Chapter 12
Microbial Bioresources and Their Potential Applications for Bioenergy Production for Sustainable Development

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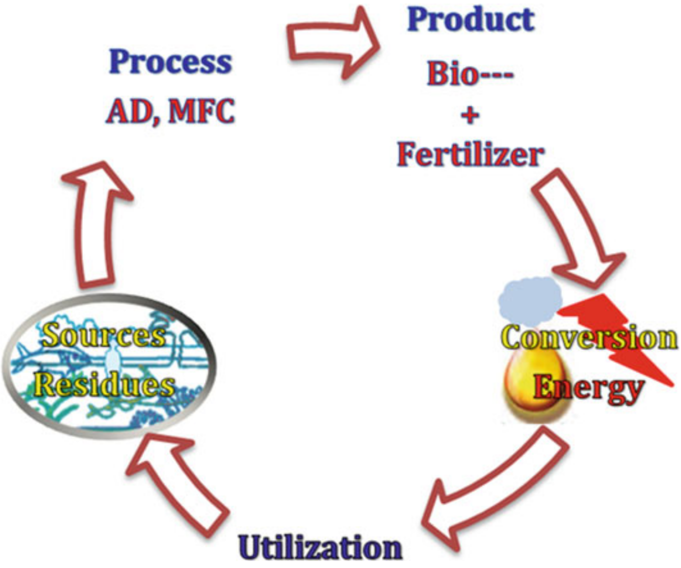
Abstract There are many inexhaustible resources in the natural environment that can be used for the production of bioenergy. There are also many ways to produce such energy, depending on your requirements. The production and utilization of different forms of bioenergy, such as bioelectric and different biofuels, helps to preserve the environment.



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12.1 Introduction

One concept behind the provision of energy is to ensure that there is not a reliance on any one form of energy production, thereby avoiding energy shortages should one energy source be depleted. Having many energy sources also eases the economic pressure associated with a reliance on any one form. Therefore, we must make good use of all the raw materials available that can be used for energy production.

In general, microbes can be produced and grown naturally when conditions are suitable in terms of moisture, temperature, and nutrients. Environments associated with agricultural processes using plants, animals, and food residues; farms, including poultry, other livestock, and fisheries; and wastewater, are considered suitable for microbe production because of their levels of organic matter, moisture, etc.

12.2 Bioresources

Bioresources are biomass or biological material from living or recently living organisms that can decompose under aerobic and anaerobic conditions using processes of burning, gasification, or fermentation to produce bioenergy. Protecting the environment and improving standards of living are the most important factors driving the management of bioresources, in addition to integrating them with energy-producing technologies (Rasool and Hemalatha 2016; Bhatia et al. 2018). Bioresources can be classified according to their origin and the different strategies required for their pretreatment and conversion into bioenergy. Sources include legume plants, algae, monocot plants, edible and non-edible vegetable oils, and animal fats (Bhatia et al. 2018; Gaurav et al. 2017).

12.2.1 Types of Bioresources

12.2.1.1 Agricultural By-Products

The production of bioenergy from agricultural biomass, such as oil palm shells, pineapple residue, forest (logging) residue, coir pith, sugarcane bagasse, empty fruit palm bunches, oil palm fronds, coconut husks, soybean hulls, corn stover, wheat straw, oil palm fibers, oil palm trunks, silk cotton, rice husks, banana residue, paddy straw, reeds, and rapeseed, is linked to microbial action on lignocellulose. Such sources are well known and considered ecofriendly (Gaurav et al. 2017; Rastegari et al. 2020; Yadav et al. 2019).

12.2.1.2 Food Processing Residue

Food processing residue comes from the manufacture of vegetable oils and the processing of meat and can be divided into liquid and solid waste (Kumar et al. 2017; Ravindran and Jaiswal 2016). Liquid waste comes from meat, vegetables, and fruits that have been washed to remove solid organic matter, starch, and sugar. However, processing fruits or vegetables produces solid waste residue from peeling and pulping. Such residue often lacks quality control standards (Bhatia et al. 2018).

