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MINI REVIEW

Potential Aspects of Bioenergy for Fueling the Future

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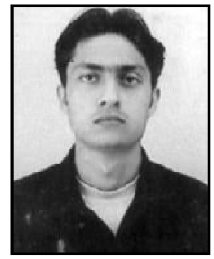
ABSTRACT

Bioenergy is unique amongst the renewable energy sources that can readily replace fossil fuels, reduces greenhouse gas emissions and promote sustainable rural development. It attracts the attention as a sustainable and renewable energy source, which is abundant and available around the world. Agricultural and forestry residues or the biomass represent a potential low cost, low carbon source for bioenergy. Biomass is a clean form of energy produced from organic material originating from different plant species including the bioenergy crops and is essentially the collection and storage of the sun's energy through photosynthesis. It covers more than 10% of the world's primary energy demand (about 50 EJ yr^{-1}). The biomass resources are by far not fully used and further research and technological development is required in this area. Biofuels are a wide range of fuels which are in some way derived from biomass. Biofuels are gaining increased public and scientific attention, driven by factors such as oil price spikes, the need for increased energy security. Various factors play a large role in the future of bioenergy in Society. Bioenergy contributes to the maintenance of rural societies, reduction of greenhouse gases, energy security, and protection and conservation of natural resources. Many of the technical barriers to bioenergy use have been overcome; the remaining hurdles are those of a less tangible nature, i.e., financial and institutional. Given a supportive policy environment, bioenergy can provide a sustainable solution to future energy demands.

Key words *Bioenergy, bioenergy crops, biofuels, biomass, renewable energy*



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The term bioenergy refers to energy obtained from biomass, which is the biodegradable fraction of products, waste and residues from agriculture, forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste (FAO, 2008). Bioenergy for heat, power and transport are foreseen to be part of future energy supply (Presidency conclusions, 2007).The potential for bioenergy supply can be divided into three main categories viz., traditional bioenergy, agricultural and forest residues and bioenergy from dedicated energy crops. Bioenergy is one of the renewable energy sources that can readily replace fossil fuels, while helping to reduce greenhouse gas emissions and promoting sustainable rural development. Recent years have witnessed a dramatic expansion of bioenergy production, particularly biofuels for the transportation sector, motivated by efforts to increase domestic energy supplies, boost rural agricultural economies, and to reduce greenhouse gas (GHG) emissions by replacing fossil fuels (Kojima and Johnson, 2005). Bioenergy is attracting growing attention as a sustainable and renewable energy source, which is abundant and available around the world. Bioenergy can contribute to the generation of new jobs especially in rural and farming communities, which in turn may result in an improvement of income distribution. Bioenergy has the potential to become a fundamental piece in a sustainable energy system, contributing not only to the country's energy diversification strategy but also to the appropriation of emerging energy technologies. The objective of this paper is to integrate several of the key components of bioenergy, including bioenergy crops, sources of biomass, production of biofuels and the benefits of utilizing various sources of bioenergy

Bioenergy Crops

Bioenergy crops are mainly classified into four groups (a) traditional cereal crops, (b) traditional sugar-producing crops including sugarcane and sweet sorghum, (c) dedicated lignocellulosic biomass feedstocks including switchgrass, miscanthus and (d) poplar and oilseed crops for biodiesel *viz.,* soybean and sunflower. Among the candidate energy crops, switchgrass, miscanthus, poplar, and sugarcane have been studied most extensively worldwide (Heaton, *et al.,* 2008). Cereal crops are a major source for starch-based ethanol production. Annual crops, particularly maize and wheat, currently make the largest contribution to bioenergy, particularly biofuels, matched only by perennial sugarcane and oilcrops. Such grain crops have been subjected to thousands of years of improvement, but advances during the 'green revolution' (1960–80) were among the most significant. Maize can be used as a bioenergy crop in two ways: the starch present in the seeds can be used to produce ethanol, and the crop residuals could potentially be used to produce lignocellulosic ethanol. Sorghum could also be used for bioenergy in several ways and is grown for grain, forage, sugar and fiber. Besides sorghum and maize, the residuals of other crops such as wheat and rice are also expected to be useful for lignocellulosic ethanol production. The osier (*Salix viminalis*), a shrub or a small tree, is also reported to be grown as an energy crop (Britt, *et al.,* 2002). Several rhizomatous grasses including switchgrass and *Miscanthus*, are grown worldwide for bioenergy (Lewandowski, *et al.,* 2003). Moreover, the agricultural and municipal wastes also can be utilized for production of bioenergy.

