Potential of Biofuels in the European Transition to Sustainable Energy

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Abstract

With the growing energetic uncertainty surrounding Europe and calls for a swift reduction of the European dependence on fossil fuels, it is important to look for sustainable alternatives that could replace these in an accelerated timeframe. For this task, biofuels have an essential advantage over most other renewable energy sources, in that it can make use of much of the existing energy infrastructure. For this reason, it could play an important role in the transition to a sustainable and energetically independent Europe. The main focus of this study is to review and compare the important biofuel synthesis processes which are applicable to the European region and to evaluate the possible extent, benefits and drawbacks of their expanded usage in the European Union. Results suggest that certain biofuels could have a big positive impact; however, while current production can still be successfully increased, scaling it to its potential can prove problematic until newer biofuel technologies mature.

Keywords: Biofuel, energy, Europe, sustainability.

Introduction

Biofuels are regenerable energy fuels derived from living matter – most commonly from plants, but also animals and microorganisms. Ethanol, commonly produced from fermenting starch or sugar crops; biodiesel, from vegetable oils; and biogas – are some of the usual biofuels produced today. The key advantage biofuels have over other sources of renewable energy is their similarity to the currently used fossil fuels. This enables them to be used as partial or full replacements of their fossil fuel counterparts without requiring in many cases any changes to the existing infrastructure. This outstanding quality of biofuels allows them to fill niches which no other renewable energy sources can, like being a short-term transition tool towards other green energy sources, like solar or wind, but also for the future where these have yet to provide viable alternatives, such as long-range aircraft or for use in on-demand secondary power sources in electric grids [1-6]. With the already ambitious but legally binding goals imposed by the Paris Agreement and the European Green Deal in place, international action plants, such as the ones presented by International Energy Agency (IEA) or the International Renewable Energy Agency, both highlight the importance of bioenergy for carbon neutrality with the former envisioning biofuels to represent close to 20% of the total energy supply by 2050 while the latter calls for a quintupling of global biofuel production by 2030 [7,8,9]. IEA also reports that countries should be doing more in the field of bioenergy, while other independent scientific groups such as climate tracker deem current efforts as 'critically insufficient' to tackle the climate crisis in fields where these technologies can have a big impact such as shipping and aviation [10,11].

One of the biggest impacts biofuels can have in the short term is in the transport sector. With the transport sector constituting over 25% of the total

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GHG emissions in Europe, potential for biofuels is great since other alternatives like electric or hybrid cars will take considerable time to replace the Internal Combustion Engine cars. In Europe, electric vehicles (EV's) currently represent only about 2.3% of the total passenger cars, and less than 0.1% of transport trucks while also having near exclusivity in the shipping and air transport sectors. Based on IEA predictions, Europe will have around 15-18% of personal cars be electric by 2030, with the figure standing at a lower 2-5% for heavy transport trucks [12,13].

Beyond these existing ambitious goals however, European energy policy has changed with the invasion of Ukraine and the energy crisis that follow such proposals like REPowerEU highlight the EU's aims of making Europe more energy independent by ending reliance on foreign gas and petrol imports and doing it quickly – with even more ambitious target for the renewable energy share, including the transport sector [14,15]. It is easy to see that Biofuels could have a great potential role to play in this plan as they can serve as a direct replacement to these fossil fuel imports. However, new revisions to the biofuel legislation from the European Commission seemingly make this more difficult, as now countries are limited to a maximum of 7% food crop-derived biofuel use in the transport sector, while also instituting a de facto ban on Palm oil and Soy based biofuels due to concerns regarding foreign Indirect Land Use Change risks associated with these imports [16]. While both could be important sources of biodiesel, previous studies have shown that in such cases where biofuel crops replace traditional food and feed crops, the carbon footprint of biofuels can be higher than that of traditional fossil fuels [17,18].

With advances in biofuel technology, they are currently categorized in four different types [19]:

- The first generation of biofuels encompasses fuels derived through fermentation or esterification from predominantly edible crops, rich in vegetable oils, sugars or starches.
- Second generation fuels use non-food sources such as the inedible lignocellulosic residues of crops and thus do not cause interference with food production.
- The third and fourth generations move away from crops towards algae biomass and genetically-engineered microorganisms respectively.

