Sustainability of Bioenergy

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Abstract

Biomass is a renewable source of energy to produce heat, electricity, fuels and bio-products. When produced and used on a sustainable basis, it is a carbon-neutral carrier and can reduce greenhouse gas (GHG) emissions. It has a good potential for income generation along its life cycle, from cultivation to harvest, processing and conversion to energy. Status of bioenergy and the research activities in BUET to use biofuel in engines are reported in the present paper**.**

INTRODUCTION

Bioenergy is the energy derived from biomass. Biomass is produced by green plants by converting sunlight into plant material through photosynthesis and includes all land- and water-based vegetation, as well as all organic wastes [1]. As plants grow, they absorb greenhouse gas (GHG), carbon dioxide and when these plants or the derived biomass are burned, the same amount of GHG is returned to the atmosphere. The use of biomass began hundreds of thousands of years ago, when human ancestors used wood fire to warm themselves and to cook food. Demand for biomass, especially wood, as energy source in developing countries is high as it is often the only readily available, accessible. The development of a large-scale technology to use biomass to produce electricity and biofuel was stimulated only in the late 20th century.

In view of prevailing energy crisis and emission problems, bioenergy can be used to significantly substitute petroleum based fuels [2]. At present, some forms of bioenergy are not economically competitive and therefore warrant special attention for its sustainability.

BIOENERGY SOURCES AND STATUS

Biomass can be derived from the cultivation of dedicated energy crops, perennial grasses, etc. and from biomass wastes such as sludge from organic waste or the wastes themselves. These can be classified into two groups [3]:

1. Energy Crops
   a. Woody crops
   b. Agricultural crops
2. Wastes
   a. Wood residues
   b. Temperate crop wastes
   c. Tropical crop wastes e.g. bagasse and rice husk
   d. Animal wastes e.g. animal manure, sewage sludge and poultry litter
   e. Municipal solid waste
   f. Landfill gas
   g. Commercial and industrial wastes

Biomass contains varying amounts of cellulose, hemicellulose, lignin and a small amount of other extractives (Table 1). Key biomass properties are [1]:

- Moisture content
- Lower heating value (LHV)
- Fixed carbon (FC) and volatiles (VM) ratio
- Ash/residue content
- Alkali metal content
- Cellulose/lignin ratio

Table 1. Properties of some biomass feedstock [1].

Biomass	Moisture (%)	VM (%)	FC (%)	Ash (%)	CV (MJ/kg)
Wood	20	82	17	1	18.6
Wheat straw	16	59	21	4	17.3
Barley straw	30	46	18	6	16.1
Lignite	34	29	31	6	26.8
Bituminous	11	35	45	9	34.0

The quantity of dry matter produced by a biomass species per unit area of production and its LHV are combined to estimate the energy yield of the cultivated crop (Table 2). Energy contents of biomass are found similar, laying in the range 17-21 MJ/kg. So, principal selection criteria for biomass species are growth rate, ease of management, harvesting and material properties e.g. moisture/ash/alkali content.

Table 2. Energy yields from selected biomass [1].

Biomass	Crop yield (dmt/ha/a)	CV (MJ/kg, dry)	Energy yield (GJ/ha)
Wheat	7 grain/7 straw	12.3 (straw)	123
Poplar	10-15	17.3	173-259
SRC willow	10-15	18.7	187-280
Switchgrass	8	17.4	139
Miscanthus	12-30	18.5	222-555

Biomass has always been a major source of energy for mankind and is presently estimated to contribute around 10% of the world's primary energy supply (Fig. 1). Share of biomass sources in primary bioenergy mix are shown in Fig. 2.

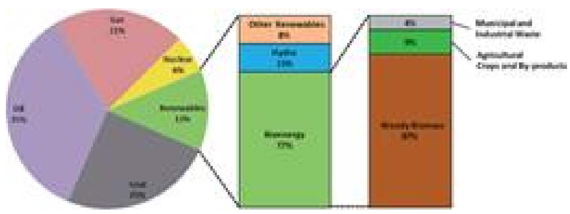

Fig. 1. Share of bioenergy in the world primary energy mix [4].

The predominant use of biomass today consists of fuel wood used in non-commercial applications, in simple stoves for domestic heating and cooking in developing countries, where biomass contributes some 22% to the total primary energy mix. In industrialized countries, the total contribution of modern biomass is on average only about 3% of total primary energy, and consists mostly of heat-only and heat and power applications [4].