12.2.1.3 Energy from Plant Biomass

Plant biomass comes from dedicated crops that are regularly replanted after harvesting. Use of this biomass resource depends on crop availability and required biomass product (Najafi et al. 2009a, b; Balat et al. 2008).

12.2.1.4 Animal and Poultry Residue

Animal residue is the perfect raw material for biogas production because it already contains most of the microbes used in this technology (biowaste-to-bioenergy). Animal residue exists in abundance as organic matter such as feathers, bones, skin, hair, and meat (Mathias 2014; Gebrezgabher et al. 2010).

12.2.1.5 Algal Biomass

Algal biomass has been used, through the process of anaerobic digestion, to produce methane. Its low level of lignin favors biofuel production. Using algae to produce biofuel has no requirement for pesticides, freshwater, or fertilizers for growth. In addition, the growth rates of algae are found to be higher than plants. Moreover, the land requirement for cultivation is lower than for agricultural plants (Bruton et al. 2009; Gaurav et al. 2017; Panjiar et al. 2017). Algae utilize enormous amounts of CO_2 for their growth, remove CO_2 from the atmosphere (some of which originates from power plant emissions), convert biomass via photosynthesis, and liberate oxygen to the atmosphere. Algal biomass can be transformed into different types of biofuel according to three types of production processes: thermochemical processes, biological processes, and chemical reactions (Figs. 12.1 and 12.2) (Dalena et al. 2017).

