Renewable and Sustainable Energy Reviews 14 (2010) 842–848

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

A visionary and conceptual macroalgae-based third-generation bioethanol (TGB) biorefinery in Sabah, Malaysia as an underlay for renewable and sustainable development

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ARTICLE INFO

Article history:
Received 5 August 2009
Accepted 9 October 2009

Keywords:
Bioethanol
Macroalgae
Biorefinery
Sustainable development

ABSTRACT

Several biofuel candidates were proposed to displace fossil fuels in order to eliminate the vulnerability of energy sector. Biodiesel and bioethanol produced from terrestrial plants have attracted the attention of the world as potential substitute. However, due to food vs. fuel competition as well as land consumption of these biofuel, they have brought much controversy and debate on their sustainability. In this respect, cultivation of macroalgae such as seaweed at sea water which does not expend arable land and fertilizers provides a possible solution for this energy issue. Carbohydrates derived from seaweeds contain hexose sugars which are suitable materials for fermentation to produce ethanol. Therefore, it is possible to produce fuel ethanol from seaweeds. The potential and prospective of seaweeds to play the role as a sustainable energy provider are demonstrated in this paper. This study offers a conceivable picture of macroalgae-based third-generation bioethanol biorefinery to stimulate the initiation of the exploration in the related field.

Contents

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1364-0321/$ – see front matter
doi:10.1016/j.rser.2009.10.001

1. Introduction

Since people learned that utilizing renewable resources was essential for sustainable development, energy policies had slowly shifted to renewable resources such as biofuel. In particular, liquid biofuel has become the priority since 40% of total energy consumption in the world is in the form of liquid fuels [1]. An upward trend is shown in global liquid biofuel production from 4.8 billion gallons in 2000 to about 16.0 billion in 2007 [2]. Technologies are then peppered with the exploitation of crops which have high energetic values such as edible oil and sugarcane to produce biodiesel and bioethanol, respectively. While development of fuels from biomass continues apace, first generation biofuel based on edible crops has raised morality and ethics issues as there are millions of people around the world still suffer from malnutrition and hunger. In order to overcome this issue, bioethanol refined from lignocellulosic biomass, namely second-generation bioethanol (SGB) offers a great option which is compatible with economic growth and morality issues [3]. However, although SGB is attractive with its non-edible feedstock, it is much debated because the cultivation of terrestrial plants requires the resources that could otherwise be used for food. Furthermore, separation of lignin content from lignocelluloses has become an obstacle to be combated. In this context, third-generation biofuel based on marine algae and seaweeds offers an excellent alternative to displace fossil fuels. The ancestors of marine microorganism exist even before the formation of petroleum. Similar to all living organism on earth, the sun provides energy for algae and seaweeds to grow. Through a couple of billion years of evolution, algae have developed an efficient system to capture limitless solar energy continuously via photosynthesis [4]. At higher photosynthetic efficiencies relative to terrestrial biofuel feedstock, carbon dioxide is absorbed from the atmosphere and hydrogen is separated from the water to build up the carbohydrates which have only one oxygen atom on each carbon atom [5]. With a proportion of the solar energy trapped in their chemical bonds [6], carbohydrates can be further refined to produce bioenergy carriers such as bioethanol. Thus, cultivation and engineering of marine algae have drawn the world's attention in advancing the ability of algae to become a substitute for petroleum. Since algae are cultured on non-arable land, there is no misgiving on fuel-food feud [7]. Coastal area is favored as algae cultivation site due to the rich content of soluble nitrogenous compounds released from sediment during the decomposition of organic matter. Macroalgae, namely seaweeds, can be cultivated by tying them to anchored floating lines at sea. Therefore, algal cultivation is not limited by agricultural expansion over terrestrial plants. On the other hand, the growth rate of algae is tremendously high relative to land cultivation crops. In other words, there is a promising supply of biomass with only simple inputs: sea water, sunlight and carbon dioxide. In fact, the utilization of sea water greatly prevents fresh water crisis. From the point of view of ecology, macroalgae assist in reducing carbon dioxide in the atmosphere and supplying oxygen to the sea. In addition, some seaweeds species are known for their ability to remove heavy metals from the water which can be very beneficial to the environment [8]. Algae are also well-known of their capability to withstand harsh conditions and survive in stressed environment.