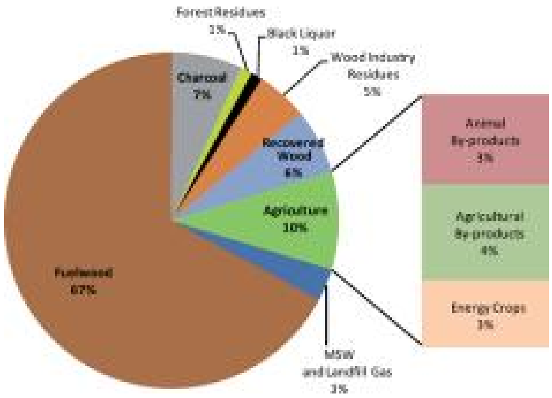

Fig. 2. Share of biomass sources in primary bioenergy mix [4].

ENERGY CONVERSION & SUSTAINABILITY

Conversion routes for producing bioenergy from biomass are plentiful and Fig. 4 illustrates the key conversion routes. Overview of biomass conversion technologies to heat and power [5] and to biofuel [6] are reported in Figs. 4 and 5, respectively.

To assess biomass sustainability, it is necessary to consider the complex linkages between the large-scale production and the use of biomass for energy and materials, food production, energy use, water use, biodiversity and climate change. In Fig. 6 this complexity is highlighted by showing some key relationships and assumptions.

Physical and combustion characteristics of biomass significantly differ from those of fossil fuels posing some technical and economic challenges:

- Bulk density and calorific value are lower, so transportation can be more difficult and costly.
- Some biomass resources are seasonal, so storage is needed to provide energy all year round.
- Untreated biomass may have higher moisture.
- Systems have to be designed specifically for clean and efficient combustion and to avoid fouling, and corrosion problems.

Expansion of bioenergy poses some more challenges: the productivity of food and biomass feedstock, the potential competition for land and raw materials, negative effects on food security and water availability, logistics and infrastructure issues [7].

A general scheme for comparing bioenergy and fossil fuel systems is shown in Fig. 7. Key environmental, social and economic aspects of biofuel and bioenergy production for sustainability are reported in Fig. 8.

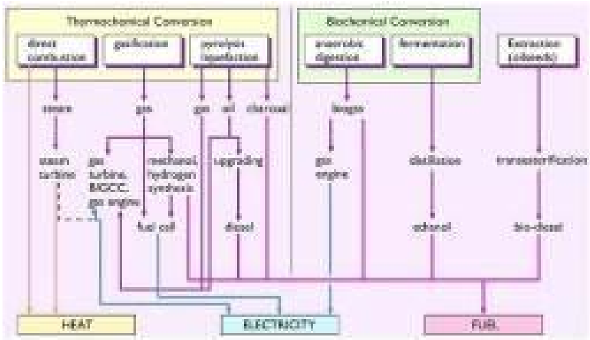

Fig. 3. Main bioenergy conversion routes [3].

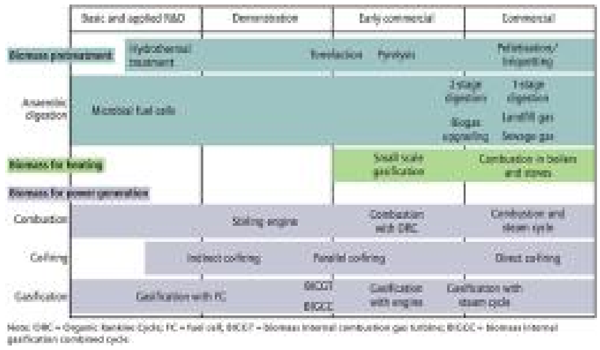

Fig. 4. Development status of main technologies to upgrade biomass and/or to convert it into heat and/or power [5].

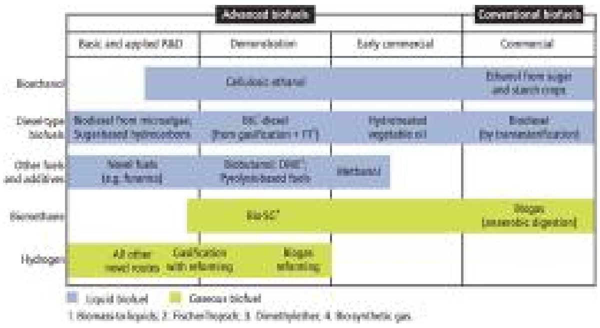

Fig. 5. Development status of the main technologies to produce biofuel for transport from biomass [6].

