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Review

Evolution retrospective for alternative fuels: First to fourth generation

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ABSTRACT

The ever increasing worldwide demand for liquid and gaseous fuels along with overwhelming environmental concerns for greenhouse gas emissions have driven scientists and technologists to consider different alternative energy sources. In past decades, several biomass sources have been identified with increasing potential to be used as new alternative sources of energy - the “Biofuels”. The evolution of biofuels is classified into four different generations.

In this article an overview of the systematic evolution of different biofuel generations with their advantages and disadvantages has been presented. The advancements in technology, reduction in greenhouse gas emission and assessment of commercial production cost of each generation of biofuel have also been highlighted. Finally this review provides an outlook for a better future generation biofuel.

1. Introduction

Inescapable growth of the global population, which is projected to exceed 9 billion by 2050, will raise the average calorie intake pushing the productivity from already scarce arable land to its limit. The energy demand in developing nations are expected to increase by 84%, and nearly one-third of this additional fuel possibly come from alternative renewable sources – such as biofuels [1]. In the last few decades major research emphasis has been directed towards sustainable and economical sources of biofuel as evident from large number of research publications worldwide, particularly from Europe and USA (Fig. 1a). The year wide distribution of research articles published on biofuels has exponentially increased over the past 20 years (Fig. 1b). This clearly depicts the growing concern to have alternative biofuel energy resources.

The paradigm in biofuel research and developments has considerably been shifted toward alternative and efficient biomass source. Starting from the production of biodiesel from of edible or nonedible seed-oils to algae metabolic engineering, this series of evolution are classified into four generations. The major feedstocks for first generation biofuels (corn, wheat, barley and sugarcane) are the sources of food, thus may result in a food-fuel competition. It was reported that though only 2% of world’s arable land had been used to grow biomass feedstock [2] for first generation biofuel production, it had significant contribution toward increased commodity prices for food and animal feeds. However, direct or indirect impact of biofuels on food price hike remains inconclusive in literature or media. The production of biofuels from agricultural and forest waste or non-food crop could resolve the crisis. Second generation biofuel from these lignocellulosic feedstocks including by-products (cereal straw, sugarcane bagasse, forest residues), wastes (organic components of municipal solid wastes), and dedicated feedstocks (purposely-grown vegetative grasses, short rotation forests and other energy crops) would also need land in competition with food and fiber production. However, energy yields (in terms of GJ/ha) from these crops are likely to be higher than those of first-generation biofuels crops or their products [3].

The search for alternative sources continued further to reduce the food cropland competition until using algae - as a sustainable and rich source of biofuel which is known as third generation biofuel. Algae do not compete with food or other crops and can be cultivated in shallow lagoons or raceway ponds on marginal land or closed ponds. Moreover, algal biofuel feedstocks can be produced throughout the year unless it is limited by light irradiation, and the oil yield can even exceed that of the best oilseed crops. For example, yield of biodiesel from algae (58,700 L/ha) containing only 30% oil by weight, is much higher when compared with rapeseed or canola (1190 L/ha) [4], Jatropha (1892 L/ha) [5], and Karanj (*Pongamia pinnata*) (2590 L/ha) [6]. However, the biofuels from above sources have limitations in terms of ecological footprint, economic performance, dependence on environment (sunlight), geographical location (latitude) and thus insufficient to replace fossil fuels.

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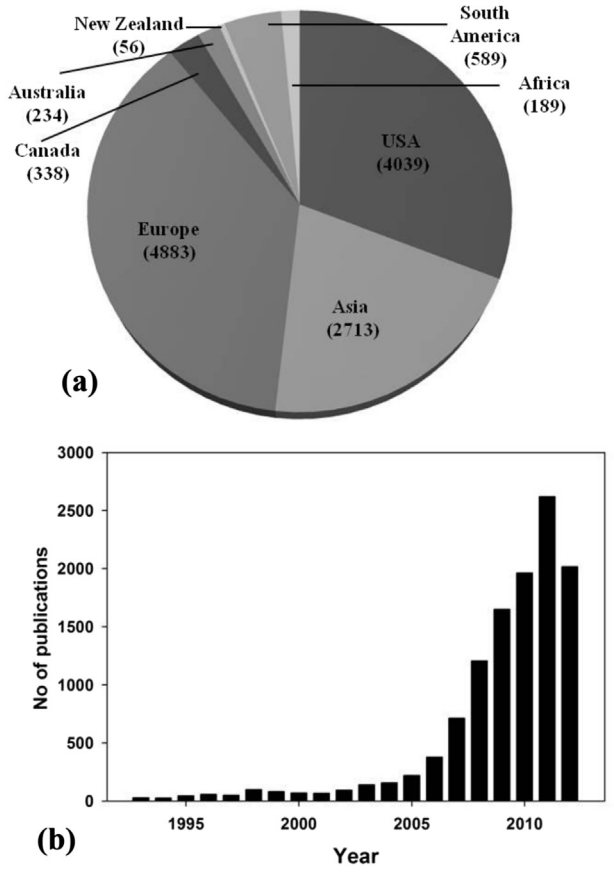

Fig. 1. Number of published paper related to biofuel (a) geographical area wise and (b) annually (based on a literature survey by using the ISI Web of Knowledge on April 2013).

