



## Biofuels - The Way Ahead

### KEYWORDS

Renewable sources, biofuels generation and microalgae

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**ABSTRACT** Depletion of petroleum derived fuel and environmental concern have emphasized the need to produce sustainable renewable fuels and chemicals. Biofuel from renewable sources can be an alternative to impart a remarkable role for maintaining sustainability and security in energy sector. A complete substitution of petroleum derived fuels by biofuel is impossible yet, marginal replacement of fossil fuels by biofuels can delay the depletion of petroleum resources and abate the radical climate change caused by automotive pollutants. Biofuels are broadly classified into three categories: first generation biofuels-from biomass that is usually edible; second generation biofuels-from lignocellulosic feedstocks or municipal wastes; third generation biofuels- from microorganisms, majorly from algae. In terms of food security, the use of those energy crops which are used as food products for biofuel production is of concern. Biofuel production using microalgae is attractive prospect in this scenario. The review presents an overview of the usage and sustainability challenges of biofuels.

### INTRODUCTION

One of the most important challenges faced by mankind in this century is the steady and inescapable depletion of the earth's fossil energy resources. Today we "borrow land from the past" (Wackernagel and Yount, 1998), by using carbon which was fixed in another era. Use of crude oil reintroduces into the atmosphere carbon trapped millions of years ago. The reports of Energy Information Administration International Energy Outlook (2007) highlighted that global energy usage is projected to nearly double in the next two decades (Herrera, S. 2006). The most recent figures from the International Energy Agency (IEA) estimate that total energy consumption from all sources will go up from 406 quadrillion Btu in 2000 to 770 quadrillion Btu (1 quadrillion Btu =  $1 \times 10^{15}$  Btu =  $1 \times 10^{10}$  GJ) in 2035 (IEA, 2010; IEA, 2010c) which is approximately the amount of electricity consumed by Italy in 2008 (CIA, 2011; CIA, 2011. The World Factbook, Central Intelligence Agency, Washington, D.C.). A large percentage of this increase in demand is expected to come from the rapid growth of non-OECD countries such as India, China, and sub-Saharan Africa (IEA, 2010). Presently, most of this energy requirement is met by the combustion of fossil fuels such as petrol, coal, and natural gas (Fernandes et al., 2007). Currently, petroleum meets around 98% of the entire demand in transportation sector and is responsible for the dangerous CO, NO<sub>x</sub>, HC and particular matters, resulting the global warming at an alarming rate. The transportation sector is responsible for the global warming of about 13.5% (Baumert et al., 2005). Global CO<sub>2</sub> emissions enlarged from 21000 million tonnes in 1990 to 30276.1mil-

lion tonnes in 2010 (Masjuki et al., 2013). The rising prices, declining supplies, global warming and climate change due to the exhaust emission of the fossil fuel and energy security associated with the use of fossil fuels are driving the development and use of alternative energy sources based on sustainable, regenerative and ecologically friendly processes (Gonzalez-Garcia et al., 2010, Singh et al., 2010 and Sahin, 2011). Biofuels, which have been produced from renewable resources, such as plant biomass, vegetable oils, and treated municipal and industrial might serve as a sustainable, carbon-neutral energy source compatible with current engine technology. They are considered potentially 'carbon neutral', due to the fact that the plants absorb the carbon dioxide which is released when they are burnt (Geoffrey P.H. et al., 2013).

A sustainable biofuel should provide a net decrease in Green house gas emissions, it should not lead to local environmental degradation, its price should be comparable to price of existing fossil fuels, it should contribute to local employment and economic development and avoid competition with food crops (Ademola et al., 2013). Biofuels have been broadly classified to differentiate between first generation (1G) biofuels, produced primarily from foods crops such as grains, sugar cane and vegetable oils and second generation (2G) biofuels, produced from cellulosic energy crops such as miscanthus and willow, agricultural forestry residues or co-products such as wheat straw and woody biomass (Alison et al., 2013).