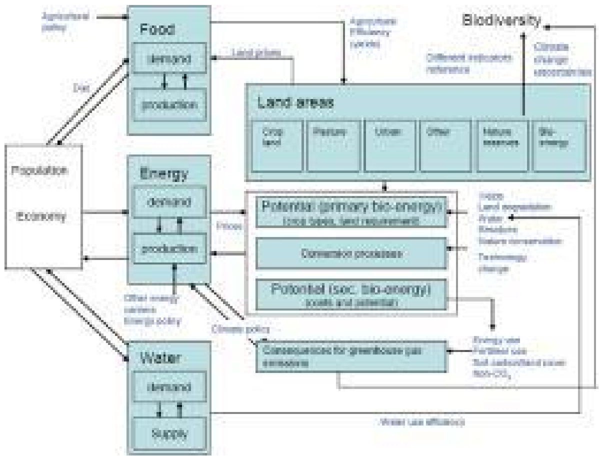

Fig. 6. Key relationships to assess bioenergy potentials [4].

Further technological development is needed to improve the efficiency, reliability and sustainability of bioenergy. In heat sector, improvement would lead to clean and reliable supply of high quality fuel, and in electricity sector, the development of smaller and more cost-effective electricity or CHP. In transport sector, improvements could lead to sustainable biofuels for efficient and safe operations [4].

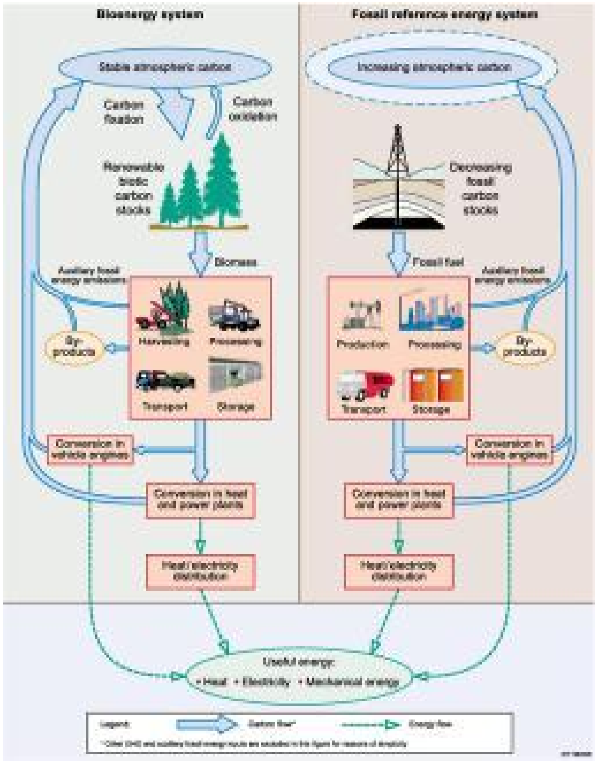

Fig. 7. Standard methodology to compare bioenergy and fossil fuel energy systems [4].


Fig. 8. Environmental, social and economic aspects of biofuel and bioenergy production [4].

BIOFUELS IN HEAT ENGINES

Biomass can be used to produce liquid biofuel, such as ethanol, methanol, biodiesel, Fischer-Tropsch diesel, and gaseous fuels, such as hydrogen and methane. Liquid biofuels are primarily used to fuel vehicles, but can also be used in engines or fuel cells to produce electricity [8]. Due to its environmental merits, the share of biofuel in the automotive fuel market is expected to grow fast. Present status of the biofuel technologies are reported in Fig. 5. Research activities of the present author and his graduate students are reported in the following subsections.

A. Vegetable oils as diesel engine fuel

High viscosity and low volatility of vegetable oils are identified as the main reasons for their unsuitability as straight diesel fuel substitute as these two parameters affect the fuel's spray pattern, atomization, vaporization and mixing with air inside engine cylinder [2]. High viscosities of such fuels are reduced to acceptable levels for diesel engines if blended with kerosene [2] or preheated to 100°C [9]. Experimentally, it is seen that these fuels result in slightly reduced engine performance without any noticeable change in engine operating condition [2,9]. Vegetable oil methyl esters (biodiesel) are prominent candidates as alternative diesel fuel. However, vegetable oils blended with kerosene or preheated using exhaust gases provide a low technology solution for the rural people.

