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Review Article

The Biodiesel Dilemma: A Techno- and Socioeconomic Review of EU Legislative Actions

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Abstract

In terms of production capacities and economical relevance biodiesel is the most important transportation biofuel. In contrast to other biofuel options, biodiesel processes have recently experienced little technology development. The industrial standard is still the conversion of edible plant oils to fatty acids methyl ester (FAME) biodiesel. The use of edible plant oils, such as rape-seed and palm oil as feedstocks in these biodiesel processes results in a fierce food versus fuel debate and is associated with enhanced loss of arable land, water resources and biodiversity. Further, CO_2 emission profiles of the current processing technologies have not improved over the last decade. To counteract these developments governments have passed legislative measures to improve the sustainability of biodiesel production. Since the European Union (EU) is one of the largest global free trading zones and regards itself a leader in renewable technologies, this report focuses on the effects of EU legislative measures on bio-oil feedstock and conversion technology selection. Further, the effects on the current FAME biodiesel market and the global socio-economic impacts are discussed. The technology outlook presents emerging technologies that could significantly improve the sustainability of biodiesel production.

ABBREVIATIONS

CFPP: Cold Filter Plugging Point; CO_2: Carbon Dioxide; CO_2 (eq): Carbon Dioxide Equivalents; EC: European Commission; EU: European Union; FAME: Fatty Acid Methyl Ester; g: Grams; GHG: Green House Gas; LCA: Life Cycle Assessment; MJ: Mega Joule; MT: Metric Tons

INTRODUCTION

To enable a sustainable transport despite climate change issues and the eminent end of fossil resources, governments have passed well-intentioned legislation to promote renewable energy solutions. Primary measures to establish sustainable transport solutions involve wind- and solar energy, biogas and as well as first generation liquid biofuels such as biodiesel and fuels compatible alcohols (i.e. ethanol, butanol) [1]. These technologies are either already established on an industrial scale or are in a pre-development phase undergoing a rapid economical expansion. However, the global socioeconomic impact of 1st generation biofuels processes is severe as they are based on edible feedstocks such as starch and lipid containing plant biomass. Particularly, biodiesel production has experienced little technology advances over the past decade, as the chemical conversion of edible plant oils to fatty acid methyl ester (FAME) biodiesel remains the industry standard [2,3]. In addition enhanced redirection of water and land resources for production of energy carriers is counterintuitive in light a significant growth in world population [4]. These issues linked to renewable energy production have to be considered as key parameters in the construction of life cycle and greenhouse gas emission saving analysis, which are the basis for most legislative actions [4].

An active legislation based on conventional life cycle analysis parameters is the cross-border binding EU directive 2009/28/EC [5] on renewable energy. As the EU is the leading provider of renewable technologies and represents the largest global trading zone, its legislative framework for sustainability actions is a blueprint for other nations. However, current actions imposed by this EU directive lead to an indirect and possibly unintentional selection of certifiable feedstocks and processing methods without consideration of long term effects on biodiversity and land use [4]. These effects are most obvious in bio- diesel sector, which in the EU experiences the highest demand and growth rates of all first generation biofuels [6].

In terms of saving carbon dioxide equivalents, palm oil will likely be the preferred feedstock option to produce near future bio-based diesel [7]. However, the application of this feedstock will demand land use change in areas of high biodiversity such as tropical rainforests. Hence the issue between (short-term) satisfaction of societies needs and the (long-term) preservation of our natural resources will become apparent. Therefore other technologies have to be implemented that provide for sustainable and climate friendly bio based diesel production without an adverse impact on the environment. This paper will analyze the impact of legislative action on feedstock and technology selection as well as their impact on food production and biodiversity. An outlook will present future technologies that will alleviate pressures on both societies transport needs without adverse impacts on nature.

LEGISLATIVE FRAMEWORK

EU Directives

The EU directive 2009/28/EC [5] on renewable energy is a binding directive for all EU member states. In addition to enabling market entry of renewable energy carriers, this action targets the reduction of the EU dependence on fossil fuels for the transport sector. It is a legislative instrument to reduce the greenhouse gas (GHG) emissions and a regulatory instrument for market control and support of renewable fuels options.

