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Assessment of algae biodiesel viability based on the area requirement in the European Union, United States and Brazil

Lais Galileu Speranza*, Andrew Ingram, Gary A. Leeke

School of Chemical Engineering, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK

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ABSTRACT

The replacement of diesel by biofuels is considered unrealistic because of the land used to produce their feedstock. One appointed solution is the use of algae which have higher productivity per unit area when compared with other feedstocks. In light of this, the total area, including water and land required for the European Union (EU), the United States (US), and Brazil was determined using international policies and targets, the present and future diesel demand, the current biodiesel production (released by international organizations), and specific data of algae productivity from the literature.

GIS software was used to locate possible cities where algae cultivation could occur nearby. Bearings on the availability of area (flat and unoccupied zones), favourable climate, proximity to the process inputs (such as nutrients (preferably from municipal waste water treatment), CO_2 and water sources) and political boundaries were used as assessment criteria. It was possible to identify seven suitable cities with more than 500,000 inhabitants in the EU, two in the USA and thirteen in Brazil.

It was also shown that it is possible to attain targets required by current policies and replace diesel with algae-derived diesel based on attainable cultivation areas.

1. Introduction

Currently the world uses a large volume of diesel, approximately 1450 billion L per year which represents a direct emission of 3886 billion kg of CO_2, 12% of the world's CO_2 emissions [1]. The biggest consumers are the US (15.2%) and China (12%) followed by India (4.8%), Germany (4.38%), France (3.9%) and Brazil (3.4%). The distribution of diesel usage does not match the crude petroleum sources around the world, and so consumers are dependent on supply from other countries. Based on this and driven by the growing debate over global warming and other environmental problems, the production of alternative fuels is strategically important.

Biodiesel is a feasible option since it can replace diesel without substantial engine modifications. This has advantages over other alternative fuels, such as hydrogen, which needs a complete new market structure. Biodiesel is defined as a fuel made up of mono-alkyl esters of long-chain fatty acids derived from bio-oils, usually fatty acid methyl esters – FAME [2] and can be produced from vegetable oil. According to the raw material and the production technology, biodiesel can be divided into three generations. The first generation is represented by fuels produced from biomass that can be used as food, such as rapeseed and soybeans; second generation is from non-food crops such as *Jatropha curcas*, and waste oil; and third generation is from algae and sea weed biomass [3,4].

In order to incentivise the use of biofuels some strategies have been created, such as mandatory targets and blending, and financial incentives (tax reduction, exemptions and subsidies). In addition, governments can intervene in the production chain by supporting some feedstock crops, subsidizing specific factors of production, granting incentives or creating import tariffs [5]. In 2012 the investment in the renewable fuel capacity was US$ 244 billion and there were 138 countries with policy targets, 76 with biofuels mandates and at least 23 with blending mandates [6].

Mainly because of these governmental interventions the use of biodiesel has been increasing significantly over the years [5]. The European Union, the United States and Brazil represent together almost 80% of the global production and for this reason these three specific cases were selected for a more detailed study. Table 1 shows the progression in production and consumption of biodiesel in the studied cases and around the world.

On one hand the government policies promote the use of renewable energy sources and the reduction of pollution emissions and climate change, on the other they can generate unexpected

* Corresponding author.
E-mail address: lxg329@bham.ac.uk (L.G. Speranza).

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Table 1
Biodiesel production and consumption in millions of litres by year [43].

	2004	2008	2012	2016*	2020*
Biodiesel production					
European Union-27	1422.2	7382.2	10,908.8	12,980.8	17,518.6
United States	283.9	1856.5	4232.1	5143.6	5849.0
Brazil	0.0	1167.2	2738.6	2822.4	3156.6
World	**2301****	**14,574****	**22,400*****	**31,706.4**	**38,195.4**
Biodiesel consumption					
European Union-27	1219.8	10,155.7	13,980	16,011.3	19,594.5
United States	283	1095.7	3952	4865.3	5717.7
Brazil	0	1170.7	2739.2	2793.7	3107.8
World				**31,706.4**	**38,195.4**

*Forecast from Ref. [43]/** [5]/*** [6].

results since the available biofuels still use food crops as their feedstock. One example of possible adverse results is illustrated by Sorda et al. [5] who stated that biofuels can be blamed for the 2006 rise in food price when 20% of the US corn supply was reallocated to ethanol production.