B. Biogas as diesel engine fuel

The organic fraction of almost any form of biomass can be broken down through anaerobic digestion into methane and carbon dioxide mixture called as 'biogas'. Biogas is an environment friendly, clean and cheap fuel. Existing stationary diesel engines can be retrofitted fairly easily for operation with biogas where biogas is supplied to the intake manifold of the engine by fumigation method [10] and small amount of diesel is injected to initiate ignition. Engine fuelled by diesel and biogas of two different compositions are investigated and results indicate very comparable engine indicator diagrams (Fig. 9) and subsequent similar engine performances.

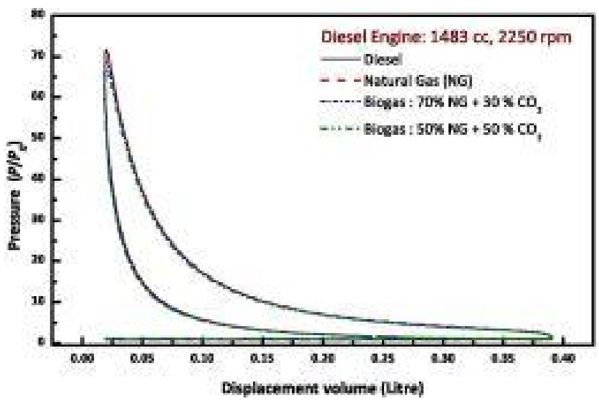

Fig. 9. Indicator diagrams for different fuels [10].

C. Alcohols as spark ignition engine fuel

Alcohols have simple molecular structure and therefore burn efficiently. These fuels reduce harmful emissions, such as carbon monoxide (CO) and unburned hydrocarbon (UHC) because of oxygen content in their molecule. High octane numbers of alcohols allow for the use of high compression ratios to lead to higher thermal efficiency. These fuels have also higher latent heat of vaporization and therefore pre-cool the intake charge to result in high volumetric efficiency and output power. Methanol, ethanol and butanol are commonly used alcohols in SI engines because of their suitable properties [11].

Because SI engines are air breathing, chemical energy entering into the cylinder depends on the fuel, and its chemical energy, stoichiometric fuel-air mass ratio, y_s and the charge density. For identical conditions of pressure and temperature, as same volume of charge is drawn into cylinder and energy density, *ED* (available energy content per unit volume) is directly related to the engine output.

Reported in Table 3 are some of heat release parameters estimated for four fuels. Lower heating values (LHVs) of the fuels are found to vary significantly. However, the values of SE (available energy content per unit mass) and ED's converge to a narrow band. Hence, in-cylinder gas pressure obtained with these fuels exhibit similar results (Fig.10) and indicated efficiencies of a SI are reported in Table 4.

Table 3. Estimated properties of some fuels [11].

Fuel	y_s	LHV	SE	ED
	(-)	(MJ/kg-fuel)	(kJ/kg-mix)	(kJ/m3-mix)
Iso-Octane	0.062	44.7	2873	3507
Methanol	0.135	21.1	2903	3424
Ethanol	0.101	27.7	2866	3466
Butanol	0.083	33.8	2878	3528

Table 4. Indicated efficiencies of a SI engine [11].

	Iso-Octane	Methanol	Ethanol	Butanol
1000 rpm	33.9%	33.9%	33.9%	33.7%
4000 rpm	35.5%	35.6%	35.5%	35.4%

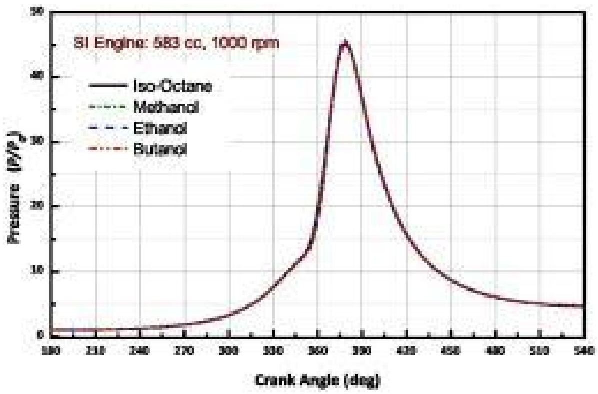

Fig. 10. Indicator diagrams of SI engine [12].

CONCLUSION

Biomass is renewable and green source of energy and it can significantly substitute the conventional fuels in a sustainable manner. It can drastically reduce GHG emissions. Most countries have biomass resources available, or could develop such a resource, making it a more evenly spread energy supply option across the globe. It is a versatile energy source, which can be used to produce power, heat, biofuels, and also serves as a feedstock for biochemicals. Biofuels can be used in spark-ignition and diesel engines without compromising engine performance.

ACKNOWLEDGMENT

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