The Directive establishes a common framework for the promotion of energy from renewable sources and sets mandatory national targets for the overall use of biofuels based on gross final consumption and with respect to transport energy. Ultimately, it establishes sustainability criteria for biofuels [8].

Every EU member state has to set its own targets and has reasonable flexibility in doing so [8,9]. However, the directive provides a clear guideline to calculate green-house-gas emissions for biofuels. Basis for this calculation is a life cycle analysis based on calculations laid outin the Annex V of the 2009/28/EC. This is an important rule for a unified GHG savings monitoring and certification system.

Life Cycle Assessment – The Basis of Legislation

Annex V of the EU directive 2009/28/EC describes a calculation for GHG savings using fossil fuel processes as a reference point. Interestingly, in this calculation the GHG emissions for all transportation fuels were set to 83.8 g CO_2 (eq)/MJ as a standard. Therefore, this value is the unified fossil reference value for any transportation fuel (diesel, gasoline or jet fuel). However, this unified value results in a high degree of inconsistency for a determining either GHG emissions or biofuel life cycle analysis, resulting in an ongoing scientific and political debate. Since progress in this issue is at hand, it can be expected that this issue will be resolved in one of the next legislative revisions.

Generally, the calculation for GHG reduction (see Equation 1) is applicable bio- and fossil fuels alike, at least in terms of grams CO_2 equivalents for the energy equivalent of one Mega-joule of fuel [10].

$$\textbf{GHG savings} = (E_F - E_B) / E_F \bullet 100\ [\%]$$

Equation 1: General formula for calculation of GHG emissions, where E_F: GHG emissions of fossil fuel including exploration, refining, transport and use in units calculated as CO_2 equivalents. E_F = 83.8 g CO_2 (eq)/MJ (Fossil fuel reference value); E_B: GHG emissions resulting from biomass feedstock cultivation, processing, transport.

For calculation of GHG emission resulting from biofuel production an addition term E_B is introduced, which summarizes biomass specific production parameters, such as cultivation, harvesting and extraction of fuel feedstock like the oil (for plant biodiesel) fraction of plant seeds.

The detailed E_B component parameters are:

$\mathbf{E_B}$ =	$\mathbf{e_{ec}}$	(extraction, cultivation and harvesting)
+	$\mathbf{e_l}$	(land use)
+	$\mathbf{e_p}$	(processing)
+	$\mathbf{e_{td}}$	(transport and distribution)
+	$\mathbf{e_u}$	(use)
-	$\mathbf{e_{sca}}$	(soil carbon accumulation)
-	$\mathbf{e_{ccs}}$	(CO_2 capture and storage)
-	$\mathbf{e_{ccr}}$	(CO_2 capture and replacement)
-	$\mathbf{e_{ee}}$	(energy excess – cogeneration)

Equation 2: Calculation of the biofuel's GHG emissions according to Annex V of the EU directive 2009/28/EC

The comparison of fossil und biofuels in terms of GHG savings is expressed in Equation 1. Examination of the E_B component parameters (Equation 2) suggests various routes to reduce the GHG emissions without changing process parameters. A common example is the process integration of heat and power generation, which allows for a significant increase in calculated GHG savings without large investment and radical technical changes to the core process. The detailed analysis of the possibilities to improve the calculated CO_2 footprint without radical process changes has been described elsewhere [11,12]. Therefore, the current measure of calculating GHG emissions provides industry numerous avenues to improve their process and product lifecycle analysis. To provide evidence of improved life cycle and GHG emissions to government bodies, certification systems were created. Industry requires GHG certification for all biofuels processes which encompass as unit processing step from biomass cultivation to the final product outlet.

Certification systems

Due to legislative pressures different certification systems appear around the globe [13]. At present the European Commission approved Greenergy Brazilian Bioethanol, RSB EU RED, RTRS EU RED, Bonsucro EU, RSBA Abengoa, Biomass Biofuel voluntary scheme (2BSvs) and ISCC [14] as biofuel certification schemes.

