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Review

New sources of feed stocks for biofuels production: Indian perspectives

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Energy security looms as one of the most important challenges of this century for scientists and users in India. Resources alternative to fossil including fungi, grasses, algae, waste oils, food crops and non-food crops are being developed. Considering the current food insecurity in the country, food crops are to be excluded from the list of feed stocks. In future, biofuels should ideally create the environmental, economic and social benefits to the communities and reflect energy efficiency so as to plan a road map for the industry to produce third generation biofuels.

Key words: Biofuels, feed stocks, India, energy security.

INTRODUCTION

In India, the energy sources include liquefied petroleum gas (LPG), electricity, kerosene, firewood and coal. Electricity is not yet available in a few villages and the gas connection is being demanded by a majority of households in cities and towns. Also, recent increased prices of the petroleum products affecting adversely the livelihood.

Energy is essential for industrial production. Therefore, there is shift from affordable energy to commercial energy including new and renewable resources and nuclear power. Fossil fuels continue to account for the overwhelming share of primary energy consumption. The traditional resource management has also gradually collapsed resulting in inequality in access to energy resources. With advancement in biofuels research and development, it is now possible to fight against climate change by not depending on non-renewable deposits of coal and petroleum. This paper discusses the current situation and perspectives of biofuels in India.

GLOBAL MARKET SCENARIO

The fuel-grade ethanol production in 2007 in China and Thailand was 1.8 and 0.3 billion litres respectively (Jadhav, 2009). For now, the energy use has already increased by about 30% in Latin America, 40% in Africa and 50% in Asia (Jadhav, 2009). The European Union produces 4.84 million tonnes/year of biodiesel with major share from Germany (2.18 million tonnes) (Jadhav, 2009) while current production is about 100 million litres in Australia and 200, 000 tonnes in Malaysia. In the USA, the ethanol production may reach a target of 136.38 billion litres by 2016. Overall, the global demand of biofuels is expected to rise by 50 to 60% in coming 20 years.

CURRENT SITUATION OF BIOFUELS DEMAND AND PRODUCTION IN INDIA

Fossil-based fuels are used extensively as energy source and are among the major causes of environmental pollution, in this century for the country; and reflect indirectly on food security because the use of food crops for biofuels production could pose threat to food supply (Gahukar, 2009). Therefore, other sources of biofuels are being searched (Shinoj et al., 2011) which include bioethnaol, biobutanol, biodiesel, bio-oils, cellulosic ethanol, biohydrogen, biomethyl ether, dimethyl tephthalate, biomethanol, 2-5-dimethylfuran, hydro-thermal upgrading diesel, Fischer-Tropsch diesel, mixed alcohols, wood diesel, and biofuel from grasses, non-food crops, non-edible oilseeds, algae and micro-organisms. High energy biofuels from agricultural residues and energy crops are also envisaged (Raju et al., 2009).

