Renewable and Sustainable Energy Reviews 64 (2016) 329–337

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Economic and policy issues in the production of algae-based biofuels: A review

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ARTICLE INFO

Article history:
Received 20 October 2015
Received in revised form
12 April 2016
Accepted 16 June 2016

Keywords:
Biofuels
Externalities
Opportunity costs
Microalgae
Macroalgae
Policy

ABSTRACT

Despite the initial environmental and supply benefits associated with conventional biofuels leading to substantial policy support, research has indicated that these benefits might have been overly optimistic. Negative externalities associated with food and resource allocation have also resulted in an increasing scepticism about the long-term potential of transitioning to biofuels. This review presents the economic benefits and costs surrounding conventional biofuels and suggests the need for further development of a third-generation feedstock based on algae. The article provides guidance on the potential for a policy framework for supporting microalgae as a source of biofuels given the numerous associated positive externalities.

Contents

1. Introduction

The security of supply for fossil fuels is an issue of concern globally, particularly for transport use. The majority of private and

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http://dx.doi.org/10.1016/j.rser.2016.06.027
1364-0321/

commercial vehicles are fitted with combustion engines that run on liquid fuels. Hence, transitioning to alternative means of transport such as electric vehicles raises the financial and technological costs, especially for consumers. Therefore, electric vehicles may not represent cost-effective substitutes for much of private and commercial transportation.

In contrast, liquid fuels derived from organic plant biomass, commonly known as biofuels[1] [2], are closer substitutes. Biofuels have similar combustion properties and can more easily substitute petrol and diesel with minimal modification to engines. There are generally two types of biofuels: biopetrol or ethanol made from carbohydrates (sugars); and biodiesel made from lipids (fats). Aside from being derived from a renewable source, these biofuels are also believed to reduce net carbon emissions and other socio-economic benefits [3–6].

Biofuels have been able to infiltrate some markets, particularly with the aid of policy support. These include corn-based ethanol (biopetrol) and soybean-based biodiesel in the United States of America [7], sugarcane-based ethanol in Brazil [6,8], and rapeseed-based biodiesel in Europe [6,9]. However, the literature has increasingly identified issues pertaining to these conventional biofuels derived from terrestrial feedstocks. These issues include (1) lower net energy returns, (2) over-estimated claims around carbon emissions reductions, (3) increased dependence on fossil fuels, and most importantly, (4) competition with food demand through crop and resource allocation. This article will provide a brief review of these issues.

Therefore, an alternative feedstock is sought that would alleviate these issues whilst achieving aims of a long-term substitute for petrol and diesel. Marine macroalgae, such as seaweed, and microalgae, a microscopic biomass, have been identified as one such potential feedstock [10,11]. Despite cultivation and conversion technologies still being in their infancy resulting in some criticism about current financial viability, the literature has generally been positive about microalgae's potential.

The purpose of this paper is to highlight the economic and policy issues surrounding first and second-generation biofuels, and subsequently, outline the benefits and limitations of algae as a feedstock in comparison. The findings from this review suggest the potential for policy support of algae as a biofuel feedstock, particularly microalgae, based on longer term economic benefits.

2. Classification of biofuels

By convention, biofuels are classified based on the type of feedstock. Conventional biofuels refer to those that are derived from terrestrial-based feedstock. They are further subdivided into first and second-generation biofuels (Table 1). First-generation biofuels employ food-based feedstock, with the most common being ethanol from corn or sugarcane molasses and wheat starch [12], and biodiesel from soybean, rapeseed/canola oil, and palm oil [1], the latter becoming increasingly employed in India, China, and Southeast Asia [13,14] as well as current high utilisation in Europe. Second-generation biofuels employ the use of non-edible lignocellulosic[2] crops as feedstock in energy production [15,16]. These primarily include non-edible plant biomass like sugarcane crop residues (bagasse) [17], firewood, perennial grass, and forest and plantation residues for biopetrol [1], and jatropha[3] for biodiesel [18].

Table 1
Classification of conventional biofuels.

Biofuel class	Feedstock characteristics	Examples of biomass (biofuel)
First-generation	Food-based crops	Corn, sugar molasses (ethanol) Soybean, rapeseed (biodiesel)
Second-generation	Non-food crops	Forest residues, sugarcane bagasse (ethanol) Jatropha (biodiesel)

3. Issues with conventional biofuels

Many conventional biofuels are encumbered with higher production costs and therefore, uncompetitive retail prices [4,7]. However, policy support through blending mandates[4] and tax credit policies have allowed some types to enter the consumer fuel market, with sugarcane ethanol in Brazil being a prime example [20].

3.1. *Energy return*

The energy return from conventional biofuels has been found to be much less optimistic than perceived when comparing the Energy Return on Investment (EROI) function. The EROI measures the usable energy produced from the resulting biofuel divided by the energy used in production. Studies have identified the EROI for both first and second-generation biofuels, which have often had energy intensive production requirements, being much lower than that for petrol and diesel. Corn ethanol, a major biofuel in USA, was particularly low in the EROI scales [21]. Second-generation variants require marginally less energy [22] and represented the more promising option for ethanol from both an EROI view [23,24] as well as an energy return per area of cropland [25]; the latter due to emphasis on fast-growing perennial crops that can produce up to ten times more energy than other bioenergy outputs [26]. However, most second-generation feedstocks were found to have comparably low EROIs relative to fossil fuels (Table 2).

3.2. *Net carbon benefits*

A number of studies have suggested lower greenhouse gas (GHG) emissions by up to 90% relative to fossil fuels [1,7,24,35]. However, often these studies have not accounted for the effect of land-use changes resulting from increased biofuel crop cultivation. The loss of standing carbon sinks from the conversion of land for biofuel feedstock cultivation, especially from deforestation [36–38], can outweigh GHG reductions from production and consumption [9,39]. It is estimated that more carbon can be emitted from land clearing (17 to 420 times), which results in a substantial "payback" period for net emissions reductions to be achieved (Fig. 1). Biodiesels in particular, such as those derived from palm oil in Southeast Asia [40,41] and Jatropha in Mozambique [42], have been found to have the highest relative carbon debt repayment time from conversion of rainforests and woodlands respectively. Induced land changes from converting existing cropland have also been a source of indirect GHG costs [36,41]. Fig. 1 also

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[1] There is also a class of biofuels that employ either waste cooking oil or tallow as feedstock for lipid-based biodiesel [1]. However, this paper focuses on cultivated biomass as feedstock given the related comparisons with microalgae.

[2] Lignocellulosic biomass is plant biomass consisting of cellulose, hemicellulose, and lignin that can be processed to produce chemical compounds for biofuels.

[3] Jatropha is a non-edible flowering plant whose seeds contain oil that can be converted into biodiesel.

[4] Blending mandates refer to legal requirements for a ratio of biofuels to regular fossil fuels (petrol or diesel) sold [19].