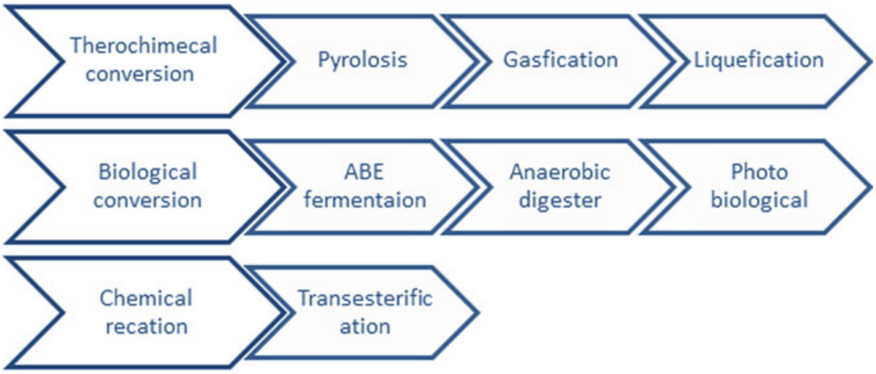

Fig. 12.1 Production processes

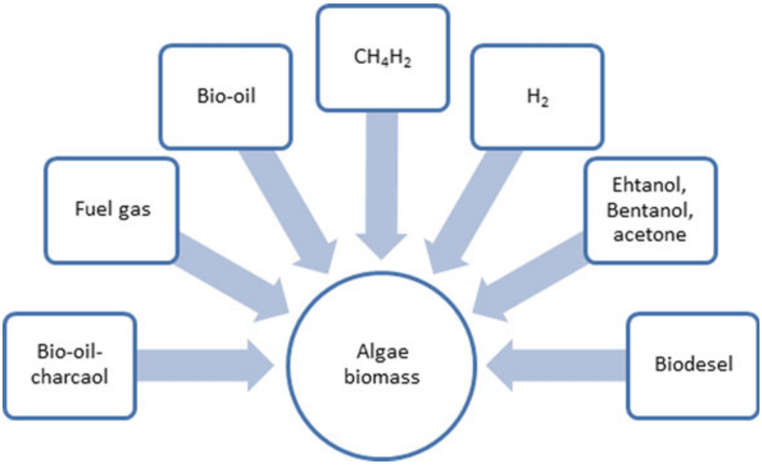

Fig. 12.2 Types of biofuel

12.2.2 Bioresource Strategies for Bioenergy Technology

12.2.2.1 Anaerobic Digestion

Anaerobic digestion (AD) is a biological process that transforms residue into energy. Anaerobic digestion is the disintegration of complex organic matter by microorganisms, in the absence of oxygen, into simpler chemical components (Chen et al. 2018; Li et al. 2019; Momayez et al. 2019; Pramanik et al. 2019; Timonen et al. 2019). The AD process is a multi-step biochemical process; four processes occur simultaneously, namely, hydrolysis, acidogenic fermentation, hydrogen-producing acetogenesis, and methanogenesis (Zhang et al. 2014; Feng and Lin 2017; Gould 2015; Li et al. 2019; Kainthol et al. 2019; Pramanik et al. 2019). AD, a gas that is often referred to as biogas, is comprised of methane and carbon dioxide as well as small volumes of other gases such as hydrogen sulphide (H_2S), ammonia (NH_3), nitrogen, hydrogen, and water vapor (Monnet 2003; Abbasi et al. 2012). Different microorganisms are important to the production of AD, with several types of bacteria degrading constantly and other bacteria producing the gas irregularly (Wang et al. 2018).

For bacteria responsible for the degradation of biowaste there is a relationship between microbial structure and process stability (Li et al. 2015). In the process of hydrolysis, carbohydrates, proteins, lipids, and other organics that are contained within insoluble complex polymers are broken down by hydrolases, produced by microbes, into simple, smaller soluble molecules such as sugars, amino acids, and fatty acids. This phase is a comparatively slow process (Ostrem 2004; Kothari et al. 2014; Zhang et al. 2014, 2015; Leung and Wang 2016). The next phase is the fermentation of molecules such as sugars, amino acids, and fatty acids which are converted into different volatile fatty acids (VFAs) and gaseous components (H_2 and CO_2) by acetogenic bacteria which also reduce these components to acetic acid. This is called the acidogenic phase (Ostrem 2004; Kothari et al. 2014; Zhang et al. 2015; Amer et al. 2019). The final stage in AD is the methanogenic process, where methane gas is produced from acetic acid, hydrogen, and carbon dioxide by bacteria on the intermediate products of the previous steps and fermentation process. A suitable pH for methanogenic bacteria is between 6.5 and 7.5 (Leung and Wang 2016). Figure 12.3 shows the four phases of anaerobic biodegradation.

Operational Conditions in the Anaerobic Digestion Process

Environmental factors affect the stability of the AD process as well as the equilibrium of microorganisms when producing biogas from biomass. Factors include temperature (Gerardi 2003; Khalid et al. 2011), pH (Appels et al. 2008; Leung and Wang 2016), VFAs (Xu et al. 2014; Shi et al. 2018), carbon and nitrogen ratio (C/N ratio) (Yadvika et al. 2004; Krishna and Kalamdhad 2014), retention time (Deepanraj et al. 2014; Mao et al. 2015), and organic loading rate (Kothari et al. 2014). The process of digestion can be wet (Deepanraj et al. 2014; Kothari et al. 2014) or dry (Kothari et al. 2014; Yi et al. 2014).

12.2.2.2 Transesterification

Transesterification is also called alcoholysis. In this process, non-edible oil is allowed to chemically react with alcohols, such as methanol and ethanol, according to their availability and cost. Another organic reaction is where an ester is transformed into another through an interchange of the alkoxy moiety. This process is used to reduce the viscosity of non-edible oil and convert triglycerides into esters (Atabania et al. 2013; Azad et al. 2017). The transesterification reaction is outlined in the following equation (Gerpen 2005; Romano et al. 2006):