## 1G AND 2G BIOFUELS: FOOD VS. FUEL

First generation biofuels are liquid fuels obtained primarily from the fermentation and esterification of food crops such as maize, soy, and palm. These are already an established energy industry in the USA, Brazil, Argentina, and the European Union (Cheng and Timilsina, 2011). These fuels can be further classified into bioethanol, biomethanol, or biodiesel. Bioethanol is currently produced using first generation technology to ferment and then distil sugar (e.g., from sugarcane, sugar beet, and sweet sorghum) or starchy crops (e.g., corn, wheat, and cassava) (Geoffrey P. H et al., 2013). It is produced by fermentation of crops high in sugar, or by a series of hydrolysis/fermentation steps for starchy materials (Hammond et al., 2008). Bioethanol has been produced from sugarcane in Brazil, and from corn (maize) and soybeans in the USA for a long time (Elghali et al., 2007). The United States and Brazil are the two largest producers of ethanol. The United States generated 49 billion liters, or 57% of global output, and Brazil produced 28 billion liters, or 33% of the total output in 2010. Corn is the primary feedstock for US ethanol, and sugarcane is the dominant source of ethanol in Brazil. Brazil is the largest single producer of sugarcane with about 27% of global production and a yield of 18 dry mg/ha. Maize is also used as a feedstock for the production of ethanol fuel. Ethanol is mixed with gasoline to decrease the amount of pollut-

ants emitted when used to fuel motor vehicles. The United States produces 40% of the world's maize harvest. Other top producing countries include China, Brazil, Mexico, Indonesia, India, France and Argentina. Worldwide production of maize in 2009 was 817 million tonnes, more than rice (678 million tonnes) or wheat (682 million tonnes) (FAO report 2009). Tuber of Sugar beet (*Beta vulgaris*), contains a high concentration of sucrose. It is also grown commercially for sugar and ethanol production. In 2009, France, the United States, Germany, Russia and Turkey were the world's five largest sugar beet producers (FAOSTAT Food and Agriculture Organization, United Nations; 2010.). In India, in 2003, the Ministry of Petroleum and Natural Gas launched the first phase of the Ethanol Blended Petrol (EBP) Program that mandated the blending of 5% ethanol in gasoline for nine states and four union territories (Singh, S.K., 2007). As India does not have any surplus of edible vegetable oil, India's biodiesel production mainly focuses on non-edible vegetable oil such as *Jatropha* tree (*Jatropha curcas*), *Karanja* (*Pongamia pinnata*), *Mahua* (*M. indica*) and *Neem* (*A. Indica*) process was given in figure 1. The Indian government through its bioethanol program has called for E5 blends throughout most of the country and is targeting to raise this requirement to E10 and subsequently to E20 (Masjuki et al., 2013).

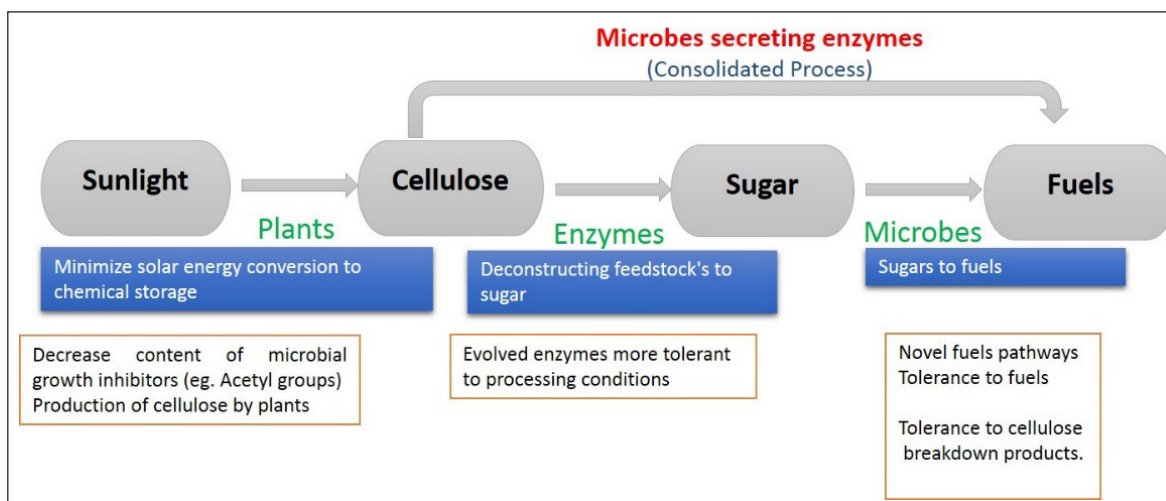


Figure 1. Rout from sunlight to fuels.