Consequently, the established targets create a concern of how to achieve the minimum percentage of renewable source fuel knowing that the land necessary to produce first and second generation of biofuels is not sufficient to achieve the targets set in the actual polices [7] and maintaining the sustainability of the biofuel production without deforestation and negative impacts in land use changes [8].

In light of this, where policies in climate change and renewable energy are becoming more frequent and pressure to replace fossil fuels is increasing, it is very important to consider possible improvements and new alternatives in biofuel production. The creation of polices and strategies, including the selection of feedstock and the investments, must be designed to take into account the actual capacity of each country whilst considering its influence on the other spheres of market.

Third generation biodiesel is a good option for biodiesel production because of algae's high lipid content, high productivity per area and the ability of growth on non-arable and non-productive land. Algae are cultivated in aquatic media offshore or onshore in ponds, photobioreactors or fermenters and need CO_2 injections (usually from power plants) and nutrients containing nitrogen and phosphorus [3].

In order to evaluate one aspect of the viability of third generation biodiesel, this paper analyses the area requirement to meet the targets and to replace the current fossil diesel demand in the three cases defined before (EU, US and Brazil), and also identifies possible locations to begin the cultivation of algae based on a global analysis of the inputs availability.

2. Methodology

An outline of the methodology is presented in this section while a more detailed explanation is combined with the results in the next sections in order to facilitate reading flow and clarity.

In the first part of this study the area requirement to produce biodiesel was assessed. The biodiesel requirements were calculated using data released by international governments in order to (i) achieve the established targets and (ii) replace the use of diesel projected to 2020. These results were divided by the algae biomass productivity based on seven scenarios established on assumptions from the literature for microalgae growth in open pond (OP) and photobioreactors (PBR) and for macroalgae.

In the second part, cities where algae might be produced nearby were identified using GIS software and by considering the necessary conditions to cultivate algae, including favourable temperature, area availability (uncultivated, unprotected and unoccupied areas) and input proximity; other land uses have been not considered. The data were obtained from the literature (ArcGis-Online [9], ArcGis-Online and Protectedplanet [10] and GEO [11]).

3. Area assessment

The area availability assessment can be calculated in three steps. First, the projection of how much biodiesel will be needed to be produced from algae by 2020 in order to (i) achieve the current targets and (ii) entirely replace diesel was determined. Secondly, the productivity of algae biodiesel per unit of cultivation area was determined, and subsequently, with the results of the two first steps, the land requirement to produce the necessary fuel was calculated.

3.1. Biodiesel requirement

The amount of biodiesel required was calculated based on predictions for 2020. The first situation was based only on the targets that each region needs to achieve (as presented in Table 2) and the second was based on the total necessary biodiesel to replace the consumption of diesel (Table 3).

The targets were taken from the directives of each region and were used as production requirements. In the Brazil case, there is not a directive, but there is pressure from biodiesel producers to increase the blending from 5% to 20% [12], so these two conditions were considered. The biodiesel volume requirements by the targets are presented in Table 2.

The total necessary production of algae biodiesel in 2020 to replace the use of fossil based diesel was calculated considering the following assumptions:

- The biodiesel necessary to replace all diesel is the sum of the projections of diesel and biodiesel consumption in 2020 less the actual installed biodiesel capacity (since the objective is not to stop the use of existing sources of biodiesel, but to use algae to raise this production), given by:

$$\begin{aligned}\text{Total} = {} & (\text{Diesel consumed 2020}/0.93) \\ & + \text{Biodiesel consumed 2020} \\ & - \text{Current Installed Capacity}\end{aligned} \qquad (1)$$

Table 2
Biodiesel targets.

	Directive	Target	Biodiesel requirement	Source
EU	EU Directive 2009/28/EC [44].	10% of biofuel in transport by 2020	27 billion L	[45]
US	Energy Independence and Security Act [46].	79.5 billion L of advanced biofuel by 2022	56.8 billion L[a]	[47]
Brazil	Mandatory Biodiesel Requirement [48].	B5 – Blending of 5% of biodiesel in diesel	3.5 billion L	[12]
	–	B20 – Blending of 20%	14 billion L	

[a] Interpreted target considering only biodiesel by 2020.