India is the sixth largest energy consumer and there is enormous scope for developing production and marketing of biofuels. At present, the supply of bioenergy looms as one of the important challenges, because India produces 30% of its annual crude oil and petroleum products requirement of 105 million tonnes and meets 70% of its requirement through import (Jadhav, 2009) with 150 to 200 tonnes of ethanol used annually for fuel blending. This demand (annual rate of 4.8%) is estimated to grow to 5.8% till 2030 (Jadhav, 2009). Nevertheless, the importance of biofuels will depend upon petroleum price, progress in bioscience and technology, and awareness among people about natural resources. In recent years, there had been steep rise in prices of the petroleum products. Although, the 100% foreign direct investment (FDI) in technologies provided the fuel for domestic use, it is speculated that biofuel production on large scale will result in non-availability of foods, rise in food prices, deforestation, diminution in biodiversity and undesirable impact on local land and water resources. Public and private firms are therefore working on technologies for the biofuel production from agricultural residues and energy crops. Likewise, the government has plans to execute greening of countryside by providing green fuels for rural electrification programmes along with employment opportunities expecting that the production will trigger huge growth in domestic plantation and processing (Jadhav, 2009). This venture is welcome since availability of land and the low cost of production have made India as one of the most favoured and potential country for biofuel production. In this sector, major activities include community development through afforestation, incentivizing the operations across the value chain, regulating the markets by curtailing import of free fatty acids, restricting handling and distribution within and outside the states and revising periodically the purchase prices of biofuel crops for the benefit of farmers. For this purpose, biofuel manufacturing has been taken by several private companies. At government level, the Ministry of New and Renewable Energy has announced the National Policy on Biofuels on December 23, 2009. The goal of this policy is to ensure a minimum level of biofuels and meet the public demand. For this purpose, 20% blending of biofuels, both for biodiesel and bioethanol, is proposed by 2017 instead of current mandatory 5% blending of ethanol and optional 10% mixing. To achieve this target, the biodiesel production has to be increased to 11.38 million tonnes by the end of the year 2012 (Jadhav, 2009). Although, statistics on use of biodiesel is not available as it is mostly distributed through unorganized means, the National Mission on Biodiesel forecasted blending of biodiesel/bioethanol with high speed diesel and about 11.19 million hectares of land, from a total 185 million hectares of cultivable land have to be converted into plantations of which 7.98% ha under jatropha (*Jatropha curcas*) alone. The policy also encourages industry with subsidies to boost biofuel processing. But the present feed stock can meet the demand of only small biofuel processing units. Therefore, basic custom duty on biodiesel will be reduced from present 7.55 to 2.5% at par with petro-diesel. If diesel or petrol price falls below the minimum purchase price (MPP) of 20% that has been set by the government as per the National Policy on Biofuels, the marketing companies will be duly compensated by the government as MPP for biodiesel marketing companies will be linked to the prevailing market price. Finally, infrastructure development, cost-effective technologies, 100% FDI, tax sops for import of required machinery shall boost the production. With these initiatives and subsidy, the government expects to generate revenue of about US$ 5280 million/year and save foreign exchange. On social front, collection of seeds of non-edible oilseed crops would provide an additional means for farmers and labourers, and would help to create an effective network (national/regional) for seed procurement.

PRODUCTION OF BIOFUELS

Among renewable energy sources, biofuels are gaining importance and there had been scientific progress in developing biofuels from various sources. The landmarks in research and development activities are presented in the course of this work.

The first generation biofuels produced by using food crops can affect the availability of foods and may result in a rise in prices. It seems that the first generation biofuels are not cost-competitive with existing fossil fuels, their life cycle emissions often exceed those of fossil fuels, and some of them produce only limited greenhouse gas (GHG) emission savings. Bioethanol is generated by fermenting plant-derived sugars to ethanol and requires the use of field crops such as, corn, cassava, sugar beet, sweet sorghum, sugarcane, wheat and other coarse grains (Rajashekhar, 2009). In the USA, 23% of corn crop alone goes into ethanol production and provides 3% of the national transportation (Ray, 2009). Also in the USA, 90% of bioethanol is derived from maize (De Oliveria et al., 2005). Japan has made a biofuel from domestically grown brown rice. In India, a private company has planted safflower, castor and *Argemone* over 400 ha in Gujarat State. In general, bioethanol is produced by the fermentation of molasses (by-product of sugar mills). Sugarcane produces about 35 to 40 tonnes of dry mass/ha, and 1 tonne of molasses can produce 12 litres of bioethanol, and is regarded as energy efficient and sustainable in the long run (Muthukumar et al., 2009). However, the sugar or starch-based ethanol can be used as an additive rather than an alternative to fossil fuels. Biobutanol is obtained by metabolic engineering and rewiring the bacteria or yeast. Biobutanol has advantages over bioethanol as it can be blended with petrol or gasoline at a much higher level and can be dropped directly in the engine. Sugarcane is a long duration crop and sugar demand is rising. On the contrary, the sweet sorghum (crop maturity in 5 to 6 months) can be a valid alternative. The supply of soybean, rapeseed and other feed stocks will be limited by competition from other uses and land constraints. The utilization of the food crops for biofuel is in a big controversy since India is facing scarcity to supply sugar and foods. Thus, biofuel production may not be possible without threatening food security (Gahukar, 2009). There is already stress on the wasteland for plantations which may make the land vulnerable leading to grabbing by corporate sector and farmers will be pushed from their own lands. Some food crops such as, beet root, corn and wheat need high doses of fertilizers which augment the emission of the GHG. Since the coarse grains are fed to animals, prices of animal feed and meat may go up. Moreover, increasing corn on large scale for biofuel production can reduce the biocontrol services in agricultural landscapes (Raghu et al., 2006). The statutory minimum price mechanism determines the price for commercial crops like sugarcane and the processors/mill owners have their profit based on byproducts and processing (distilleries).