The common approach of all certification systems is a cradle-to-grave allocation of selected greenhouse gases like CO_2, Methane, N_2O. However, the allocation methods and weighing parameters differ depending on the certification scheme, resulting in inconsistent GHG savings for the same process and product [13,14]. In addition, using current methodology the effects of indirect land use change and reduction of biodiversity remain unresolved [4].

This issue is further complicated as current conception of how land use change impacts biodiversity and the CO_2 balance of our planet is rudimentary [15]. In consequence, intensive research is required to understand the interaction of the world's ecosystems. The ultimate goal should be a quantitative description valuing the contribution of the different natural reserves on GHG reduction and climate change.

Despite these scientific limitations certification systems are operational. Therefore, certification systems and legislative actions regulate trading of raw biomass feedstocks and biofuel products in the EU. Since bioethanol plays a minor role in Europe we focus on biodiesel in this article [16]. In 2010 the biofuels consumption in the EU added up to 13.3 billion MT, where biodiesel accounted to 9.9 billion tons or 74 % of the total biofuel consumption [17].

CONVERTING LEGISLATION INTO INDUSTRIAL ACTION

Technical framework

In the EU, the use of rape seed oil as the major first generation biodiesel feedstock is driven by technical biodiesel specifications, which are interdependent with the local climate [18]. These technical limits restrict the use of palm oil to ca. 20 % in summer and ca. 10 % in winter for any fatty acid methyl ester (FAME) biodiesel product. This is mainly due to the adverse cold flow properties of the high palm oil containing FAME biodiesel products. The reason for these limitations is dependent on the chemical nature of the fatty acids contained in the respective vegetable oil feedstock. The ratio of unsaturated/saturated fatty acids for rape-seed and canola oils exceed 15, compared with palm oils reaching only a ratio about 1. Therefore palm oils have a much higher paraffinic nature compared to rape-seed oils, which have olefinic properties. The degree of olefinicity has a direct impact on the cold flow properties and cloud point. Comparing paraffins and olefins of equal carbon atom number, the melting and crystallization points of olefins are much lower. Driven by van-der-Waals interactions, paraffin like molecules form zigzag aggregates. On cooling these paraffinic aggregates act as nuclei, which trigger crystallization and solidification of the FAME biodiesel product. Any structure disturbing the zigzag aggregation restricts the number of crystallization nuclei and therefore decreases the crystallization tendency. Consequently, the cold flow properties in terms of cloud point and CFPP improve towards lower temperatures. The same principle applies for fatty acid methyl esters. Therefore, the application of paraffinic palm oils in FAME biodiesel is limited [19].

Analysis of current market trends

As the use of palm oil derived fatty acid methyl ester (FAME) biodiesel is technically limited, the argument biodiesel contributes to rain forest destruction does not hold. More severe is the aspect of misusage of arable land for energy instead of food production– often described as food versus fuel dilemma [4]. However, there is change on the horizon as governmental tax incentives for growing energy crops will be gradually eliminated [9]. This measure results in increased pricing of vegetable oils beyond the threshold required for economical biodiesel production.

In the EU, this effect has already taken a toll on biofuel producers, since small and medium sized biodiesel production facilities have disappeared. Additionally, remaining large processing plants are far away from capacity limits, thereby preventing utilization of economies of scale for FAME biodiesel production.

Major petroleum traders like Glencore, Dreyfus, Mercuria have invested in buying large biodiesel companies. This appears to be a good investment since the European countries have a mandate or tax incentive for biodiesel or biofuels admixed to conventional transportation fuels. Since vegetable oils prices mostly exceed biodiesel selling prices the gross margin is negative [20] and the price difference is compensated through hedging. One example is the constantly negative net income even of large biodiesel producers like Biopetrol AG, Suisse [21].While it is just a matter of time until the financial markets realize that hedging instruments are not sustainable, soy-bean derived biodiesel especially out of Latin-America boasts prices that remain low enough to satisfy the non-EU markets.

