]. It has been claimed that the addition of these ethers to diesel improves the cold properties, reduces emission of the particle matters (PM), and increases the economics of the biodiesel process [31,32].

4. Routes to synthetic biodiesel

Synthesis routes involving thermochemical processes are used in the production of biocomponents for diesel. A more appropriate name for the diesel obtained in this manner would be synthetic biodiesel. The thermochemical processes can be divided into three groups: vegetable oil hydrogenation, biomass to liquids (BTL), and pyrolysis of biomass [23,27].

4.1. Vegetable oil hydrogenation

Diesel components produced by the hydrogenation of vegetable oils can be considered as "one-and-a-half" generation biofuels, as these biocomponents have the high quality properties of second generation biofuels but are produced from first generation feedstocks [28]. The hydrogenation of the triglycerides gives a mixture of hydrocarbons without oxygenates, water, CO₂, CO and propane. This process has the advantage of avoiding the formation of glycerol as byproduct but the disadvantage of requiring H₂.

Two types of processes exist for the hydrogenation of triglycerides: stand-alone and co-processing. In the former, a separate plant is constructed for the hydrotreatment of vegetable oils. In the latter, the triglycerides are cofed to existing hydrotreating units in the oil refinery. This reduces the capital cost but also the fossil diesel capacity [33].

The leading companies in the hydrogenation of vegetable oils are Neste Oil (Finland), UOP (USA), Petrobras (Brazil), and ConocoPhillips (Ireland). In NExBTL developed by Neste Oil vegetable oil or animal fats are hydrotreated under high pressure. NExBTL diesel yields of 97–98 vol-% are obtained with a requirement of 2–3 wt-% H₂. UOP develops stand-alone and co-processing technologies for the processing of vegetable oils and greases. Their product, called “green diesel”, is fully deoxygenated paraffinic diesel. High diesel yields (> 98 vol-%) and quality of the product are obtained with a H₂ consumption of 0.8–2.9 wt-% [4,28,33].

The HBIO process developed by Petrobras converts mainly soy oil into a diesel component. The first stage of the process is the mixing of the vegetable oil with fossil oil. This is followed by the hydrotreatment at high temperature and H₂ pressure in the distillate hydrotreaters. Yields of more than 95 vol-% are reported with only low amounts of propane as byproduct. ConocoPhillips began the commercial production of synthetic diesel using hydrotreatment technology in 2006 [23,28,34].

4.2. Biomass to liquids

In the biomass to liquid processes (BTL) the synthetic liquid fuel is produced form synthesis gas (syngas, a mixture of H₂ and CO). The FT synthesis converts syngas into liquid fuels and chemicals. The synthetic crude obtained is refined into diesel (also named syndiesel or Sundiesel) [27,28].
Different technologies are available for the gasification but entrained flow and fluid bed gasifiers are the most frequently used. Entrained gasifiers have the advantage of producing syngas with low concentrations of tars and hydrocarbons, while fluid bed gasifiers are used for CHP units where high calorific value gas is desired [28,35].

The gasification of biomass does not produce a syngas with the proper $H_2/CO$ molar ratio for efficient conversion in the FT process. Therefore, the water gas shift reaction is used to correct the molar ratio. Also, contaminants such as sulfur, tars, acidic gases such as HCl and $H_2S$, ammonia, and solids must be removed to avoid the poisoning of the FT catalyst. Several processes exist for the removal of contaminants and new technologies for the efficient removal of e.g. tars are under development [27,35].

Choren (Germany) developed a BTL technology called Carbo V. In this process slow pyrolysis of the feedstock (wood) is performed first to obtain solid char and gases. Both gas and char are fed to the gasifier. The oxidation of the gas provides the energy for the gasification of the char. The resulting syngas is free of char and contains low levels of methane. Choren uses Shell FT technology in the production of synthetic fuels. There are also other companies studying the gasification of biomass. FZK (Germany) and IFP (France) use wood or straw as raw material and Neste (Finland), UPM-Kymmene (Finland), and Gussing (Austria) use wood [28].

4.3. Pyrolysis for the production of liquid fuels

Fast pyrolysis of solid biomass performed at high temperatures in the absence of oxygen converts biomass into gas, vapour and char. The cooling and condensation of the vapours give a dark brown liquid (pyrolysis oil) that has half of the heating value of conventional fuel oil. The gas byproduct is burnt to provide heat needed for the pyrolysis process while the char is gasified to syngas. Pyrolysis increases the energy density of biomass; therefore the transportation of pyrolysis oils is more effective than that of solid biomass. This will become more important in the future when large amounts of biomass will be needed at the large scale biorefineries [27,35,36].