First generation biofuels have sparked many debates with varied opinions amongst scientists since these use up crops destined for food and feed and can detriment the global food security [20,21]. Currently, the war in Ukraine has destabilized both the European fuel and food markets – the former through the reduction in Russian gas and oil imports, and the latter through the Ukrainian crop production and distribution not working at full capacity [22-25]. As both nations were among the leading trade partners with Europe in their aforementioned categories, solutions to both issues are needed and the food vs fuel debate is only going to get more problematic [26].

This paper will analyse the first- and second-generation biofuels classified by the petrochemical they replace, then explore the emerging technologies of the third- and fourth generation biofuel methods separately.

Ethanol

It is produced extensively in the top 2 biofuel producers in the world, by the US from corn starch and in Brazil from the much more efficient sugar cane. The EU takes the third place in ethanol production, however, it only accounts for 7% of the global ethanol fuel production, much smaller than the US and Brazil, which combined produce 70% of the world's ethanol fuel [27].

The mechanisms through which bioethanol synthesis occurs are similar for all the feedstock. The key lies in microbial fermentation of the carbohydrates to ethanol. This is most straightforward for crops containing sugar, as fermentation by the yeast *Saccharomyces cerevisiae* is the only necessary step. This does not occur at maximum efficiency however, as only half of the glucose mass can be theoretically converted into ethanol, and in practice this is even lower due to the microorganism consumption of glucose for energy. For bioethanol fermentation from starch crops such as corn, the starch must first undergo hydrolysis into glucose syrup. This happens via enzymes produced by modified bacteria such as *α-amylase* by *Escherichia coli* or *glucoamylase* by molds like *Aspergillus niger*. Hydrolyzing more complex carbohydrates from lignocellulosic biomass into glucose is an even more complicated and expensive process, but possible with as high as 95% efficiency with proper physico-chemical pretreatment [27,28].

Ethanol is used in either specific ethanol engines which are better suited to combustion proprieties of ethanol, or in gasoline blends used by regular internal combustion engines. Ethanol also helps increase the octane number of the fuel, and can be used in regular engines in blends of even 15%. However, it has a substantially lower heat of combustion compared to regular gasoline, with only 60% of the gasoline's combustion energy density [1]. Currently the EU standards are E5 and E10 for 5% and 10% ethanol by volume respectively. All the gasoline sold in the member states has some portion ethanol as of 2020, with the average commercialized situated at 6.4% ethanol [29].

Currently the EU bioethanol production is comprised overwhelmingly from first generation origins – maize makes up 40% of the ethanol production, followed by sugar beet with 31% and wheat, rye and barley together accounting for another 27% (figure 1).

Sugar cane is the most efficient crop for ethanol fermentation as it has a very high yield of sugars per acre (figure 2). It also has a large amount of biomass production which can also be converted into ethanol with more advanced methods [30]. While it has been very successful in Brazil, the climate requirements make it unsuitable for large scale production in the European Union.

Maize is the world's most used crop for biofuel production, and in recent years it has also been the EU top feedstock for bioethanol production. In the US almost 94% of all bioethanol produced is fermented from maize, which translates to roughly 40% of the maize production of the US going towards ethanol fuel production [31].

The sugar beet is a sugar crop extensively cultivated in Europe due to suitable climate and is presently the second biggest source of bioethanol in the EU.

Other cereals also play an important role in biofuel synthesis, with wheat, rye and barley kernels accounting for over 27% of the bioethanol produced in the EU – despite their lower yield per hectare (figure 1) [32].

However, with Ukraine being also a large producer and exporter of cereals like maize, and wheat, it is believed that biofuel production will drop for these fuels as they will be prioritized for the food industry [32].