Impact of legislation on european FAME biodiesel markets

The latest EU legislative action introduced sustainability accounting in terms of CO_2-equivalents for all biofuels processes [5,9,14]. This legislative action imposes tracking of CO_2 equivalents along the whole production and transportation chain according to equation 1. Without certified proof that biofuels exceed the minimum green-house gas (GHG) savings, usage, storage and trade is prohibited. Clearly, this will have an impact on global trading of biodiesel and associated biomass feedstocks.

Actually the European law sets a minimum GHG saving of 35 % for biodiesel produced in existing biodiesel plant as of 2013 (Figure 1). In the year 2017 the mandatory GHG savings must be equal or exceed 50 %, while in 2018 minimum GHG savings of at least 60 % has to be achieved for all biofuels [4]. The following analysis provides a roadmap for certifiable biodiesel processes in the coming years.

Soy bean FAME biodiesel: Based on default values, soy-bean derived FAME biodiesel (31 % projected GHG savings) is going to be eliminated by 2014 as it does not meet the mandated GHG saving threshold. Especially for soy bean oil from Latin America cradle-to-gave analyses show that there will be no access to the EU biofuels market by 2014 [22-24]. For US based soy bean oil the situation looks somewhat better. If US producers give proof by accredited certification exceeding 35 % GHG savings could be achieved [10]. We might see some US origin soy bean biodiesel or processing soy bean oil for biodiesel after 2013 to 2016. The 50 % GHG savings requirement form 2017 onwards will

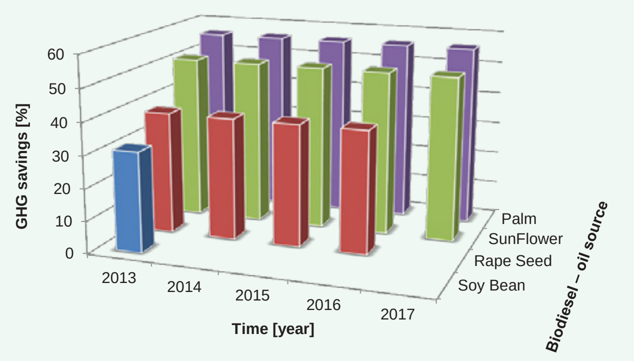

Figure 1 GHG emission savings (default values) for FAME biodiesel in dependence of the raw vegetable oils. The graph shows the time dependent GHG certifiable technology option with respect to EU legislation. Note that the GHG savings for Palm only refer to palm oil produced using methane capture technology.

definitely exclude soy bean derived FAME from the EU market. However, the domestic demands in US and Latin America for soy bean based FAME biodiesel remains high [25] and the impact of EU regulations will be negligible.

Rape seed FAME biodiesel: As GHG savings of rape-seed oil by default add up to 38 %, rapeseed based FAME biodiesel is certifiable until the end of 2016 [5,24]. By 2017 the biodiesel industry has to meet a 50 % GHG saving threshold. It is not likely that rape-seed FAME biodiesel will meet these GHG reduction requirements (Figure 1). In the EU rape seed is the predominant source for biodiesel. About 63 % of planted rape is utilized for biodiesel production [26]. The elimination of rapeseed biodiesel will affect the agricultural practice for this crop in the EU but not in other countries [27,28].

Sun flower FAME biodiesel: Sun flower FAME with a default value of 51 % GHG savings appears to be the biodiesel raw vegetable oil of the future [5]. However, both FAMES derived from crude and processed sunflower oils did not show adequate fuel performance due fouling issues and carbon deposits [29]. Additionally, farming of sun flowers requires special growth conditions and intensified pesticide application [30,31]. Therefore, sunflower based FAME's are not significant in future biodiesel applications.

