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Prospects of using microalgae for biofuels production: Results of a Delphi study

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ABSTRACT

Advanced biofuels, such as those obtained from microalgae, are widely accepted as better choices for achieving goals of incorporating renewables and non-food fuel sources into the transportation sector, and for overcoming land use issues due to biofuel crops. Main challenges are currently the feasibility of large-scale commercialization of microalgae biofuels, since there are still some technical problems to overcome (e.g. the high energy consumption associated with biomass processing) and the majority of economic and financial analyses are based on pilot-scale projects. Therefore, this article presents the results of a Delphi study aiming to identify the main obstacles and most critical issues affecting the potential of large-scale commercialization of microalgae biodiesel and its incorporation into the fuel market. According to the authors' knowledge, this is the first Delphi study with this objective. The respondents are worldwide market specialists in the survey themes that ranged from biofuels economics to their environmental sustainability. One of the key findings is that most of the experts believe that production of microalgae biofuels will achieve its full commercial scale until 2020, and that from 2021 till 2030 it could represent from 1% to 5% of the worldwide fuel consumption. The study results also showed that environmental issues are where expert opinion differs more.

1. Introduction

It is consensual today that current production and consumption habits are unsustainable in the medium to long term. This is particularly true when considering energy production and consumption, a cornerstone of modern developed societies. We live in a world where fossil fuels, in particular oil and coal, are still the major source of energy to provide and meet the world needs. Besides that, they have a significant environmental impact, due to their exploration and, in particular, their utilization that contributes to pollution and climate change. Increasingly in future, cost and supply problems will lead to more significant economic, political and even social problems, as fossil fuels are very dependent on the geopolitical context, leading to oil price volatility. This is a big issue for most countries dependent on imports to meet energy needs, threatening their energy security. Due to these reasons much effort has being put on research and development of renewable energies, trying to find and develop good alternatives for fossil fuels with the long-term goal of providing reliable and cheap energy sources. The European Union (EU) has very ambitious targets till 2020, known as 20/20/20, which goals defined in the Directive 2009/28/CE [1] are to reduce the primary energy by 20%, increase the share of renewables in the final energy mix by 20%, and reduce the greenhouse gas emissions by 20% till 2020 compared to 1990.

Despite the challenges and depending on local conditions and practices, renewable energy sources are already a significant contribution to the energy mix. Two examples are wind and hydroelectric power that, in some European countries, represent more than fifty percent of the electricity consumed, and bioethanol in Brazil that currently represents 30% of fuel

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consumption in the transportation sector. However, from a global perspective, we are still far from the goal of producing most energy from renewable sources. Although all this condition is common to all activity sectors, the situation is even more delicate in the transportation sector, which has a global energy consumption share of about 30% [2] and the available options are limited and still have a modest impact. Other concerning aspect is that global energy use in transportation is increasing rapidly, especially in developing economies like China and Brazil, joining the fact that the transportation sector heavily relies on oil based products, where 95% of fuels are either gasoline or distillate fuels. Therefore, it is expected that CO_2 emissions from transportation will continue to rise. For that reason, there is a strong interest, both from companies and governments, to foster the development of renewable energy feedstocks.

Biodiesel and bioethanol are the two liquid biofuel options currently looked upon with more attention and under more vigorous development, since they can be used in today automobiles with little or no modifications of engines, for replacing diesel and gasoline respectively. The Directive 2009/28/CE also targets the transportation sector fuels; in particular each member state should reach a minimum 10% share of renewable energy by 2020. It is to mention that the pace that member states have been tracking is uneven among Europe, depending on their national specificities [3]. Complementarily, this Directive also states that this must be possible by using electricity and sustainable biofuels (i.e. based on a sustainable production). It also mentions that correct sustainability criteria should be adopted for biofuels, so that the rising world demand for biofuels does not destroy or damage land biodiversity, and establishes many others recommendations to ensure total sustainability of biofuels. An interesting point of this Directive is that, it recommends member states to incentive and support the use of biofuels that add supplementary diversifying benefits, such 2nd and 3rd generation biofuels (e.g. biodiesel from microalgae or bioethanol from lignocellulosic materials). Some changes were recently proposed to the Directive 2009/28/CE [4], in particular dealing with the calculation of carbon footprint, namely how to account for the ILUC (indirect land use changes), and setting new goals deemed more adequate to promote the growing European biofuels industry.