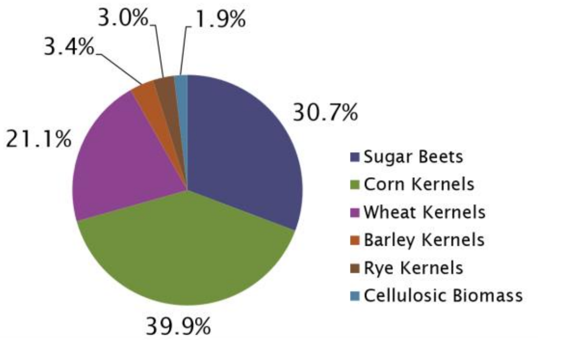

Figure 1. EU biodisel production by source [32]

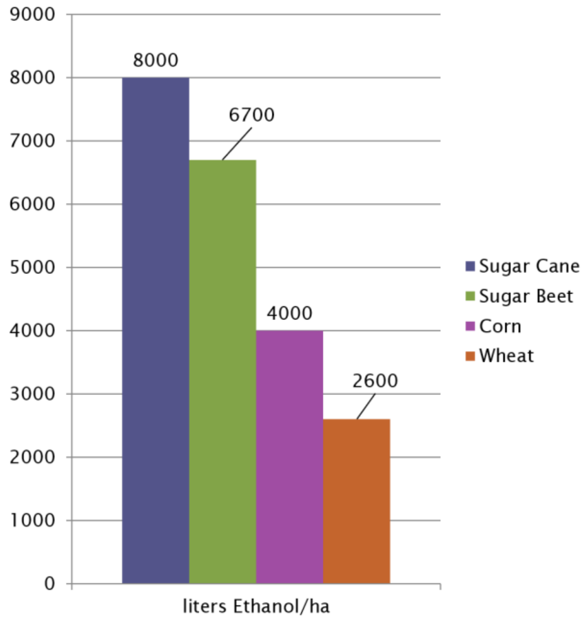

Figure 2. Ethanol yield for common crops [33,34]

The data clearly indicates that relying solely on first-generation bioethanol would be completely unsustainable. The amount of arable land needed to fulfil the EU's bioethanol demand far exceeds future availability and would have to come at the expense of indirect land use change which would be even more harmful to the environment [17,18].

Besides the starchy and sugary crops, bioethanol is also sourced from plant residue and biomass consisting of cellulose, hemicellulose and lignin through thermochemical and biological processes. This second generation of biofuels currently accounts for less than 2% of the total bioethanol produced, with the largest advanced bioethanol plant being situated in Romania and having a capacity of only 65 million litres a year [32]. This is partly due to the increased cost and complexity of these biofuel refineries which does not yet render them economically viable without subsidies. The available plant biomass in the EU far exceeds the necessary for biofuel production; estimated at over 400 million tons per year, using just 20% of that would in theory completely cover bioethanol need for E15 in EU. In practice this is a very hard task as it would equate to a 100-fold increase in cellulosic bioethanol production [35].

Biodiesel

Since ethanol has proprieties that would make it unsuitable for use in Diesel engines – such as the high-octane number – an alternative more similar to petrodiesel is needed.
Biodiesel synthesis occurs through trans-esterification. This is a process in which a triglyceride or complex fatty acid is turned into an alcohol ester, most often through addition of sodium methoxide. This process is needed in order to reduce the high viscosity of vegetable oils, which would make them unsuitable for use in diesel engines. [36, 37]
Blends of up to 20% biodiesel can thus be used with no modifications needed for even old engines. [2]
Biodiesel is used on a much larger scale than ethanol in the EU, who is also the world's leading producer of biodiesel, with almost 30% of the world's total production in 2022 – but having dropped in recent years as other countries increased their biodiesel production [38].
Petrodiesel also plays a bigger role in the EU transport sector compared to gasoline, as the Energy equivalent of diesel used is almost three times higher than that of gasoline [13]. Fact also showcased through the fact that the EU standards for biodiesel are B7 and B+, at 7% and 7%+ biodiesel by volume respectively, with the average situated at 8.2%, with biocomponents in all commercialized diesel [29].
Moreover, biodiesel also has the advantage of a 50% higher energy density in comparison to ethanol (albeit still smaller than regular petrodiesel, at only 80% of its energy density) [32].
Currently the biodiesel production in Europe originates as follows: the largest share (42%) comes from rapeseed oil – due to the suitable climate for cultivating it and the good output per hectare [32]; the other vegetable oils provide a lower percentage of the production, rapeseed being followed by palm oil (9%), soybean oil (5%) and sunflower oil (2%). Non-food sources are also very important for EU biodiesel production: used cooking oil accounts for 29% of total production, animal fats for 7% and other sources making up 6% of production (figure 3, figure 4).
Palm oil and soy fuels will no longer comply with the new EU regulation for biofuels sustainability. Due to them being predominantly imported, there were concerns about unsustainable practices and indirect land use change in the origin countries, such as deforestation in the Amazon Rainforest which would have grave environmental repercussions [32].
For crops such as rapeseed and soy, the EU's policy on genetically modified crops also renders them less competitive in comparison with other countries [39].
With Ukraine being the world's largest supplier of sunflower, the current conflict in the area is estimated to reduce sunflower oil supply and use in biofuels [32].