Palm oil FAME Biodiesel: Palm oil production is associated with a negative environmental impact due to deforestation and increased pesticide use [32,33]. Further, discharge from seed oil extraction was stored in open lagoons, leading to release of the GHG methane (biogas) [34]. Due to these practices palm oil production is associated with a GHG saving default value of 19% according to the Annex V of the EU directive 2009/28/EC [5]. To address these issues the "Roundtable on Sustainable Palm Oil (RSPO)" was established in 2004 [13]. A significant step to enhance sustainability of palm based biodiesel was implementation of the methane capture in biogas units, which are utilized to produce process energy [3,35,36]. Biodiesel derived from palm oil production with methane capture technology results in a significantly higher GHG savings of 56% (default value) [5]. Nonetheless, in the EU and US the share of palm oil derived biodiesel will remain low due to aforementioned technical limitations [27].

In summary, soybean derived FAME's will be eliminated from EU markets by 2014, while rape-seed FAME biodiesel will maintain its position until 2016 (Figure 1). Beyond 2016 palm oil and sun flower oil derived FAME biodiesel do not represent replacements as these products do not fulfill criteria of the EU biodiesel standard DIN EN 14214. As none of the current FAME products meets goals sets by EU legislation, it is conceivable that FAME biodiesel will disappear from the European market by 2017. This scenario will in vokea legislation driven technology change towards drop-in biodiesel produced by hydro treating technologies.

LEGISLATIVE DRIVEN TECHNOLOGY SELECTION

In 2010 the world wide CO_2 emissions reached a record 33.5 billion (10^9) tons [37]. There is no doubt that first world governments will increase measures for CO_2-saving activities. The instruments of CO_2-certificate trading and legislative actions will certainly affect the energy, mineral oil and biofuels market, thereby inducing strategic changes [38]. Presently, the involvement of the mineral oil majors in FAME biodiesel technology has been scarce. Oil traders and the major oil companies prefer to buy in biofuels from the market instead of producing it by themselves.

Aside from technological uncertainties there are simple economic and psychological restrictions for the oil companies: First, the biodiesel demand is small compared to the fossil oil processing. It is not attractive spend financial capital for a product with low or negative margins. Second, current batch biodiesel (FAME) technology does not fit to the complex continuous production of a petroleum refinery. Additionally, admixtures of FAME with petroleum products are limited. Therefore, in-view of the oil refining business FAME biodiesel is an additive and not a fuel replacement. These technical limitations contrast the biodiesel equivalents produced by hydrotreating of vegetable oils. Since hydroprocessing is an established technology in petroleum refineries, core processes can be modified for conversion of vegetable oils to diesel and jet fuels [39]. Hydroprocessing of vegetable oils and fats works in any mixture with fossil diesel precursors and all types of vegetable oils and animal fats. Chemically, bio-derived diesel and jet fuel is a hydrocarbon, which can be mixed in any concentration with fossil oil products, a characteristic that contrasts the properties of FAME biodiesel.

From an engineering perspective only minimal adjustments are required to enable vegetable oil processing in petroleum refineries, which translates into reduced financial invest to convert bio-based feedstock into bio based-diesel. The cloud point issue caused long paraffinic chains of the raw vegetable oil can easily be eliminated applying isomerization or mild hydrocracking in the very same reactor. Basically, only minor adjustments in catalyst composition or reaction severity allow the production of hydrocarbons meeting the technical and legislative specifications.

Aside the chemical equivalence of hydroprocessed vegetable oils to fossil fuel products the legislative technology selection will lead to the demise of FAME biodiesel and rise of hydroprocessed vegetable oils [3].

Inspection of the default GHG savings of hydroprocessed vegetable oils (Figure 2) demonstrates that the scenario appears comparable to the FAME situation albeit at higher GHG saving levels (compare Figure 1 and Figure 2). In effect, hydrotreating technology does not significantly extend the certifiable lifetime of soy oil derived bio-diesel products. However, in the course of 2013 market availability of soy bean oil twinned with a low price regime will economically favor soy-bean oil derived biodiesel over rapeseed oil equivalents [40]. This economic driver will lead to an increasing market penetration of hydrotreated vegetable oils from 2013 onwards [41]. Consequently, the oil refining industry will start taking over the biofuels market in 2013, which may induce the next economic crisis for the classical FAME biodiesel industry.