Pyrolysis oils are a mixture of hundreds of chemical compounds. They are difficult to use due to their high water content (up to 25 wt-%), acidity (pH 2.5), high viscosity, potential phase separation and high solid content (mainly char) [27,36]. Furthermore, the high concentration of oxygen containing compounds makes them thermally and chemically unstable [27,35]. These liquids are used in heat and power production or as fuel for fire boilers and furnaces [36]. The future applications of pyrolysis oil include its upgrading to transport fuels by hydrotreating. This upgrading technology requires a catalyst, high temperatures and $H_2$ pressure. It is a promising approach due to the economy of the pyrolysis process [28,35,36]. However, the processing of pyrolysis oil in the refinery units is expected to be feasible only in 5–10 years time because of the modifications and experience required to handle this feedstock [28].

Several companies commercially produce pyrolysis oil and have developed their own fast pyrolysis technologies, for example BTG (Belgium, rotating cone reactor), Dynamotive (Canada, bubbling fluid-bed reactor), FZK/Lurgi (Germany, twin screw reactor) and Ensyn (Canada). BIOeCon and Biomass Engineering are still developing the process. UOP (USA) and TNO (Austria, commercial cyclone dust filter) are developing pyrolysis as an alternative route to biofuels. They propose the upgrading of pyrolysis oil via catalytic hydrocracking before it is incorporated to the refinery unit [28,33].
5. Properties of biofuels

Biodiesel can be used in conventional diesel engines without significant modifications. However, the chemical composition of biodiesel is essentially different from the composition of conventional diesel. In Table 3, the properties of biodiesel are summarised and compared to the properties of other fuels [4,23].

The fuel properties of biodiesel such as density and cetane number are suitable for diesel engines. Therefore, biodiesel can be used as a blending component or as a neat fuel. However, there are some end-use problems especially at high concentration of biodiesel. Due to the end-use challenges, only 5% blends of biodiesel in conventional diesel are used in the EU [23].

Table 3. Properties of biodiesel, other biofuels, and conventional diesel [4,37,38,39].

<table>
<thead>
<tr>
<th>Diesel</th>
<th>Cetane number</th>
<th>Polyaromatics (wt-%)</th>
<th>Oxygen (wt-%)</th>
<th>Sulfur (ppm)</th>
<th>Density at 15 °C (kg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biodiesel</td>
<td>≈ 51</td>
<td>0</td>
<td>≈ 11</td>
<td>&lt; 10</td>
<td>≈ 0.885</td>
</tr>
<tr>
<td>NExBTL</td>
<td>84 – 99*</td>
<td>0</td>
<td>0</td>
<td>&lt; 10</td>
<td>0.775 – 0.785</td>
</tr>
<tr>
<td>GTL</td>
<td>≈ 73 – 81</td>
<td>0</td>
<td>0</td>
<td>&lt; 10</td>
<td>0.77 – 0.785</td>
</tr>
<tr>
<td>Green diesel</td>
<td>70 – 90</td>
<td>0</td>
<td>0</td>
<td>&lt; 2</td>
<td>0.78</td>
</tr>
<tr>
<td>Bio-DME</td>
<td>55 – 60</td>
<td>0</td>
<td>34.8</td>
<td>0</td>
<td>0.66**</td>
</tr>
<tr>
<td>EN590/2005 Diesel (summer)</td>
<td>≈ 53</td>
<td>≈ 4</td>
<td>0</td>
<td>&lt; 10</td>
<td>0.82 – 0.845</td>
</tr>
</tbody>
</table>

* Blending cetane number
** Relative gas density (15 °C/0.1 MPa)

Synthetic biodiesel produced from the hydrogenation of vegetable oils is a mixture of hydrocarbons. Therefore, it is an excellent blending component for conventional diesel and it is a high quality product with similar properties as FT diesel. Unlike biodiesel, synthetic biodiesel resists microbial attack and has excellent performance in cool climates. It also has a high cetane number (80–100) without any aromatic, sulfur and oxygen compounds. Its use gives low NOx, PM and CO emissions. Furthermore, the existing diesel engines do not need any modifications when using synthetic biodiesel. The high cetane number and low sulfur content of FT diesel allows refiners to blend it in all proportions with low quality fossil diesel (Table 3) [28,23].

6. Conclusions

Legislation plays an important role in accelerating the development and introduction of biofuels into the European market. The use of biofuels reduces the GHG emissions and the dependence on fossil fuels. However, the market share of biofuels is small and the targets set by the EU legislation are not yet met.

Biodiesel (FAME) is the most important biofuel in the EU. This first generation biofuel is produced via the transesterification of vegetable oils or animal fats with methanol. Extensive research is done on ways to improve this conventional process and the quality of the product. The use of feedstocks that compete with the food production and some end-use challenges associated with its use are the main disadvantage of biodiesel. Therefore, in the future first generation biodiesel is expected to be replaced by second generation biofuels.
Technologies are available for the production of biofuels via the hydrogenation of vegetable oils. The gasification of biomass to synthesis gas followed by the FT synthesis combines gasification and FT technologies which are already well known. The cleaning up of the synthesis gas before FT is still a challenge. The production of pyrolysis oil followed by the upgrading of these oils to transportation fuels is also a promising alternative for the future.

However, much more research is still required before the optimal solution for the sustainable production and use of biofuels can be defined.

References