Third-generation bioethanol (TGB) represents fuel ethanol produced from algal biomass. Generally, ethanol is mainly produced from enzymatic fermentation of mono-sugars such as glucose. Certain species of algae have the ability to produce high levels of carbohydrates instead of lipids as reserve polymers. These species are ideal candidates for the production of bioethanol as carbohydrates from algae can be extracted to produce fermentable sugars. Seambiotic, in collaboration with Inventure Chemicals, successfully demonstrate the production of bioethanol by fermentation of the algal polysaccharides. In their plant, algae were cultivated in fossil-fuel power plants to absorb CO_2 emitted as source of inorganic carbon [9]. Apart from that, instead of extraction, there are also algal species able to conduct self-fermentation. Ueno et al. [47] reported that dark fermentation in the marine green algae *Chlorococcum littorale* was able to produce 450 μmol/g-dry wt. ethanol at 30 °C. Algenol Biofuels Inc. claims that its plant is able to produce ethanol at a rate of over 6000 gallons per acre per year. They stressed on the tolerance of the engineered algae on high heat, high salinity, and the alcohol levels present in ethanol production [10]. It is believed that discoveries of ways to exert the algal resources, both macro and micro-types of algae would ignite a remarkable energy revolution in the future.

With increase of food supply results from advancement in agriculture sector, Malaysia's population had risen sharply in an unstoppable momentum, escalating to a new height of 27.17 million in the year 2007 [11]. At the same time, the energy demand is rising exponentially to 44,268 ktonnes in 2007 with the soaring surge of population [12]. Around 35.5% of the demand comes from transportation sector which mostly utilizing liquid fuels. Therefore, third-generation bioethanol (TGB) which is carbon 'neutral' and essentially free from sulphur and aromatics can become one of the most suitable candidates for displacing petroleum-derived fuels in Malaysia and also the world. With only carbon dioxide and water released from combustion of TGB, Malaysian would be able to enjoy a cleaner environment.

Until recently, there are numerous studies focuses on production of biodiesel from microalgae [13] but still lack of research on production of bioethanol from seaweeds. Macroalgae in fact contain high amount of carbohydrates which can be utilized for the production of bioethanol. Thus, the aim of this study is to highlight the possibility, perspective and challenges of production of TGB from seaweeds in Malaysia. In this work, Sabah state was proposed as the location for the production TGB. In the first part, potential and advantages of conversion of seaweeds into TGB is briefly discussed. Next, site selection in the state was discussed for cultivation and refining of seaweeds. Subsequently, the concept of algal biorefinery was elucidated. This paper also discusses the national and state policies on renewable energy and seaweed cultivation. Finally challenges and constraints in developing TGB industry in Malaysia are elaborated.

2. Seaweeds for bioethanol production: *Euchema* spp.

2.1. Seaweeds availability in Sabah

Sabah embraces numerous species of seaweeds. Among these species, *Euchema* spp. is one of the most abundant species along the coastal area. Eucheumata is a multiaxial filamentous red algal genus with thalli weighed up to a kilogram. They have high vegetative regenerative capacities and grow very fast. They are found from just below the low tide mark to the upper subtidal zone of the reef in slow or moderate water movement. These endemic seaweeds require sandy-corally or rocky substrata to grow. At the tip of the branches, there is a group of apical meristem cells which divide actively. It is best to describe the life cycle of *Euchema* spp. as a triphasic one. They transform from gametophyte (n) (dioecious) to carposporophyte (2n) and finally the sporophyte (2n) [14]. The most important component of seaweed, in terms of industrial use, is a substance called carrageenan also commonly known as seaweed flour. The seaweeds cultivation industry is growing fast in the recent years, from less than 5000 tonnes in the year 1985 to more than 110,000 tonnes in the year 2005. The main producers are the Philippines, China, Indonesia, Malaysia (Sabah), Tanzania and Kiribati [14].