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Bioenergy: A Sustainable Energy option

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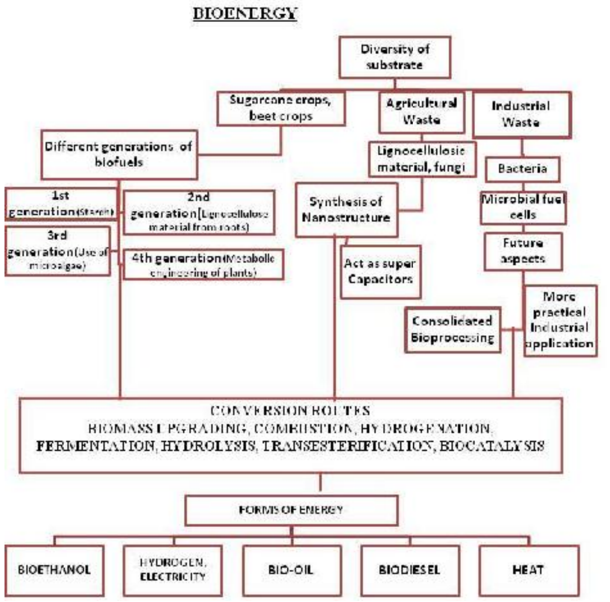
Graphical Abstract



Abstract.

Bioenergy is the renewable and sustainable source of energy produced from organic matter. The challenge of depleting non-renewable resources can be addressed by exploiting the capability of biotic systems to produce bioenergy.The study talks about switching from first generation biofuels produced from sugars and seed oils to fourth generation biofuel that involves metabolically engineered plants. Recent developments in molecular biology techniques have provided valuable tools that could effectively optimize and control the processes involved in bioenergy production in the near future. Production of biofuels employing fungi that have high potential for bioconversion of lignocellulosic materials abundant in nature can also be an effective means. Synthesis of nanostructures using fungi that can serve as super capacitors would be a solution to the problem of storage of bioenergy. The paper also discusses the role of bacteria in Microbial Fuel Cell (MFC). General biochemistry involved in MFC is also presented. Possible limitations or shortcomings are also identified and importance of identifying newer approaches is stressed upon in order to match the future demands.

Keywords

Bioenergy, Biofuels, Microbial Fuel Cell

Introduction

Bioenergy is the energy produced by means of living systems, involving whole cells, enzymes produced by specific microbes or through metabolic activities of living organisms [1]. The challenge of depleting non-renewable resources can be addressed by exploiting the capability of biotic systems to produce bioenergy. Under favorable conditions substantial growth for bioenergy production is possible over the next 20 years. Bioenergy potential from biomass residues and energy crops is estimated to range between 4.4 - 24 EJ by 2030 in EU [2]. Over the coming decades, supply of sustainable energy in adequate amount would be one of the main challenges that mankind will face, particularly because of the need to address climate change. Environmental concerns and the depletion of oil reserves have also resulted in governmental actions and incentives to establish greater energy independence and promotion of research on environmentally friendly & sustainable biofuels such as bioethanol and biodiesel.

Agriculture and industry are the driving forces of the Indian economy. However, both agriculture and Industry produce large amounts of waste that causes significant pollution in the environment. Microbes, specifically fungi and bacteria, can serve a dual purpose in treating these organic wastes while providing us bioenergy [3]. Production of biofuel through fungal action upon lignocellulosic materials holds high biotechnological value. The low-cost remediation by fungi captivates high application rate. Industrial wastes that mainly contain effluent with lots of carbohydrates can well serve as a substrate for microbial growth and hence can be the principle component of Microbial Fuel Cells (MFC), another effective way of bioenergy generation. Moreover, these MFC's helps in reducing COD (chemical oxygen demand) by 80% and thus can also aid in reducing pollution due to putrification of biomass. Table1 presents different stages through which biomass associated bioenergy production has evolved. Crop biotechnology and plant genetic engineering has the potential to optimize biomass productivity in favor of energy crops. This aspect has been implemented in the fourth generation energy crops. These modified crops have resulted in enhanced biomass conversion into biofuels [4]. Biologists are using genetic engineering to overcome two major difficulties that hinders the conversion of lignocellulose into fuels: higher requirement of cellulases which adds to the processing cost and the limited ability of the microbes to ferment the breakdown products which affects the process and product quality.

Table1. Different stages of evolution in biomass associated bioenergy production

Generation	**Feedstock and technology**	**Advantages**	**Disadvantages**
1stgeneration biofuel	Starch, sugar and seed oil	Use of renewable sources	Food ethics issues, blended with conventional fuel
2ndgeneration biofuel	Lignocellulosic material from grasses and trees	Not competing with food, environment friendly	High energy input, high cost bio fuel
3rdgeneration biofuel	Use of microalgae because of high rapid growth	Higher energy yield, lower requirement for fertilizer and land	Capital and operating costs
4thgeneration biofuel	Metabolically engineered plants and algae	Carbon negative fuel due to carbon capture	High research and investment at primary stage