The second generation biofuels are produced by using cellulose and lignin derived from plants such as, residue of non-food parts (stems, leaves and husks) which are left in the field after crop harvest. This woody and fibrous biomass is locked in with useful sugars by energy-rich cellulose and lignin; cellulose is a tough polymer from which cell walls of plants are made. The lingo-cellulosic ethanol is made by freeing the sugar molecules from cellulose using enzymes, steam heating or other pre-treatments. These sugars are fermented to produce ethanol in the same way as first generation bioethanol production. One tonne of cellulosic biomass yields up to 400 litres of bioethanol making it potential and feasible option. The byproduct (lignin) of this process is burnt as a carbon neutral fuel to produce heat and power for the processing plants and electrification. When cellulose alone is used for biofuel, other biomass is used for human beings and animals. Another advantage is that lingo-cellulosic ethanol can reduce GHG emissions by about 90% compared to fossil petroleum.

Among the available non-food crops such as, certain oilseeds, forest trees, cereals bearing small grains, rubber and industry waste (wood chops, skins and pulp from fruit pressing units), jatropha has been considered as an ideal crop from the view of land use pattern (can be planted with horticultural and medicinal plants), cultivation on poor soils, absorption of phosphate from soil, low GHG emission and better livelihood of marginal farmers. Following these benefits, the Biodiesel Mission of India (2002) planted jatropha over 50,000 ha in eight states but these plants died due to drought. Therefore, Bharat Renewable Energy will develop and deploy only elite hybrids of jatropha over 34,500 ha. In fact, contiguous land with irrigation is needed for jatropha cultivation and its oil content is often over-estimated than normal content of 34.4%. The viability of jatropha plantation in degraded soils and waste land has not yet been established. Also, the area under wasteland in India is limited to 38 million hectares. Therefore, irrespective of long plant development period, an indigenous tree karanj (*Pongamia pinnata*) may be a viable choice. Since it is a leguminous tree, soil fertility is maintained. It grows well in wasteland and the seed contains 30 to 40% oil that can be converted into biodiesel (Gahukar, 2009). Similarly, Singh et al. (2010) recommended 10 species that can be grown in arid region. Oilcakes can also be excellent feed stock which can be burnt to generate power.

The current approach is solely based on non-food crops/feed stocks to be raised on degraded or fallow land, in forest and non-forest areas and wastelands that are not suitable for agriculture. Thus, a possible conflict of fuel versus food security could be avoided. There is no danger for these crops since ethanol is obtained from residues and does not hamper crops for animal grazing. For example, biofuel produced from indigenous brown rice in Japan is blended up to 3% with petrol. In Europe, flax rich in cellulose produces 0.3 kg ethanol/kg of dry biomass. Biofuel from a crucifer, *Brassica carinata* through enzymatic hydrolysis followed by fermentation and distillation is encouraged for mixing with petrol. Another crucifer, *Camelina sativa* containing 40% oil has been introduced in India (Agarwal et al., 2010).

