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Soy biodiesel pathways: Global prospects

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ABSTRACT

This survey paper critically reviews the performance and prospects of soy biodiesel production on a global basis as assessed by some 30 life-cycle analyses (LCAs). The paper compares agricultural and industrial practices. Soy biodiesel is not a most sustainable product in all global circumstances. Life-cycle energy depends on specific climatic conditions, and on the agro- and processing technologies used. Alternative oilcrop cultivation practices and technologies were evaluated. Opportunities have been identified to improve the biodiesel life-cycle energy efficiency and environmental impact in relevant production areas (mainly USA, Brazil, Argentina and P.R. China) by implementing new technologies in agriculture as well as in industrial processing. The consequences of large-scale renewable energy action plans in the European Union and of biodiesel mandates in numerous countries worldwide are critically considered. The paper concludes with perspectives and recommendations.

Contents

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1. Introduction

Liquid biofuels (107.5 billion L) provided about 3% of global road transport fuels in 2011. Amongst these, biodiesel (20%) is the dominant product in Europe and Asia and bioethanol (80%) in the Americas. The potential volumes of these biofuels are limited. As the land area requirements for biodiesel production are considerably larger than for bioethanol, it is unlikely that biodiesel will ever reach the same production level as bioethanol. Moreover, there exist serious concerns regarding interferences of biofuels with food supplies [1], as expressed by organisations such as OECD-FAO [2], IMF, World Bank and Oxfam, as well as reported poor energy balances, ecosystem destruction and land displacement issues [3,4]. More advanced biofuels without most of the environmental drawbacks of first-generation biofuels are still immature with little prospectives of significant market penetration before 2020.

The term 'biodiesel' (BD) was coined by Wang [5] in 1988. There is huge interest in biodiesel. SciFinder 2011 reports 1766 articles and 679 patents related to biodiesel 2010. Perceived benefits of biodiesel (fatty acid methyl esters, FAMEs) are many: political (national energy security); economical (trade balance, employment); agricultural (rural development); environmental (renewable, biodegradable/non-ecotoxic, emissions savings); technical (engine lubricity); health (less harmful exhaust emissions); and safety (higher flash points). Vegetable oil esters are much more biodegradable ($>95\%$) than mineral oils (25–40%) and consequently pollute less than conventional diesel (CD) in a sector (transportation) which is an important contributor to global greenhouse gas (GHG) emissions [6]. Biodiesel's suitability as a fuel is determined by its ignition quality (cetane number, CN), heat of combustion, pour point (PP), cloud point (CP) and (kinematic) viscosity [7]. Biodiesel is miscible with conventional diesel in all ratios and can be used in diesel engines without significant engine modifications. Some problems connected with biodiesel use are oxidative (in)stability, cold-flow properties, slightly enhanced NO_X exhaust emissions [8], and price. The product needs further improvement both ecologically and economically.

Biodiesel was originally conceived largely in the context of national fuel needs [9] and use of local resources but has emerged more recently as a global industry and commodity. Biodiesel production (2010) worldwide amounted to about 16.1 Mt (Europe 9.5 Mt, USA 1.1 Mt, Argentina and Brazil 3.8 Mt, ROW 1.7 Mt), which was mainly derived from rapeseed oil (47%), soybean oil (35%), palm oil (10%), sunflower oil (4%) and other oils and fats (including tallow, waste oils and corn oil) (4%). International biodiesel trade streams were of the order of 2.25 Mt in 2010 [10].