Sources of Biomass

Biomass is the term used for all organic material originating from different plant species and is essentially the collection and storage of the sun's energy through photosynthesis. The examples of biomass energy sources include wood and wood wastes, agricultural crops and their waste byproducts, municipal solid waste, animal wastes, waste from food processing, and aquatic plants, algae, energy crops such as trees and sugarcane that can be grown specifically for conversion to energy. Worldwide, biomass provides about 14% of the world's energy needs; it also accounts for about 38% of the primary energy consumption in developing countries and it often makes up more than 90% of the total rural energy-supplies in those countries (Dumanli, et al., 2007). The average majority of biomass energy is produced from wood and wood wastes (64%), followed by municipal solid waste (24%), agricultural waste (5%) and landfill gases (5%) (Demirbas and Demirbas, 2007).The use of biomass for energy (i.e., bioenergy) is deemed to be one of the most promising renewable energy alternatives.

Biomass Residues and Wastes

Biomass residues and wastes are materials of biological origin arising as by-products and wastes from agriculture, forestry, forest or agricultural industries, and households (Hoogwijk, *et al.,* 2003). Unlike dedicated bioenergy crops, biowaste and residues are not produced specifically for use as an energy resource. Biomass for conversion to bioenergy may also be derived from waste sources such as sawmill residues. It may also be noted that the production of biowaste occurs anyway, the diversion of biowaste to energy recovery options does not usually increase any environmental pressures.

Biomass from Dedicated Energy Crops

Biomass seems one of the most common form of renewable energy source for feasible utilization (McKendry, 2002). The ideal energy crop has efficient solar energy conversion resulting in high yields, needs low agrochemical inputs, has a low water requirement and has low moisture levels at harvest. While it is difficult to find a crop that meets all these criteria, perennial C_4 grasses such as Miscanthus and switchgrass are particularly promising (Venturi and Venturi, 2003). Biomass is also obtained from forestry and agriculture, either from dedicated systems, where the entire crop or forest is harvested for bioenergy, or as a by-product of crop or timber production. Among different conversion processes for biomass, biological anaerobic digestion is one of the most economic ways to produce biogas from various biomass substrates.

Production of Biofuels

Modern bioenergy relies on efficient conversion technologies for applications at the household, small business and industrial scale. Biofuels (mainly bioethanol, hydrogen and biodiesel) are obtained from biomass and can be used as a substitute for transportation fuels and to generate heat, power and/or chemicals. Solid or liquid biomass inputs can be processed to be more convenient energy carriers. These include solid biofuels (e.g., firewood, wood chips, pellets, charcoal and briquettes), gaseous biofuels (biogas, synthesis gas, hydrogen) and liquid biofuels (e.g., bioethanol, biodiesel) (GBEP, 2007). Among the different segments of the bioenergy sector, the largest and most rapid growth has been seen in liquid biofuels (FAO, 2008). Biofuels are an inexhaustible resource since the stock can be replenished through agriculture. Technologies like fuel cells and electric vehicles depend on hydrogen and the electric grid, respectively, and are effectively dependent on depletable sources like natural gas and coal, respectively. With biofuels, most countries will be able to grow one or more types of crops in which they possess a comparative advantage and use them to meet either domestic or foreign demand or both. This increased demand for agriculture is expected to increase farm income. Biofuels are generally divided into 'first generation, second-generation, third generation and fourth generation biofuels'. The division is not strict and is based on different parameters, such as the level of establishment in the market of a particular technology, the type of processing technology or the type of feedstock (WBGU, 2010).