Metabolic engineering of algae for production of biofuel is considered as fourth generation of biofuel and has great potential in providing sustainable and clean energy [7].

The advantages and limitations of different generations of biofuel are given in Table 1. Fig. 2 shows a comparative view on research performed on different generations of biofuel in past years.

Though the idea of first generation biofuel had emerged a long time ago, it gained significant attention in early 90's. However, the majority of research work has been carried out in between 2006 and 2010. Whereas fourth generation biofuel research has set in from that period only. Based on published research articles, it appears that in last two years third generation biofuel has received the maximum emphasis.

The aim of this paper is to provide the evolutionary path of biofuel research in terms of feedstock development and technological advancement to obtain sustainable and economically feasible replacement of fossil fuel. The review presents the cost effectiveness, GHG mitigation and energy efficiency of each biofuel generation compared to fossil fuel. Altogether the paper describes about each generation of biofuel with its merits and demerits, and how the limitations of each biofuel generation have been overcome by its successor.

2. Biomass production for different generations of biofuels

Biofuels are classified in four different generations depending on their biomass feedstock. Following sections discuss about the biomass feedstock for different generation biofuels and their suitability to be used as replacement of fossil fuel. Table 2 shows the feedstocks and the end products of different generations' biofuels.

2.1. First generation biofuel feedstock

As discussed earlier, first generation biofuel feedstocks mainly comprised of oilseed, sugarcane and other oil containing food and animal feed crops. First generation bioethanol is mainly produced from sugar containing plants or cereal (grain) crops. Till date the largest volume of biofuel is produced in the form of ethanol, 80% of which has come from corn and sugarcane. Hayashida et al. [8] obtained about 20% (v/v) ethanol conversion from raw ground corn using a mutant of *Aspergillus awamori* var. *kawachi*. Rolz and de Leon [9] studied the ethanol production from sugarcane at different maturity levels. They observed better ethanol yields after 300–325 days of planting. Vegetable oils are also used after a range of conversion to fatty acid methyl or ethyl esters. Nabi and his coworkers [10] obtained 77% biodiesel yield with 20% methanol in

Table 1
Pros and cons of alternative fuel options.

Generation	Pros	Cons
First	GHG savings Simple and low cost conversion technology	Low yield Cause food crisis as a large portion arable land required for growing crops
Second	GHG savings Utilize food wastes as feed-stock No food crop competition Use of non-arable land for growing few energy crop	Costly pretreatment of lignocellulosic feedstock highly advanced technology need to be developed for cost effective conversion of biomass to fuel
Third	Easy to cultivate algae Higher growth rate No food crop competition Versatility: can use wastewater, seawater	More energy consumption for cultivation of algae (for mixing, filtration, centrifugation etc), low lipid content or biomass contamination problem in open pond system High cost of photo-bioreactor
Fourth	High yield with high lipid containing algae More CO_2 capture ability High production rate	Initial investment is high research is at its primary stage

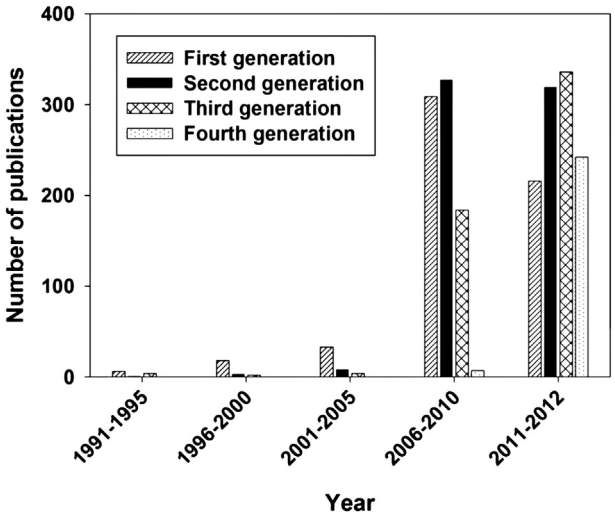

Fig. 2. Number of published paper related to different generations of biofuel in last 20 years (based on a literature survey by using the ISI Web of Knowledge).