A key bottleneck with bioethanol production is that the availability feedstocks can vary significantly from season to season and depend on geographic locations. Another major problem is that ethanol production from lignocellulose requires pre-treatment. Lignocellulosic materials contain cellulose and hemicellulose bound together by lignin. Cellulose and hemicellulose are both polymers built up by long chains of sugar monomers, which after pretreatment and hydrolysis can be converted into ethanol by microbial fermentation (Pettersson et al., 2007 and Gunnur, 2013). A serious drawback of these biofuels is that they can lead to a direct competition between the use of such crops for food and fuel, and indirect competition for agricultural land used to produce food crops which can further lead to the conversion of forested land for expanding crop production (Mueller et al., 2011). First generation biofuels are also limited by their inability to achieve targets for oil-product substitution (without threatening food supplies and biodiversity) and for GHG reductions. The limitations of 1G biofuels have led to research into alternative sources and technologies. Work is now being done to develop methods for the sustainable use of the residual, non-food components of existing biomass sources such as the stems, leaves, and husks, along with the cultivation of non-food crops such as *jatropha*, *Mahua*, *Tobacco* seed and *Miscanthus* (Mueller et al., 2011). In contrast to 1G biofuels,

more advanced second generation biofuels like biodiesel are generally produced from cellulosic biomass which include herbaceous lignocellulosic species [such as *miscanthus*, *switchgrass* and *reed canary grass* (perennial crops) and trees such as *poplar*, *willow* and *eucalyptus* (short rotation crops)], as well as forestry and agricultural residue (Hammond et al., 2008 and Hammond et al., 2012). Biodiesel is a liquid fuel made up of fatty acid alkyl esters, fatty acid methyl esters (FAME), or long-chain mono alkyl esters. It is produced from either oil extracted from seeds or oil-rich nuts, or recovered waste vegetable oils and animal fats. Biodiesel is obtained by transesterification of these feedstocks to produce methyl ether (Hammond et al., 2008). Transesterification process is an alcoholysis process that converts triglycerides of vegetable oil to fatty acid methyl/ethyl esters by displacing alcohol from an ester by another alcohol (Srivastava et al., 2000). Transesterification of triglycerides was for the first time conducted by E. Duffy and J. Patrick in 1853. Oils from soy, canola, corn, rapeseed, and palm are common raw materials for biodiesel. New plant oils that are under consideration include mustard seed, peanut, sunflower, and cotton seed (Demirbas, 2009). Biodiesel can be used in compression-ignition diesel engines, normally as a 5% blend, although it can be employed at 100% in specially-modified engines (Hammond et al., 2008). The world's largest biodiesel producer

is the European Union, accounting for 53% of all biodiesel production in 2010 (World Watch biofuel report, 2010). A speedy growth in production capacity is being observed not only in developed countries like Germany, Italy, France, and the United States but also in developing countries like Brazil, Argentina, Indonesia, and Malaysia (Santos et al., 2012). Soybean oil and rapeseed oil are commonly used for biodiesel production in United States and many European countries respectively. Coconut oil and palm oils are used in Malaysia and Indonesia for biodiesel production. In India, the *Jatropha* tree, *Karanja* and *Mahua* are used as significant fuel sources (Demirbas et al., 2009). Palm oil is widely used in Southeast Asia to generate a high yield biofuel, which is an advanced feedstock option for a longer term. The main producers of soybean are the United States (35%), Argentina (27%), Brazil (19%), China (6%) and India (4%) (United States Department of Agriculture. World Markets and Trade. Feb. 17, 2012). In addition, soybean is used mainly as animal feed.

Second generation biofuels, unlike 1G biofuels do not compete directly with arable land and so are thought to be sustainable (Chisti, 2007). They also have a lower environmental impact than first generation biofuels as they require less fertilizer, water, and pesticide inputs (Carriquiry et al., 2011). However, land-use changes that have taken place in relation to the growth of these crops challenge their sustainability (Havlik et al., 2011). Especially, commercial production of these second generation non-food crops on fertile land had placed them in direct competition with arable land used for food production (Achten et al., 2010). In 2010, the US consumed nearly 220 trillion liters of diesel. To produce this volume of fuel using soybeans for example (average yield of 600 liter per hectare), would require 367 million hectares, in contrast with the only 178 million hectares that is currently available for cropland and the 930 million hectares of total US land area (EIA, 2012; EIA, 2012. Annual Energy Outlook).