The third generation biofuels are extracted from several recently identified sources such as, water melon juice, algae, fungi, grasses etc. The water melon juice contains 7 to 10% of glucose, fructose and sucrose and 15 to 35 umol/ml of amino acids. High water content in fruit helps to dilute molasses in biofuels by 25%, and only concentrated juice (3 times) can be used. Algae are gaining importance as a fuel of the future (Ramaswamy, 2011). There are nearly 4000 strains of algae which convert sunlight and carbon dioxide (CO_2) into lipids and oils. Algae can be grown on arid land, saline soil or solid waste, and brackish/salt water with a short harvesting cycle (<10 days), and do not compete for food supplies on arable or marginal land. Algae live in symbiosis, and are voracious consumers of CO_2 and may probably help to decrease the content of GHG gases. Also, conversion of carbon emissions into biofuel through industrial bio-sequestration is possible because this process converts waste CO_2 into oxygen and biomass through photosynthesis of micro-algae (Horn, 2009). Up to 60 to 80% of this biomass is converted into oil or lipids and a maximum annual yield of oil (182,000 litres/ha) can be obtained. Algal fuel leaves no carbon residue since up to 99% of CO_2 in solution can be converted and returned into the air when biofuel is burnt. From this emitted CO_2, 50% can be used for algal farming and 25% for farming *Spirulina* (edible algae). Bioreactors tap CO_2 streams from coal-based thermal power plants to produce rich algae. Thus, CO_2 content can be reduced for lowering global warming effect. Some algae secrete hydrocarbons in a form that can be continuously collected for use as fuel and produce nearly 300 times more oil per unit area than soybean or jatropha because of its low production cost (Ray, 2009). Also, algae produce 10 or more times more fuel/ha than corn used for ethanol or soybean for biodiesel. Similarly, marine algae such as, *Thraustrochytrium* sp., *Crypthecodinium cohnii, Schizotrichium* sp. can be grown in coastal areas in India as a source of fatty acids. The algal technology can be integrated with a power plant or sponge iron factory where CO_2 emission is very high.

The endophytes live inside the plant tissue residing latently or actively, colonizing locally or systematically without any visible harm to the plant. The endophytic fungi are well known for production of volatiles including low molecular mass hydrocarbons (Shankar Naik and Krishnamurthy, 2010). Slurry made from grasses/weeds is a suitable medium for the growth of yeast, *Saccharomyces cereviceae* (Sharma et al., 2010). Two endophytic fungi, *Gliocladium roseum* isolated from angiosperm, *Eucryphia cardifolia* and *Muscodor albuds* isolated from *Cinnamomum zeylanicum,* are found abundantly in the tropics, and are capable of producing a mycodiesel hydrocarbons and hydrocarbon derivatives that are similar to diesel. Fungi can even make these diesel compounds from cellulose which contributes to organic waste and can be grown in laboratory on an oatmeal-based jelly or cellulose. In breweries, the bioreactor sludge contains microbes especially bacteria which produce methane from brewery waste. Search for such organisms in the environment needs to be launched because it may be possible in future to produce fuel straight out of tiny plants and microbes by using genetic engineering.

The buffalow grass (*Buchloe dactyloides*), aquatic duck weed (*Lemna gibba*) and switch grass (*Panicum virgatum*) have been identified as a potential source of biofuel because their growth rate is fast, they contain high amount of carbohydrate cellulose and hemi-cellulose, and can yield large amount of dry mass (Sharma et al., 2010). The slurry of duck weed is a suitable medium for the growth of yeast, *S. cerviceae*. The genetically modified (GM) plants with decreased lignin content may show susceptibility to pests and may lose the structural rigidity. On the contrary, the cyanobacteria churn out the building blocks of hydrocarbon fuels and link it up with another organism which takes energy (carbon) from the photosynthetic organism and converts that into hydrocarbon. The genotypes that are suitable for economic production are being studied to identify genetic basis for traits particularly for disease and drought resistance and the composition of cells. But the breaking down of cell walls which is an essential step in producing ethanol from cellulosic biomass seems to be difficult at present. Bioethanol can be produced from yellow flowers of flax, a crucifer, *B. carinata* and GM switch grass variety ‘Alamo’. Another grass, *Brachypodium distachyon* has been considered as a model organism for biofuel because it is easy to cultivate, its genome is similar to that of switch grass but being smaller, its cell walls can be broken down easily. It facilitates to find genes linked to specific traits such as, stem size and disease resistance, and to insert foreign DNA into it to study gene function and targeted approaches.

CHALLENGES AND SOLUTIONS

The difficulty is how to separate energy-rich cellulose from the wood to make ethanol and it is a costly process requiring high amount of heat and caustic chemicals. Moreover, fungal enzymes that attack lignin are not very efficient in breaking up lignin and not easily available. Therefore, instead of decreasing lignin content, its biosynthesis or the structural rigidity of the plant and other mechanisms are being searched.

