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Algae – A quintessential and positive resource of bioethanol production: A comprehensive review

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ABSTRACT

Alternate renewable energy has created a tremendous place for itself in today's scenario of energy studies. Depleting fossil fuels and high environmental pollution leading to threatening climatic changes have led to the search of alternative energy systems. Fuels derived from biological sources, the third generation biofuels – biodiesel, biohydrogen and bioethanol are being explored by researchers and scientists extensively and renewable fuel yielding biomass is now a center of attention. Algae, one such biomass, are unique biological sources with distinctive characters to produce biofuel. They are highly adaptable and can grow in all types of land and water, yielding high content of lipids or carbohydrates. Bioethanol is a biofuel reducing green house gases, carbon-di-oxide emissions and global warming, yet research have been carried out to standardize its potentialities and commercialization. This review throws limelight on potentially utilizing macroalgae for producing bioethanol and application of nanotechnology for extracting carbohydrates for bioethanol production.

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1. Introduction

In recent years, research has moved towards futuristic alternate fuels due to continued use of fossil fuels leading to declining resources [1]. Fossil fuels play important roles in energy sectors and global economy [2] and about 80–88% of basic energy used by humans comes from fossil fuels [3,4]. Fossil fuels not only dominate in field of energy but also involved in accumulation of green house gases in atmosphere resulting in global warming due to which such fuels become widely recognized as unsustainable [5–9]. Day by day the voice is raised universally against global warming due to change in weather patterns, world's sea level increase enveloping lowlands, deltas and islands and a tendency for global temperature increase by more than 2 °C. Moreover, hundreds of millions of people could lose their lives and up to one million species could become extinct [10].

Oceans absorb about one third of CO_2 released each year by anthropogenic activities and dissolved after absorption in sea reducing the water pH to more acidic. This pH decrease may cause the quick loss of coral reefs and marine ecosystem biodiversity with huge implications in ocean life and consequently the earth life [11]. An additional problem with fossil fuel is their uneven allocation in the world, for example Middle East possess 63% of the global reserves and they are the dominant supplier of petroleum [3,12]. As countries not wealthy of petroleum reserves face energy and foreign exchange crisis [13]. The research has therefore been directed to alternate clean fuel from another renewable source.

Nowadays, biologically produced fuels are looked upon with much interest and identified as a potential alternate energy source [14–16]. Bioethanol is considered as a clean and renewable fuel, due to its biodegradability, non toxicity and produce low or no pollutant to the environment and is an ideal replacement for gasoline [17–20]. It can be produced from many different biomass feedstocks especially from sugar cane or corn starch and other lignocellulosic biomass. However these sources are economically competitive to fossil fuels and also influence the increase in price of food [7,21]. Therefore, research examines the alternate source which doesn't affect the food chain and agriculture. Algae are having the capability of producing energy rich storage polysaccharides which can be hydrolyzed chemically or enzymatically and converted into bioethanol by fermentation [21].

This review paper deals with commercial possibilities of bioethanol production from algae and its advantages over various feedstocks. This article also covers the differences between microalgae and macroalgae, various pretreatment processes for the conversion of carbohydrate to ethanol, current and previous studies on bioethanol production from algae and various applications of algae and their products.

2. Need of renewable transportation fuel

The transport sector contributes almost 60% of global oil consumption and responsible for 21% CO_2 emissions to the atmosphere and power plant occupies the second place [12,22]. This may increase the greenhouse gases emissions up to 23% in 2030 [2] which might be due to use of vehicles by constantly increasing population worldwide. Around the world, there are about 806 million cars and light trucks on the road. These numbers are predicted to increase upto 1.3 billion by 2030 and to over 2 billion vehicles by 2050. China and India are world's leading populated countries and their annual oil consumption rate is 7.5% and 5.5% respectively. Especially in India, after the development of information technology, the middle class families are obsessed with buying cars and utilizing them as routine transportation by avoiding mass transport systems like bus and train. If the current situation continues, these two countries would face serious problems regarding fuel requirement for increased transportation and 45% of oil ought to be consumed from the total amount of fossil fuel sources in 2030 [1].

Biofuel has been recognized as a potential alternate fuel in future's transportation scenario. Biofuel could be a positive replacement of fossil fuel as it could mitigate the surplus demands of the latter in the near future and also could reduce the carbon emissions. 'Green' biofuel has also found its own niche in the economy of the developing countries like China and India in order to cut off the rapid rise in oil prices of fossil fuels [2,23].

Biodiesel is another ideal alternate fuel generally referred to as fatty acid methyl esters synthesized from animal fat or vegetable oil by the transesterification reaction [24–29]. However it has some disadvantages such as long term storage problem because of oxidation [30,31], nitrous oxide production while burning [30], high viscosity, low energy content and freezing properties during cold conditions [32]. Thus the meritorious features of bioethanol aid in fulfilling the current requirement and is being commercially produced in Brazil, Canada and United States for transportation [19,33]. Especially Canada, a world's leading country has committed to reduce the greenhouse gas emission levels by 6% from 1990 between 2008 and 2012 according to the Kyoto Protocol [34].

3. Chronological background of bioethanol feedstock

Bioethanol production is not a new concept; it was initiated during fuel crisis worldwide in 1970 s and the capacity of ethanol production grew from less than one billion liter in 1975, reached 39 billion liter in 2006 and expected to reach 100 billion litters in mid 2015 [21,35] due to their wide applications in many sectors particularly transport. Bioethanol production is categorized into first, second and third generations based on various feedstocks, production technology and their level of development [2,4,17,18,34,36]. Synthesis of each generation bioethanol and respective feedstocks are shown in Fig. 1. Ethanol produced from food crops like corn, wheat, barley and sweet sorghum is called grain alcohol where as ethanol produced from lignocellulosic biomass and agro residue such as rice straw, wheat straw and grasses is known as biomass ethanol or bioethanol [37].

3.1. First generation biofuel

The first generation of bioethanol sources have been exploited for nearly three decades [2] but undoubtedly it was argued with many social issues. During this period, sugarcane, sugar beet, wheat, molasses, barley and maize were used as feedstock for ethanol production which created serious problems on food versus