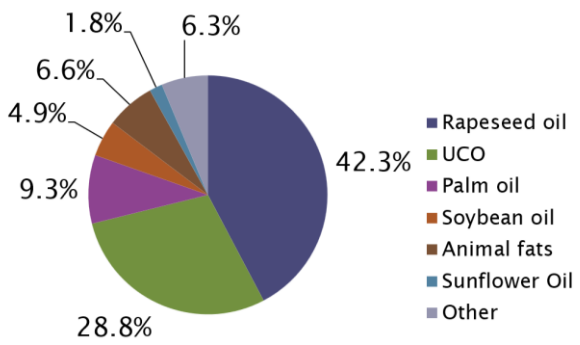

Figure 3. EU biodisel production by source [32]

Used cooking oil (UCO) is also a very important biodiesel source in Europe, accounting for 29% of the EU's biodiesel production. UCO imports have also been on the rise for the EU, with over 2 million tons to be imported in 2023. [32].
Domestic UCO collection from commercial sources is well developed in western Europe; Improvements in collection from other member states could increase total production by another 20%. Household UCO is however very undeveloped with only a handful of nations having any notable collection. while it only accounts for 6% of the total UCO collected in 2021, the potential is estimated to be much higher, on par with the ones from commercial sources.

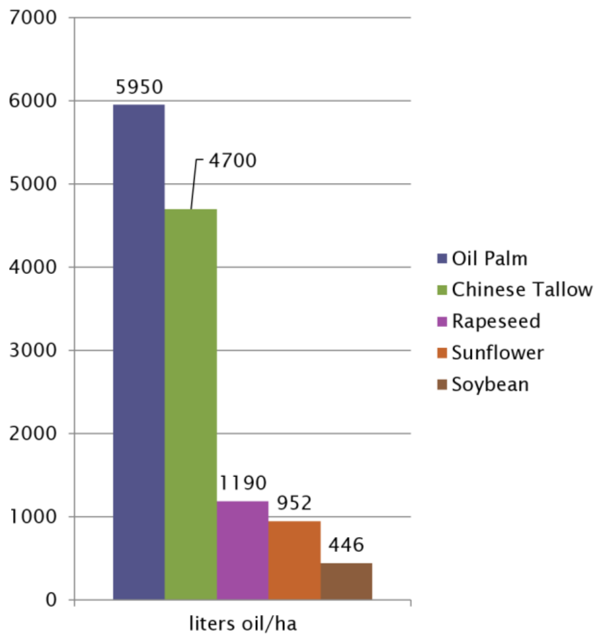

Figure 4. Oil yield for common crops [33,40]

This means there is large potential for greatly improving UCO collection in member states and thus also the Biodiesel production from used cooking oil. Thus, UCO collection could more than double if the potential was tapped, which would result in a total of 1.6 million tons available for biodiesel production. This would reduce reliance on foreign UCO imports and/or increase domestic biodiesel production [41].

