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Potential of microalgal biodiesel production and its sustainability perspectives in Pakistan

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ABSTRACT

Pakistan has a strong potential of biodiesel production if the available feedstock resources are used sustainably and implementable policies are made in appropriate direction. To meet the energy demands and to find alternative and non-conventional resources of energy different challenges like research and development, infrastructure development, decentralized type of power delivery system, commercialization, market development, education and outreach programs, public awareness, monitoring, subsidies, government participation, technology transfer and evaluation must be considered and a comprehensive policy must also be made to systematically control and integrate them at national level. Pakistan is enriched with a wide variety of feed stocks which can be used for biodiesel production. Pakistan has an enormous potential of biodiesel production from jatropha, plants seed oil and microalgae which needs more consideration and practical applications. Harvesting the potential of microalgae for biodiesel production in Pakistan can be helpful to make it self-sufficient for energy demands. Pakistan is also facing several challenges like climate change, lack of financial resources, state of art technology and absence of appropriate government policies, which limit the commercialization of biodiesel. Although Government of Pakistan has established different institutions to promote and develop alternative energy technologies and to achieve 10% share of bioenergy in the energy sector by 2020, but still the targets are to be achieved on practical grounds. In this article, we have reviewed the potential of biodiesel in Pakistan, feed stocks, biodiesel production process, barriers and future developments. Future policies on biofuels, trends, recommendations, and the implication of existing policies are also discussed with research and developments goals for the promotion of biodiesel in Pakistan.

1. Introduction

The world is facing serious energy crisis in this century due to increased industrialization and overuse of natural resources such as fossil fuels. Fossil fuels comprise 88% of the global energy consumption [1]. The shares of oil, coal and natural gas are 35%, 29% and 24% respectively. It was estimated that there would be approximately 53% increase in energy demands by the year 2030. It is expected that in USA alone, the petroleum demands may escalate to 116.00 million barrels per day by 2030. With the same pattern of consumption for coming 40 and 60 years may result in depletion of most of the oil and gas reserves [2]. The use of fossil fuel resources imparts serious negative impact on the environment. Burning of fossil fuels generates greenhouse gases which aggravate the global warming. It is estimated that the burning of fossil fuel contributes the maximum share in the emission of greenhouse gases [3]. By 2006, the fossil fuels associated CO_2 emissions were 29 billion tones. CO_2 emission also affects the ecosystem biodiversity [4]. For example, 1/3rd of emitted CO_2 is absorbed into the oceans, which change the water pH. The change in water pH results in the death of marine species. Depletion of fossil fuels is essential to be addressed for the energy security, climate changes and sustainable development [5]. In view of extensive dependence on non-renewable sources for energy, there is dire need to utilize the alternative sources of energy. These sources should hold the trait of sustainability and green economy. In this perspective, biofuels have emerged as potential alternatives [6,7].

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Biofuels are promising alternative source of energy as they are prevalent in nature. They are renewable and available throughout the world. Biofuels can be obtained from existing biological resources [8]. In coming decades the share and utilization of biofuels in the motorised fuel market is more expectedly to grow rapidly. Therefore, biofuels production is expected to grow fast in coming years [9]. European countries have made reasonable policies in this context and planned to utilize about 5.75% of biofuels at the end of 2010 and 10% till 2020. High crop productivity can also play an important role in the energy budget. The global biodiesel production was estimated as 5.8 billion litters in 2006 [10]. As far as the global biofuel production is concerned, different countries differ in biofuels production shares they add i.e. Germany (48% of total), other European countries (30%), USA (15%) and several other countries, such as Brazil, China, India, Canada, Colombia, and Malaysia, almost have 7% share [6].

According to the estimates of 2007, about 7% of global vegetable oil production was required for biodiesel plants in European Union [11]. The global vegetable oils production reached about 115 million tonnes in 2006 of which the basic share was among few countries i.e. Brazil, China, India, Indonesia, Nigeria, Philippines, Pakistan, Thailand, USA, and Uzbekistan contributing about 80% of the total production. USA and Brazil were the leading producers in the same years producing about 8 million tonnes of tallow which is the most important animal fat [12].

Biofuels production has a rich history. Through past few decades, a wide range of feed stocks have been examined for biofuels productivity. For biodiesel production, feed stocks are grouped as first generation (G1), second generation (G2), and third generation (G3) biofuels. In the following section, we will discuss these feed stocks in detail [13,14].

This article is a review of the barriers in production, future developments and potential of biodiesel production in Pakistan. Future policies on biofuels, trends, recommendations, and the implication of existing policies are also discussed with research and development (R & D) goals for the promotion of biodiesel production in Pakistan. The review overviews the feed stocks i.e. G-1, G-2 and G-3, suitability and technology implications for biodiesel production in Pakistan.