First-generation Liquid Biofuels

First-generation fuels are generally made from sugars, grains or seeds, i.e., using only a specific (often edible) portion of the above-ground biomass produced by a plant, and relatively simple processing of the biomass is required to produce a finished fuel (Larson, 2008). The two main first-generation liquid biofuels are currently biodiesel and bioethanol, representing about 15 and 85% of current global production respectively (FAO, 2008).

Biodiesel

Biodiesel, or vegetable oil methyl ester (VOME), is the second most commonly used liquid biofuel in the world. Biodiesel is derived from oleaginous plants (i.e., rapeseed, oil palm tree, soy, sunflower or jatropha). It is produced through a transesterification reaction of vegetable oil and alcohol such as methanol or ethanol. Biodiesel can be used in its pure form or mixed with conventional diesel for use in conventional diesel engines (TOTAL, 2003). Bioenergy input requirements would account for 0.8% and 18.2% of the total energy consumed in the electricity sector by 2015 and 2030, respectively.

Bioethanol

Ethanol, also known as ethyl alcohol, can be produced from any biomass that contains appreciable amounts of sugar or materials that can be converted into sugar, such as starch or cellulose. In producing bioethanol from sugar crops, they are first processed to extract the sugar. The sugar is then fermented to yield ethanol. Starch and sugar-based ethanol is often referred to as a first-generation biofuel. Ethanol production has a particularly important role in transforming petroleum-based economies to biomass-based sustainable and environment-friendly economies.

Second-generation Liquid Biofuels

Second-generation fuels are generally those made from non edible lignocellulosic (LC) biomass, either residues of forest management or food crop production (e.g., corn stalks or rice husks) or whole plant biomass (e.g., grasses or trees grown specifically for biofuel purposes) (Larson, 2008). There is major interest in moving from the current first generation of liquid biofuels to the second-generation biofuels. By increasing energy supply, biofuels can also undermine efforts at improving energy efficiency and energy conservation. Thanks to technology development, second-generation biofuel production could make use of high quantities of lignocellulosic residues and wastes which are already available: they can constitute the main raw material sources, which can be also supplemented with non-food crops such as perennial grasses, and short rotation forestry, grown on abandoned or marginal agricultural land.

Third Generation Biofuels

Algae fuel, also called oilgae or third generation biofuel, is a biofuel obtained from algal sources. Algae are generally low-input, high-yield feedstocks to produce biofuels (Aylott, 2010). Based on laboratory experiments, it is claimed that algae can produce up to 30 times more energy per acre than field crops such as soybeans (Hartman, 2008), but these yields have yet to be produced commercially. With the higher prices of fossil fuels (petroleum), there is much interest in algal culture (farming algae). One advantage of many biofuels over most other fuel types is that they are biodegradable, and so relatively harmless to the environment if spilled . Algae, such as *Botryococcus braunii* and *Chlorella vulgaris* are relatively easy to grow but the algal oil is hard to extract. Macroalgae (seaweed) also have a great potential for bioethanol and biogas production. However, if biocatalytic cracking and traditional fractional distillation are used to process properly prepared algal biomass i.e., biocrude, then as a result the following distillates were establised: jet fuel, gasoline, diesel, etc. Hence, they are named as the third generation or green fuels.

