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Surveying techno-economic indicators of microalgae biofuel technologies

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ABSTRACT

The need to develop innovative technologies that could replace fossil fuels and, consequently contribute to the reduction in emissions of greenhouse gases is now clear. In this circumstance, algal biofuels are generating considerable interest around the world. The purpose of this study is to provide an integrated assessment of microalgae potential as a source of biofuels, while comparing its costs with that from other emerging biofuel technologies. This article emphasizes the importance of emerging United States and European Union energy policies that will encourage the development of innovative, and sustainable technologies in their respective regions. An ample review of the scientific literature was carried out, contributing to the analysis of cost, economic and technical indicators. The results obtained allowed the detection of important gaps of information that need to be filled, in order to guide future investment decisions concerning this rising technology.

Contents

1. Introduction

Emerging technologies hold great promise and high risk, being a challenge to determine which emerging technologies have the best chance of becoming industry changing and commercially successful. In this article we contribute with a comprehensive set of information that will be key for a deeper techno-economic

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analysis of next-generation biofuel technologies, with an original focus on microalgae.

Advanced biofuels are defined by the American Energy Independence and Security Act of 2007, as being "*renewable fuels, other than ethanol derived from corn starch, that have lifecycle greenhouse gas emissions that achieve at least a 50 percent reduction over baseline lifecycle greenhouse gas emissions*". They include cellulosic ethanol, biomass based biodiesel, and other unspecified types of biofuels other than conventional corn-based ethanol and vegetable oil-based biodiesel. In this article we are analyzing microalgae specificities, bringing evidence on current costs provided by different authors. This paper is structured as follows. In the first section, we provide a literature review on the ascending relevance of microalgae for biofuels. Secondly, we present a brief review of some theoretical ideas of innovation adoption and diffusion and it is followed by an overview of recent investments and policies in both United States and European Union. Subsequently, the research methodology is presented describing sample selection, used data analysis and scrutiny of results. At last, final remarks are drawn.

2. The rise of microalgae for biofuels

A set of articles can be found in the literature evidencing the technical feasibility of growing algae for biofuel production [1–17], in which the majority of them demonstrate the absence of the major drawbacks associated with current 1st generation biofuels. For example, the most common drawback pointed out of 1st generation biofuels as being the affect on food prices due to massive arable land use.

Microalgae are microscopic organisms that are found in both marine and freshwater. These organisms use solar energy to combine water with carbon dioxide (CO_2) to create biomass [9]. The mechanism of photosynthesis in microalgae is similar to higher plants, with the difference in efficiency, microalgae are capable of producing 30 times as much oil per unit of land area as compared to terrestrial oilseed [9]. This technology uses the oils from microalgae as the raw material to produce biofuel.

In autotrophic microalgae cultivation, carbon dioxide must be fed constantly during daylight hours. Algae biodiesel production can potentially use some of the carbon dioxide that is released in power plants by burning fossil fuels. This CO_2 could be available at little or no cost [2]. However, the fixation of waste CO_2 of other sorts of business could represent an important source of income to the algae industry. Although this is a very promising future possibility, and some species have proven to show themselves capable of using the flue gas as nutrients, there are few species that survive at high concentrations of NO_x and SO_x present in these gases [18].

The nutrients for the cultivation of microalgae (mainly nitrogen and phosphorus) can be obtained from liquid effluent wastewater (sewer); therefore, besides providing its growth environment, there is the potential possibility of waste effluents treatment [19,20]. This could be explored by microalgae farms as a source of income in a way that they could provide the treatment of public wastewater, and obtain the nutrients the algae need.

After the process of extracting the oil from algae, the resulting product can be converted to biodiesel. The biodiesel produced from algal oil has physical and chemical properties similar to diesel from petroleum, to biodiesel produced from crops of 1st generation and compares favorably with the International Biodiesel Standard for Vehicles (EN14214) [3].

Commercial algae production facilities employ both open and closed cultivation systems. Each of these has advantages and disadvantages, but both require high capital input. In the surveyed literature neither open ponds nor closed photobioreactors (hereafter PBR) seem to be mature technologies. Therefore, until large-scale systems are built and operated over a number of years, many uncertainties will remain [21].

Like a refinery, it is still possible to obtain other products in the cultivation of microalgae, such as ethanol, methane and biohydrogen. The latter is being largely studied but still much work has to be done toward commercialization [22–25]. Therefore, they are possible proven processes in the laboratory, but still lack applied studies in industrial scale to become viable options.

As of today, it has been shown that it is scientifically and technically possible to derive the desired energy products from algae in the laboratory. The question lies, however, in whether it is a technology that merits the support and development to overcome existing scalability challenges and make it economically feasible [26]. Additionally, the basic economic motivation for biofuels is that they are a convenient, low-priced, domestically producible and a substitute for oil, an energy source that is getting costlier and it is mostly imported from politically volatile regions [27]. Economic feasibility is believed to be currently the main hurdle to overcome for this technology. Current costs associated to both the state of the science and technologies are sizeable and represent a main factor hampering development.

3. Innovation and diffusion of emerging technologies

High costs often prevent the market diffusion of novel and efficient energy technologies. As microalgae biofuel is not a mature technology, it becomes important to provide a revision of technological innovation and diffusion aspects to enlighten some available options that may help overpass the barriers found by innovative technologies.

It is widely recognized that modern economic analysis of technological innovation originates fundamentally from the work of Joseph Schumpeter [28], who stressed the existence of three necessary conditions for the successful deployment of a new technology: invention, innovation and diffusion. His seminal work has been constantly referred by many authors [29], and each of keywords represent different aspects, in particular: invention includes the conception of new ideas; innovation involves the development of new ideas into marketable products and processes; and diffusion, in which the new products and processes spread across the potential market.

Emergent technologies are relatively expensive at the point of market introduction but eventually become cheaper due to mechanisms such as learning-by-doing, technological innovation and/or optimization, and economies of scale. The combined effects of these mechanisms are commonly referred to as technological learning. Over the last decades, learning theories combination with evolutionary economics have led to the innovation systems theory that expands the analysis of technological innovation, covering the entire innovation system in which a technology is embedded. In particular, "An innovation system is thereby defined as the network of institutions and actors that directly affect rate and direction of technological change in society" [30].

In the emerging energy technologies field, there is a strong need to influence both the speed and the direction of the innovation and technological change. With that in mind, policy-makers are putting their efforts on lowering the costs of renewable energy sources to support the development of renewable technologies, either through direct means such as government-sponsored research and development (R&D), or by enacting policies that support the production of renewable technologies. It is well documented [31,32] that both higher energy prices and changes