Animal products, such as animal fat or wax are also important sources of biodiesel. A large part of animal fat is not fit for human consumption, and such can be used for biodiesel production without worrying about impact on food production. However, animal fats are highly saturated which in turn leads to a lower freezing point of the produced biodiesel. This, combined with the limited availability of the feedstock, means animal sources cannot be scaled to the required levels. But, while production from animal fats has remained relatively constant over the recent years, studies show that the production chain could be modernized to use newer processes for better efficiency and economic viability [37, 42].

Biogas

Biogas is the product of anaerobic digestion of methanogenic organisms. Its main components are methane (>50%), carbon dioxide (>25%), some nitrogen and trace amounts of other undesirable compounds. Renewable natural gas (RNG) is biogas that was processed and purified further so that it can be used in natural gas installations with no modifications required [43].

Methane is the second most important greenhouse gas, after only carbon dioxide. Not only is it the second most abundant, studies also consider it between 50 to 100 more times more potent than carbon dioxide on a 20-year timeframe. And much like carbon dioxide, it also has direct adverse health effects for humans [44].

Around 25% of the methane released into the atmosphere comes from ruminant animals and has the potential to be captured and turned into biogas or RNG [45].

Methane capture is not a new technology, and while it is already implemented in some of the farms of the EU, more progress could yet be made With data on EU cattle farms and cattle methane emissions it can be estimated that complete capture would displace over 10 million tons of methane emissions each year. Refining this into renewable natural gas would also replace 3.7% of the EU's natural gas consumption [46,47].

Using methanogenic bacteria directly in bioreactors is also an established route of biogas production. These can take in a wide variety of feedstock such as plant residues, manure or algal biomass – but crucially also other types of waste like municipal biomass or industrial waste. Methane bioreactors are an established technology undergoing rapid development, where recent developments in reactor monitoring and recent understanding of the microbial processes promise even more efficient and economic pathways for biogas production [48,49].

Third- and fourth generation biofuels

More advanced methods for biofuels also exist. Using microorganisms like algae for biofuel production has many great advantages. They do not compete with crops for land use, and they can also devote a much larger share of their energy towards production of biofuel or their precursors.

Third generation biofuels are produced from the biomass of microorganisms like algae. This can either be used for bioethanol production if the algae stockpile their energy reserves in the form of starch, or biodiesel for fat reserves – through the biochemical processes described earlier. Algae also have a great advantage because they can be grown in saltwater, which also makes them sustainable in regards to the limited global fresh water supply [19, 50, 51].

Fourth generation biofuels would consist of microorganisms bioengineered to produce biofuels more efficiently than the current available technologies.

However, the technologies for microorganism-derived biofuels are still developing, and while efforts to make them economically viable on the large scale are ongoing, studies have shown that while promising, they are not viable yet and cannot provide a short-term solution until the technologies matures [19].

Conclusions

Biofuels are thus sure a pivotal role in the European transition to sustainable energy, by filling niches that other renewables cannot.

First generation biofuels alone cannot sustain a high growth in biofuel production in an environmentally friendly and economically sound manner.

Second generation biofuels produced from lignocellulosic biomass are assessed as a good source of ethanol, however while they could in theory, cover current bioethanol needs entirely, the production would need to be substantially increased and subsidized for it to have a noticeable impact.

This paper has identified biodiesel as having the greatest potential to supplement petrol fuels due to the extensive use of diesel in the European transport network – but also due to the suitable production methods available locally – with used cooking oil providing a very economically and environmentally sound option and EU-grown rapeseed being able further supplement production. Here, the emphasis should be placed on increasing UCO collection from households in the member states.

Renewable natural gas would also be a worthwhile prospect, as it would both reduce the EU's methane emissions and decrease its need for foreign natural gas imports. Methane bioreactors are a promising area of active development and the modernization of farms to capture methane and turn it into biogas is already underway.

Third and fourth generation biofuel production methods are deemed to still be at their infancy and such do not provide any short-term prospects – but they should still be pursued for long term viability of biofuels.

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