Once the certification of soy derived hydro-processed biodiesel expires, it will not be replaced by domestic rapeseed but more economically efficient palm oil derived hydrotreated products [42,43]. In contrast to palm oil derived FAME biodiesel, the hydrotrated equivalent does not face technical limitations to meet biodiesel specifications. However, only palm oil originating from processing plants with integrated biogas production will meet the requirements of the minimum 35% (2013) and 50% (2017) GHG savings mandated by EU directives. Nevertheless there is enough time for the palm oil industry to implement these requirements for methane capture and integrated energy utilization.

Since vegetable oil hydroprocessing refineries are a powerful economic factor, there is an incentive for palm oil producers to apply sustainable technologies. As a result palm oil production will become more sustainable based on GHG savings [42]. In consequence, biogas production will expand alongside production of palm oil in the coming years. However, the increasing demand for palm oil will both exacerbate the food or fuel dilemma and will initiate further rain forest destruction in favor of palm oil plantation [4].

The current meta-analysis indicates that well intentioned legislative actions may foster a bio-based but not necessarily a more sustainable economy. If these legislative technology selections are not corrected in future, a global environmental crisis cannot be prevented. Therefore, there is an urgent need to identify and develop sustainable fuel technologies that do not exploit arable land or lead to destruction of areas with high biodiversity.

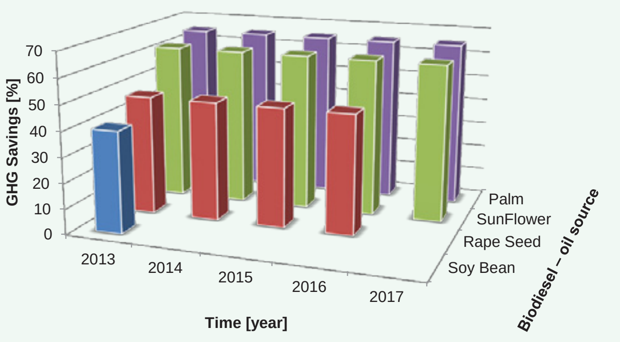

Figure 2 GHG emission saving for various vegetable oil hydrogenation processes to bio-based diesel. The graph shows the time dependent GHG certifiable technology option with respect to EU legislation.

OUTLOOK ON TECHNOLOGIES UNIFYING SOCIETY NEEDS AND NATURAL PRESERVATION

A major sustainability issue with current industrial biodiesel production processes is the use of edible vegetable oil as raw material. The continuous use of these feedstocks will increase the socioeconomic divide between industrial and developing countries [44,45]. Further, associated effects of land use change, excess water and fertilizer use are severe resulting in loss of arable land [4]. To combat these developments requires changes for production of bio-oils for fuel applications. A short term advance is the use of non-edible oil producing plants, such as *Jathropha curcas*, which can be cultivated on degraded land. However, cultivation of these oil-plant species is limited to the tropical and subtropical climate range. Therefore, the production facilities will not be adequate to satisfy the global demand for oil containing biomass feedstocks [46]. A rapidly emerging technology is the use of agricultural waste hydrolysates as a fermentation feedstock for microbial oil producers, such as the oleaginous yeast *Rhodotorula graminis* [47] or the filamentous fungus *Umbelopsis isabellina* [48]. Agricultural (i.e. straw) and forestry waste (i.e. wood chips) are locally available and their use in industrial processes does not compete with food production and is not associated with land use change. Another option for large scale bio-oil production is the cultivation and conversion of microalgae in desert regions, which are predominantly located in underdeveloped parts of the world [49]. Although all of these technologies are expected to significantly improve the sustainability and CO_2 emission footprint of biodiesel production, intensive research efforts are required to derive economically viable processes. As non-arable land is plentiful particularly in undeveloped nations, industrial countries should have an invested interest to enable a competitive biofuels industry in these parts of the world to satisfying the demand for transportation fuels in an ecological, economical and socially fair manner. This development should be guided by adequate legislative measures, which have to be coordinated and implemented in a cross national approach. These legislative guided technology developments should enhance economic development in undeveloped countries thereby positively impacting global sustainable growth.

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