Planting of biofuel crops in the land of food crops would intensify the food production and availability to consumers. Whereas, the crop productivity is nearly stagnant (Gahukar, 2011). Diversion of maize and sugarcane for biofuel may create shortage for human and animal consumption. Then, how to solve the food insecurity in the country with rising food inflation? Research is therefore needed on waste (old/expired) cooking/vegetable oil, rejected oil from animal fats particularly the tallow (from beef and mutton fat) collected from restaurants and food processing units. Biofuel from these sources emits significantly less GHG than normal diesel. On business side, there are no established players since technology is still in development and demonstration stages.

New technique of direct solar liquid energy is being studied in the USA where engineered organisms are used for ethanol and other organisms for marketing diesel fuel. There is no intermediary like algae or cellulose. Recently, Subhandra and George (2011) suggested an algal biorefinery-based industry as an effective and practical approach to fuel and food insecurity. India has a long coast line of 5,700 km where marine algae can be grown. These measures may be adopted in near future. Genetic engineering and chemically induced mutations are being used to know how algae can potentially produce more fuel. However, using genetically modified algae in huge quantity with a mixture of genes of other organisms may cause environmental problems since algae play a vital role in the environment and are the base of the marine food chain. The greatest challenge is how to secure quality feed stocks to keep up with growing demand due to constraints of expensive oil than other commercially available fuels, cultivation and harvesting of algae or production of endophytes under controlled condition are the other difficulties. Thus, commercial feasibility and viability of different feed stocks remains to be ascertained. Meanwhile, cheaper and potential feed stocks may be imported for decreasing the current high prices. Search for micro-organisms should be intensified and continued through surveys. Cultivation of jatropha and other plants on field bunds and grasses on marginal lands should be sponsored by the government or oil companies. Policy on the minimum support price for jatropha seed and the minimum purchase price for biodiesel needs to be redefined with assessment of financial feasibility and commercialization while considering economic, social and environmental needs. Paying subsidy to farmers and industries to encourage lower GHG emissions and utilization of waste land may prove as viable solution.

Farming on lease or contract basis in the degraded and non-forest lands involving farmers and landless labourers can be tried. Otherwise biofuel crops may attract deforestation and would increase CO_2 emission from forests because forests capture a large portion of emitted CO_2 and it is stored in wood and soil that can last thousands of years. This recent finding challenges the assumptions, based on previous studies, that biofuels from forest sources would be carbon-neutral or even reduce GHG emissions and about 3 tonnes of CO_2 release is prevented with every tonne of biodiesel (Patnaik, 2011). Eventually, the forest management practices incompatible with natural resources may have negative impacts on soils, biodiversity and habitat.

The biofuel production might increase the emission of GHG through burning of fossil fuels during crop cultivation and industrial processing. Therefore, raising the target to 20% blending is rather questionable. As such, specifications and standards for the quality production and blending of ethanol in gasoline have to be set up. In future, Bharat Petroleum in collaboration with Hassan Biofuel Park in Karnataka would sell blended biodiesel and the Indian Oil Corporation will collaborate with the Department of Biotechnology to set up the Centre for Advanced Research on Bioenergy. These companies suggested that the government should offer subsidies or remove the value-added tax levied on biodiesel.

The biofuels can be toxic to micro-organisms which convert the biomass into biofuel resulting in death of bacteria and stopping the conversion process. Algae modified to be energy crops would be uncompetitive against wild algae if they were to escape. Algae cannot thrive without a farmer to nourish them and fend off pests. However, a few non-governmental organizations (NGO) argue that if government can provide irrigation for biofuel crops, why can they not provided this for pulses and oilseed crops of which the country is facing acute shortage? The policy makers for development should consider this challenge.

RECOMMENDATIONS

The possible way is to link employment wages in jatropha and other plantations with National Rural Employment Guarantee Act. Patents on jatropha hybrids have been awarded recently to private firms. This procedure may be detrimental in future as it may result in reduction in genotypic variability, exploitation of farming communities and introduction of monopoly system in villages. Spending on research and development activity should be prioritized in future programmes; for example, planting and processing of biofuel crops if looked after as primary sector by the financial institutions including banks, would be an attraction for innovative techniques, development and extension.

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