1.1. What is the potential of microalgae

Of the various potential biofuels' feedstocks much attention is being given to microalgae. This is a class of photosynthetic organisms with more than 30,000 known species that can grow in a wide variety of environments and conditions, including fresh, salty and brackish water. They have higher biomass and lipid productivity, requiring much less land area, of up to 49 or 132 times less, when compared to rapeseed or soybean crops, currently used as biodiesel feedstocks [5]. Also, they can be harvested either daily or every few days [6]. Generally, they are efficient CO_2 fixers, using solar energy to convert it to biomass, and can be considered almost carbon neutral, if the CO_2 released on combustion balances the saving from carbon capture during microalgae growth, and the energy needs for biomass processing are obtained from residues or other renewable energy sources, avoiding the usage of fossil fuels. Although open ponds' microalgae cultivation suffers from many limitations compared to closed cultivation systems, such as more susceptibility to invasions by other organisms and stronger temperature's variations [7], the essential cultivation requirements are small, as most species only need water, CO_2, and some essential nutrients such as nitrates and phosphates, without the need for fertilizers or even pesticides [8]. Besides that, biodiesel and other biofuels produced from microalgae have similar properties to petroleum diesel and to biodiesel produced from agricultural crops, currently named 1st generation. Extensive reviews dealing with the various aspects of microalgae cultivation and usage as feedstock for biodiesel production are available in literature [5,9–20]. A complete review of the main problems was done by Lam and Lee [21] and Januaun and Ellis [22], showing that many hurdles are directly linked with the process economics, due to its high energy requirements; in particular for processing microalgae biomass and for lipids extraction and refining.

1.2. Objectives

Currently, much experimental and even theoretical/simulation work is being done to ensure that biofuels from microalgae become a reality in the short to medium term. Some aspects were already identified as significant for the overall competitiveness, such as: the microalgae should have high biomass and lipid productivities [23–25]; the processing system should be highly efficient and integrated with other processes following the biorefinery concept [26]; there must be markets or valorization potential for the process byproducts or other high value products that may be obtained [27]; waste streams and/or remaining nutrients should be used to reduce operating costs and increase the process sustainability [25]; among others. Each of the previous possibilities has a positive impact on the competitiveness of using microalgae as a feedstock for biofuels, but there is a lot of discussion in which one should focus efforts of research and development.

To fulfill this gap, and building on previous work by the authors [28–30], this article presents a study based on the Delphi method to obtain more concrete information and predictions on how this area should be further developed. This way it will be possible to better define which lines of research should be supported, and what policy and funding instruments are more adequate. To the authors' awareness, no study can be found in the literature addressing these questions, involving the usage of microalgae as feedstock for biofuels.

A related work is the National Roadmap Algal Technology Roadmap [31], the result of a two day workshop that brought together specialists from various areas, including engineers, scientists, policy makers, financiers, and others, to discuss the present and future of microalgae as a feedstock for biofuel production. The final document was intended to serve as a revision of the current state of the art in the area, and to identify which are the key challenges that must be considered to achieve a commercial scale production, serving as a guide to ongoing efforts. The study is rather comprehensive and extensive but fails to highlight which are the areas and aspects that are considered to be more important and should be considered first, from a cost–benefit point of view.

Also related, the EurEnDel project was a European wide Delphi study on the future developments in the energy sector, with a time horizon of 2030 based on the situation up to 2003. Its main goal was to provide advice on energy R&D activities in this key area. Hundreds of responses from experts in a wide range of topics were gathered, several future scenarios were developed, and in which concerns biofuels, there is a short-term need for new production processes and an increase in their market share [32,33].

In 2009, a Delphi study was published dealing with the potential of biofuels in Alabama [34]. The information gathered supported the idea that there are no simple and unique technology answers for the commercial implementation, and that local questions and an array of technologies and feedstocks is the most adequate strategy. Similar conclusions were reached by Celitkas and Kocar [35] in their Delphi study of the renewable energy sector in Turkey, and by Lubieniechi and Smyth [36] in their work on the barriers to biofuels in Canada.