Fungi as source of Bioenergy

Accumulation of lignocellulosic residues from woods, grass, agricultural, forestry waste and municipal solid wastes in large quantities results not only in deterioration of environment but also in loss of possible utilization, especially in bio-energy generation [5]. Bioconversion of lignocellulosic residues to useful, higher price products commonly needs multi-step processes that include: (1) Biological pretreatment (2) hydrolysis of polymers to supply readily metabolizable molecules (hexose, simple sugars); (3) Use of these molecules to support microbial growth or to supply chemical products; and (4) Separation and purification. Numerous life forms degrade and utilize cellulose and hemicellulose as carbon and energy source. The structural complexity of lignin, its high relative molecular mass, and its insolubility make its degradation very difficult. However, filamentous fungi belonging primarily to the basidiomycetous group have an ability to degrade or modify lignin, the most obstinate part of the plant cell wall. There are several advantages utilizing fungi including higher capacity to degrade lignocellulosic material due to their proficient enzymatic framework and their applicability as low cost bioremediation ventures [5]. Fungi have two types of extracellular enzymatic systems: the hydrolytic system responsible for degrading polysaccharides and the oxidative ligninolytic system, which degrades or modifies lignin. The most efficient and widely studied white-rot organism capable of degrading polysaccharides and lignin simultaneously is *P. chrysosporium*. Efficient hydrolysis of polysaccharides requires the action of three enzymes: 1. endo-glucanases to cleave random inter monomer bonds; 2. exoglucanases to remove mono and dimers at the end of the glucose chain; and 3. β-glucosidase, hydrolyzing the glucose dimer. The lignolytic system includes phenol oxidases (lignin peroxidase (LiP), manganese peroxidase (MnP)) and laccasees. While LiP and MnP oxidize the substrate by two consecutive one-electron oxidation steps with intermediate cation radical formation, the laccasees have broad substrate specificity and oxidise phenols and lignin substructures with the formation of oxygen radicals [6]. Biodegradation of lignocellulosic wastes has several uses including its use as raw material for ethanol production, paper manufacturing, compost making for cultivation of edible mushroom, and even as direct animal feed [6]. Ethanol as biofuel would cut back gas emissions and improves air quality while providing strategic economic benefits. Ethanol is currently used as blended fuel in petrol engines.

According to recent research, fungi can be used as templates for the synthesis of nanostructures with potential applications in biosensors, batteries and super capacitors. Supercapacitors are currently considered promising energy storage systems. Supercapacitors store energy in the electric field generated at the interface between a metal electrode and an electrolyte. Fungal cell wall is considered as two-phase system consisting of a chitin skeleton framework embedded in an amorphous polysaccharide matrix [7]. Fungal cell walls can act as cation exchangers due to the different functional groups (e.g., carboxylic, phosphate, amine or sulfhydryl) present. Fungal cells have walls that mainly contain chitin which becomes a rich source for metal binding ligands. NiO microtubes were synthesized using the fungus *C.cladosporioides* as a biotemplate, exhibiting pseudo-capacitive properties with high capacitance, long cycle life and good coulombic efficiency [8]. Such technologies can further empower wider storage and utilization of bioenergy.

Bacteria as source of Bioenergy

Microbial fuel cells (MFC) are a sustainable source of energy. They employ micro-organisms to generate electricity from the energy produced during metabolism of organic substrates. MFCs facilitate direct conversion of chemical energy of substrate into electrical energy. Bacteria are the preferred source of microorganisms in MFC. Research suggests that waste water sources (municipal, domestic, industrial) rich in organic substances can be used as a substrate for bacteria in MFC, thus serving the dual purpose of waste water utilization and generation of bioenergy.

A typical MFC has two compartments: an anodic and one cathodic compartment. In the anodic compartment, the microorganisms are provided with the substrate rich in organic compounds (*viz*., organic waste). The cathodic compartment is provided with a continuous supply of oxygen or a potential electron acceptor. The two compartments are separated by Proton Exchange Membrane. The anode and cathode are connected by an external circuit with a resistor at which power is obtained. MFCs work when bacteria switch from a natural electron acceptor such as Oxygen to an insoluble one like MFC anode. Bacteria oxidize the substrate (electron donor), resulting electron is then passed onto anode and goes through the external circuit through resistor and reach cathode, whereas the proton generated passes through the proton exchange membrane and reach cathode to complete the circuit. The oxygen in the cathodic compartment gets reduced to form water. The transfer of electrons from the bacterial surface to anode is a critical step and there are several ways which can be employed for the same. Mediators such as phenazines, phenothiazines and Quinone's are well known for electron shuttling property [9]. Also, bacteria transfer electrons through nanowires. The electron transfer from the microbial cell to the fuel cell anode, as a process that links microbiology and electrochemistry, represents a key factor that defines, the theoretical limits of the energy conversion. The more positive the redox potential of a terminal electron acceptor (with a given substrate—the electron donor), the higher is the energy gain for an organism [10].

Future of energy Systems: Microbial fuel cell (MFC) has failed at Industrial Scale. Some strategies to overcome the limitations can be: a. Over expression of genes that code for nanowires and pili that could enhance the electrogenic capacity of microbes and increasing the production of mediators that shuttle the electrons like flavins and phenazines; b. Preventing bacteria from dispersing from anode could be targeted; c. Sometimes, there is a nutrient limitation for biofilm bacteria by the matrix surrounding it. So, a manipulation that can cause the dispersion of non-biofilm bacteria can be targeted.

Conclusions

Traditionally India's energy system is dominated by ancient feedstock, conventional energy systems and petroleum products, but these methods failed to meet the growing energy requirements of the population. According to recent studies, it has been proved often that bioenergy technologies have the potential to provide ample energy production to fulfill the power desires, and contribute to bridge the demand–supply gap. Accumulation of lignocellulose residues presents a disposal problem along with deterioration of environment. The use of fungi in low cost bioremediation projects might be attractive given their highly efficient lignocellulose hydrolysis enzyme machinery. Microorganisms that can couple the oxidation of organic compounds to electron transfer to electrodes offer the promise of self-sustaining systems that can effectively convert waste organic matter and renewable biomass into electricity. Significant optimization of microbial fuel cells will be required for most applications. Further investigations into the physiology and ecology of microbes that transfer electrons to electrodes are essential to carry out these optimizations in a rational manner.

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