### 3G BIOFUELS

The disadvantages of first and second generation biofuels, has resulted in the development of third generation biofuels obtained from microalgae. This is due to the potential for deriving higher productivity per unit area than previous feedstocks, in addition to avoiding direct competition with food crops (Wijffels and Barbosa, 2010). Microalgae are a collection of photosynthetic microorganisms that can grow rapidly and live in harsh conditions, due to their simple unicellular or multicellular structure. Their position is at the bottom of food chains. There are more than 300,000 species of micro algae, diversity of which is much greater than plants (Schenk et al., 2008). They are thallophytes plants lacking roots, stems, and leaves that have chlorophyll as their primary photosynthetic pigment and lack a sterile covering of cells around the reproductive cells (Brennan et al., 2010). The biomass that is produced can be harvested from large open ponds or customized closed chambers called photo-bioreactors (PBR), dried, and then processed to produce bioethanol or biodiesel (Mata et al., 2010). Growth rates can be accelerated through careful improve their yields (Mata et al., 2010). The potential for biodiesel production from microalgae is 15 to 300 times more than traditional crops on an area basis (Nigam et al., 2011). Algae with 30 wt% oil could produce 12,000 L ha<sup>-1</sup>yr<sup>-1</sup> compared with 5950 L ha<sup>-1</sup>yr<sup>-1</sup> from oil palm, and 1892 L ha<sup>-1</sup>yr<sup>-1</sup> from *Jatropha* (Schenk et al., 2008).

Microalgae provide significant advantages over plants and seeds as they: i) synthesize and accumulate large quantities of neutral lipids (20-50 % dry weight of biomass) and grow at high rates; ii) are capable of all year round production, therefore, oil yield per area of microalgae cultures could

greatly exceed the yield of best oilseed crops; iii) need less water than terrestrial crops therefore reducing the load on freshwater sources; iv) cultivation does not require herbicides or pesticides application; v) sequester CO from gases emitted from fossil fuel-fired power plants and other sources, thereby reducing emission of greenhouse gas (1 kg of dry algal biomass utilize about 1.83 kg of CO<sub>2</sub>). Compared with conventional crop plants which are usually harvested once or twice a year, microalgae possess a very short harvesting cycle (1 to 10 days depending on the process), allowing multiple or continuous harvesting with significantly increased yields [Nigam et al., 2011 and Scott et al., 2010]. Furthermore, the microalgae generally have higher productivity than land based plants as some species have doubling times of a few hours and accumulate very large amounts of triacylglycerides (TAGs). Most importantly, the high quality agricultural land is not required for microalgae biomass production (Schenk et al., 2008). However, significant engineering challenges remain before algal-based technologies can be practical, including large-scale cultivation.

In recent years, the exploration of microbial oils has been paid much attention rather than other sources. In the future, it might become one of latent oil sources for biodiesel production. Microbial oils produced by some oleaginous microorganisms, such as yeast, fungi, bacteria, and microalgae. It is also known as single cell oils (SCOs) (Ma et al., 2006). This is a green and renewable energy that helps in conserving fossil-fuel usage due to the advantages emphasized as short microbial life cycle, less labor required, less affection by venue, season and climate, and easier to scale up (Li and Wang 1997). Thus, SCOs had might become one of promising oil feedstocks for biodiesel production in the future. Microbial oil sources have been proposed as a sustainable alternative, and microbes have been engineered to produce fatty acid ethyl esters (FAEEs) directly. FAMEs and FAEEs typically range in length from 12 to 22 carbon atoms and have a comparable energy density to petrodiesel. The high energy density and other advantageous properties, such as good lubricity and lower emissions, make FAMEs a good renewable diesel replacement.

### CONCLUSION

Economically, environmentally and socially sustainable biofuel production faces several challenges like, biofuel versus food competition, recalcitrance of biomass for biofuel production, and less-than-ideal physical properties of biofuels. The 'first-generation' biofuels appear unsustainable because of their impact on food prices and the environment. The controversy surrounding first generation biofuels has helped to articulate sustainability issues and challenges that need to be considered in implementing second generation biofuels. Given the current state of technology, and the uncertainty remaining about the future breakthroughs that would potentially make some second-generation biofuels cost competitive, policymakers need to carefully consider what goals are to be pursued in providing support to different biofuels. Third-generation biofuels are mostly produced from algae. Algae produce biomass faster and on reduced land surface as compared with lignocellulosic biomass. However, production of algal biomass presents technical challenges such as lipid extraction and dewatering, as well as geographical challenges. The future of biofuels relies an integrated approach combining policies designed to reward environmental performance and sustainability of biofuels, as well as to encourage provision of a more abundant and geographically extensive feedstock supply.

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