At variance to soybeans and associated products (meal, oil), which are driven by global market forces, biodiesel production does not depend on such free market forces but is merely determined by political choices and governmental incentives such as mandates, subsidies and tax cuts, at both sides of the Atlantic. Mandates pass the higher costs directly to the consumer; subsidies are transfers from governments to industry. In May 2003, the European Union (EU) has issued the Biofuels Directive (2003/30/EC) with a specific EU-wide obligation of 5.75% (by energy) or about 18.0 Mt/yr of biofuels for the transport sector by 2010. Although this target was not even met in an unsustainable way by most member states (actual average blending of only 4.26%), a still more ambitious EU biofuels target of 10% (by energy for 2020) has later been defined in the Renewable Energy Directive 2009/28/EC (RED) [11]. This target is not unchallenged (as voiced by many). A regulations rethink is necessary. Global biofuels policy issues are increasingly leading to undesired consequences. Expanded oilseed production is limited by the availability of cropland. Indiscriminately increasing the amount of biofuels may not automatically lead to the best reductions in emissions [12]. In particular, indirect land-use changes are a valid concern.

Biodiesel has been a fast growing alternative fuel in Europe (from 300 kt in 1998 to 10.6 Mt in 2011) as well as in the United States (from 2 Mg in 2000 to over 800 Mg in 2011). EPA has extended its Renewable Fuel Standard (RFS2) volumetric compliance level from 500 Mgal/yr in 2009 to 1 Bgal/yr by 2012. It is to be noticed that domestic US diesel use is very limited, quite opposed to the consumption in Europe. Expectations of entrepreneurs have run high and as a result biodiesel nameplate capacity has grown abnormally and beyond measure (up to 22.1 Mt/yr in Europe 2011; 3.0 Bg in USA) and currently determines largely underutilised EU and US capacities and idle plants, undermining the economics of the biodiesel sector as a whole. Worldwide use of the niche product biodiesel stays marginal and just accounts for 4.5% of diesel use in Europe and 1.7% in the USA.

Greenhouse gas emissions must be reduced by 50% to 85% by 2050 if global warming is to be confined to between 2 °C and 2.4 °C [13]. Transport is the only sector that has seen its emissions increase over the past two decades. An OECD recommendation [2] urges replacing mandates for biofuels production by technologically neutral policies (such as carbon taxes) that stimulate energy efficiency and by a certification requirement. The EU's Fuel Quality Directive (FQD) aims at reducing transport fuel emissions by 6% by 2020 [14]. Because the carbon in biodiesel is recycled, the product is advocated as a partial solution to the increasing atmospheric CO_2 concentrations [15]. However, there is little consensus on the degree of sustainability for various agricultural cultivation practices and production methods. Clearly, the total emission of all GHGs required to produce, transport, and process the biodiesel feedstock must be less than the emissions from the displaced fossil fuel. As illustrated for the case of rape biodiesel [16], a range of such products exists differing widely in terms of energy balance, environmental sustainability as well as in economic profitability.

The net benefits of biodiesel production from energetic, environmental, and socio-economic perspectives are still widely debated [3,4,12,17–20]. Although certain conditions are inductive to a negative energy balance for biodiesel [21,22], most others have determined net positive balances. These situations generally rely on modern agricultural production technologies, resulting in higher yields and lower energy inputs in crop production (*e.g.* more efficient fertiliser management, reduced tillage).

As the use of bioenergy crops has recently come under serious criticism as to their true environmental cost [23,24] it is an objective of this survey paper to gain insight into the future prospects of soy biodiesel in a global energy system. Quantification of the net impacts of various widely available soybean oil feedstocks by life-cycle assessments (LCAs) from field to fuel use provides a way of determining the relative benefits of respective production pathways and of biodiesel in comparison with fossil diesel [25]. In this paper we have compared a set of very recent LCAs of soy biodiesel (*cf.* Table 1). The conclusions from these studies differ significantly. Data on soybean production methods and agricultural practices are georeferenced.

This paper critically analyses soybean-based biodiesel production worldwide but focuses more in particular on the four main producers (USA, Brazil, Argentina and China). Developing countries such as Brazil and Argentina have favourable climatic and environmental conditions for plant growth, low labour costs, low energy input in agricultural production and hence low production costs for energy crops. The limit to growth and spread of soybeans is the capacity of global markets to absorb additional sustainable production. The potential of soy biodiesel is constrained by the growing demand of edible oil and by its sustainability.

Other objectives of this paper are the identification of the most important environmental loads in soy biodiesel life-cycle systems