Fourth Generation Biofuels

A number of companies are pursuing advanced “bio-chemical” and “thermo-chemical” processes that produce “drop in” fuels like “green gasoline,” “green diesel,” and “green aviation fuel”. While there is no one established definition of “fourth-generation biofuels,” some have referred to it as the biofuels created from processes other than first generation ethanol and biodiesel, second generation cellulosic ethanol, and third generation algae biofuel. Some fourth generation technology pathways include: pyrolysis, gasification, upgrading, solar-to-fuel, and genetic manipulation of organisms to secrete hydrocarbons. GreenFuel Technologies Corporation developed a patented bioreactor system that uses nontoxic photosynthetic algae to take in smokestacks flue gases and produce biofuels such as biodiesel, biogas and a dry fuel comparable to coal. Hydrocarbon plants or petroleum plants are plants which produce terpenoids as secondary metabolites that can be converted to gasoline-like fuels. Latex producing members of the Euphorbiaceae such as *Euphorbia lathyris* and *E. tirucalli* and members of Apocynaceae have been studied for their potential energy uses (Kalita, 2008 and Ramawat, 2010).

Benefits of Utilizing Various Sources of Bioenergy

Environmental and Ecological Benefits

One of the factors driving the current interest in bioenergy cropping is the potential environmental benefit through the reduction in greenhouse gas emissions (Sims, *et al.,* 2006). As reviewed by Markard *et al.,* 2005, biogas from agriculture has many ecological advantages. Biogas production also reduces unpleasant odours in agriculture in the vicinity of populated areas. Of course, efficient fertilizing reduces agrochemical pollution of surface and ground waters (Schulz and Eder, 2001). Biomass crops and bioenergy production as an offset to fossil fuel have the potential to ameliorate global warming. Transportation biofuels produced from residue streams and second generation raw materials (e.g., lignocellulosic biomass, algae, jatropha oil, etc.) usually have larger GHG savings than first generation biofuels. For instance, several studies investigated 2nd generation biofuels finding a strong reduction in GHG emissions (Spatari, *et al.,* 2005; Fleming, *et al.,* 2006; González-García, *et al.,* 2009; Vliet, *et al.,* 2009, Williams, *et al.,* 2009; Spatari, *et al.,* 2010).The potential environmental benefits that can be obtained from replacing petroleum fuels with biofuels and bioenergy derived from renewable biomass sources are the main driving forces for promoting the production and use of biofuels and bioenergy.