The current review presents up-to-date information on biodiesel production from various feed stocks with special emphasis on microalgae as substrate. Structurally, the paper comprises of 11 sections. The overview of the biodiesel feed stocks is presented in Section 2. In Section 3, the mechanism of microalgal biodiesel production is elaborated. Sections 4 and 5 describe advancements in methods of biotechnology and lipids metabolism in microalgae, respectively. Sections 6, 7 and 8 are based on the future policy on biofuels, midterm policy for biofuels and biodiesel policy recommendations for Pakistan, respectively. Detailed biodiesel policy recommendations are given in details in Section 9 and the impacts of biofuels on socioeconomics and Pakistan's potential of biodiesel and bioethanol are elaborated in detail in Sections 10 and 11 respectively.

2. Biodiesel feed stocks

2.1. First generation feed stocks

First generation feed stocks for biofuels are mainly oil seeds and food crops. Feed stocks such as soybeans, rapeseed, sunflower and palm oil comprise first generation feed stocks because they were primarily used to produce biofuels [15]. Biodiesel production from aforementioned first generation feed stocks is easy as these are obtained by simple pressing of oil-bearing biomass [16]. Energy generation is not restricted by technological limitation; instead it could be increased by increasing feed stocks. For improving domestic energy security, first generation biofuels can offer some benefits concerning carbon sequestration. Different energy demands by source are expected till 2030 worldwide (Fig. 1). On annual basis, almost 50 billion liters of

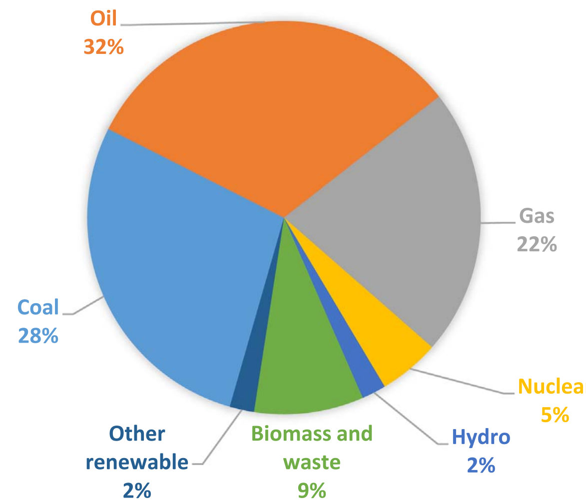

Fig. 1. Different energy demand by source expected till 2030, worldwide [22].

1st generation biofuels are produced [17]. First generation biofuels can be categorized on the basis of either their potential to be blended with petro-fuels or to be combusted directly in engines. These can be circulated through existing infrastructure, or through utilization in alternative vehicle technologies like Flexible Fuel Vehicle (FFVs) or in vehicles using compressed natural gas (CNG) [18].

Based on their macromolecular composition, the first generation feed stocks consisting of vegetable oils and animal fats are mainly composed of triglycerides and di-glycerides as major constituents and mono-glyceride as a small fraction. The vegetable oils are long chains molecules with multiple alkyl branches with increasing molecular size. The relative molecular weight of vegetable oils ranges from 850 a.m.u. to 995 a.m.u. which is much higher than diesel (168 a.m.u. on average) [19,20]. The chemical formula for common diesel fuel is $C_{12}H_{23}$. After reducing the viscosity and specific gravity of vegetable oils they can substitute petro-diesel. For this purpose different techniques are examined and employed. Among these, transesterification is commonly employed technique, which is the most reliable, most feasible, and can easily be used for biodiesel production. It has many advantages over other processes e.g., it is performed under normal conditions and it returns good quality and quantity of biodiesel [21].

Trans-esterification is a catalytic chemical method in which the triglycerides are converted into di-glycerides which are then converted into mono-glyceride in the presence of methyl or ethyl alcohol and from an ester linked molecule called biodiesel [19]. The production of biodiesel from oil through trans-esterification mainly depends upon the nature of feedstocks exploited, quantity and kind of catalyst, alcohol, operational temperature, and chemical reaction time [23]. Various procedures have been investigated for the production of biodiesel from vegetable oil and upon the chemical analysis of the product. It was evident that the chemical properties were similar to that of petro-diesel. The methods of biodiesel production are: transesterification, microemulsification, cracking, blending, and pyrolysis. Trans-esterification is the chemical conversion of the oil into fatty acid methyl esters (biodiesel). The viscosity of vegetable oil is also reduced through the process of trans-esterification, therefore it is widely used [24].

The transesterification reaction occurs in the presence of suitable homogeneous catalysts i.e. base catalyst such as potassium hydroxide (KOH) or sodium hydroxide (NaOH) and base catalyst such as sulfuric acid, or heterogeneous catalysts such as metal oxides or carbonates. NaOH is well-known and widely employed because of its low-cost and high product yield efficiency [25]. The following factors influence trans-esterification process: reaction temperature, ratio of alcohol to vegetable oil, amount of catalyst, mixing intensity, raw oils used, and catalyst [26]. Among first generation feedstocks, rapeseed oil (especially) has the highest prospective to be utilized as a fuel for diesel