Few Milestones in the Utilization of Bioenergy

Until the early 1900s, most of the energy used by human societies was derived from agriculture and forests. Even the first petrol and diesel engines were initially designed to run on ethanol and peanut oil, respectively (Collins and Duffield, 2005). By the early 1970s, the energy crisis stimulated a renewed interest in producing energy from crop biomass. Gielen, *et al.,* 2001 focussed on issues regarding biomass for food, timber, fibre versus bioenergy production, availability of land for bioenergy/reforestation, use of biomass in the energy sector under various carbon price scenarios and did not explicitly discuss food prices and quality of land used for bioenergy. Karekezi, 2002 looked at the different renewable energy options to deliver energy to the poor in Africa. Among the options he discussed small-scale and large-scale biomass energy technologies. Sands and Leimbach, 2003 used a top-down economic approach with a highly-aggregated, globally-regionalized agricultural sector and analyzed changes in carbon pools and land used for energy crops under various carbon price scenarios. Vikman, *et al.,* 2004 report gave a review of methods and approaches for assessment of greenhouse gas mitigation and cost-effectiveness in biomass-based energy systems, identifying methodological strengths and weaknesses. Boylan, *et al.,* 2005 reported an encouraging pioneer experience of cofiring grasses (i.e., *Panicum virgatum* L., *Cynodon dactylon* L. Pers. and *Festuca spp*.) in an existing coal-fired plant: about 10% of the energy from biomass was successfully achieved. Dufey, 2006 presented the technical potential and outlook for biofuels, the role of current domestic policies in the development of biofuel markets, and an extensive discussion of the WTO rules applicable to the different biofuels and feedstocks. Fritsche, *et al.,* 2006 in a study commissioned by the WWF Germany, set out a platform for sustainability standards in bioenergy production. The international, European and German legal frameworks were discussed, as well as the various instruments for the implementation of standards. Tiwari *et al.,* 2007 studied an optimized process of biodiesel production from jatropha oil (improved transesterification process). Greiler, 2007 in an issue paper for the Swiss Agency for Development and Cooperation (SDC), gave a good summary of the DCs perspective on biofuels. Smeets, *et al.,* 2007 presented a model for estimating bioenergy production potentials in 2050, called the Quickscan model. The global potential of bioenergy production from agricultural and forestry residues and wastes was calculated to be 7696 EJ per year in the year 2050. Verdonk, *et al.,* 2007 looked into the question of how to best govern bioenergy systems in order to promote their sustainability. The purpose of study of Edward, *et al.,* 2007 was to evaluate the global energy production potential of woody biomass from forestry for the year 2050 using a bottom-up analysis of key factors. Their results indicated that forests can, in theory, become a major source of bioenergy, and that the use of this bioenergy can, in theory, be realized without endangering the supply of industrial roundwood and woodfuel and without further deforestation. Based on review of published papers and elaboration of software data concerning greenhouse gas and energy balances of bioenergy, other renewable and conventional fossil systems, Cherubini, *et al.,* 2009 discussed key issues in bioenergy system LCA. Prochnow, *et al.,* 2009 summarized the knowledge on suitability and sustainability of grassland biomass for combustion. Ruane, *et al.,* 2010 provided an overview of the current status of bioenergy development, focusing on first and second-generation liquid biofuels, considering drivers of growth and risks that have raised concerns over recent years. Davis, *et al.,* 2010 evaluated the biogeochemical cycling and relative greenhouse gas (GHG) mitigation potential of proposed biofuel feedstock crops by modeling growth dynamics of *Miscanthus giganteus* Greef et Deuter (miscanthus), *Panicum virgatum* L. (switchgrass), *Zea mays* L. (corn), and a mixed prairie community under identical field conditions. Of the feedstock crops evaluated in their study, miscanthus would result in the greatest GHG reduction.The review of Frac, *et al.,* 2010 presented the classification of biofuels, with special focus on microalgae and their applicability for the production of biodiesel. Sannigrahi, *et al.,* 2010 reviewed published research on the composition of the key chemical constituents of hybrid poplar species used for biofuels. The objective of the paper of Scarlat and Dallemand, 2011 was to provide a review on the latest developments on the main initiatives and approaches for the sustainability certification for biofuels and/or bioenergy. A large number of national and international initiatives lately experienced rapid development in the view of the biofuels and bioenergy targets announced in the European Union, United States and other countries worldwide.

Fueling the Future- The Concluding Remarks

Major objectives of the current expansion in bioenergy cropping is to reduce global greenhouse gas emissions for environmental benefit. Ecological impact assessment methods for bioenergy projects should address not simply changes to species abundance at field level, but include larger scale issues, including changes to landscape diversity, potential impacts to primary and secondary habitats and potential impacts on climate change. Future research should focus on three main challenges: changing (photo) thermal time sensitivity to lengthen the growing season without limiting remobilization of nutritional elements following senescence; increasing above ground biomass without depleting belowground reserves required for next year's growth and thus without increasing the requirement for nutrient applications; and increasing above ground biomass without increasing water use. Furthermore, bioenergy is not, and should not be, limited to higher plants, although higher plants are likely to provide the most important feedstock for first and second generations of biofuels. Studies of microbes that have the capacity to digest plant cell walls will also be important components of bioenergy research. In addition, green algae should be considered as a potential feedstock choice because of their fast growth. Biofuel cells might also be an option if more mature technologies become available through engineering breakthroughs. It is essential to incorporate feedstock production, energy conversion, and environmental benefits/ costs into consideration in the development of bioenergy projects and policies. Also, the importance of bioenergy in relation to employment creation and fuel import dependency reduction needs to be further addressed. Moreover, these aspects need to be addressed by policymakers promoting the use of bioenergy for its better utilization. Overall, bioenergy research is emerging as a field full of opportunities to re-shape the future energy supply of human society.

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