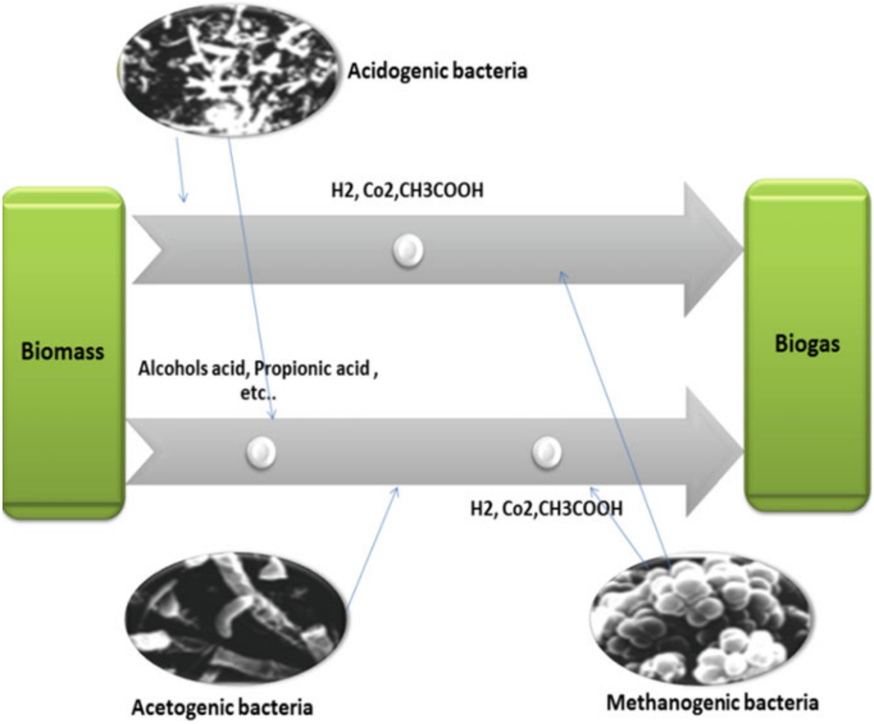

Fig. 12.3 The four phases of anaerobic biodegradation

$$\mathrm{RCOOR}^{'} + \mathrm{R}^{''}\mathrm{OH} \overset{\mathrm{cat}}{\Longleftrightarrow} \mathrm{R}^{'}\mathrm{OH} + \mathrm{RCOOR}''$$

where RCOOR′ is an ester; R″OH is an alcohol; R′OH is another alcohol (glycerol); RCOO R″ is an ester mixture; and “cat” represents a catalyst.

The drawback related to this process is the length of time needed for the separation of the oil, alcohol, catalyst, and saponified impurity mixture from the biodiesel (Azad 2017). Transesterification can be basic, acidic, or enzymatic.

Base-Catalyzed Transesterification

Base-catalyzed transesterification is the most economical and commonly used technique because it demands only low temperatures and pressures. Base-catalyzed transesterification produces a conversion yield of over 98% when the starting oil is low in moisture and free fatty acid (FFAs) content—a high FFA content causes the formation of soap which reduces catalyst efficiency, causes increased viscosity, leads to gel formation, and makes the separation of glycerol difficult (Singh et al. 2006; Leung and Guo 2006).

Acid-Catalyzed Transesterification

Acid catalysts can be used to produce biodiesel from low-cost lipid feedstock with FFA contents greater than 1%. In this process, residue cooking oil was found overall to be the most economically feasible, providing a lower total manufacturing cost and a lower biodiesel break-even price (Zhang et al. 2003; Lotero et al. 2005).

12.2.2.3 Microbial Fuel Cells

Microbial fuel cell (MFC) technology converts biomass or biowaste directly to electricity using microbial catalyzed "anodic" and microbial, enzymatic, abiotic "cathodic" electrochemical reactions (Santoro et al. 2017; Kumar et al. 2019; Rastegari et al. 2019). In other words, this technology combines classic abiotic electrochemical reactions and physics with biological catalytic redox activity (Logan et al. 2006; Rinaldi et al. 2008). The most important advantages of MFC are considered as an energy-saving technology. Because it reduces the energy used for aerating. Moreover, this technology can be used for the removal of pollutants, retrieval of nutrients, and generation of electrical energy from wastewater (Oh et al. 2010; He et al. 2015; Palanisamy et al. 2019). MFCs are categorized according to electrolyte nature and alignment: (1) single-chambered MFCs (SCMFCs), (2) double-chambered MFCs (DCMFCs), (3) stacked MFCs, and (4) up-flow mode MFCs (Ou et al. 2016; Wu et al. 2017).

Microbial Fuel Cell Operation

Initially, substrate oxidation occurs inside an anode chamber. This leads to the generation and transportation of electrons and protons (He et al. 2005; Palanisamy et al. 2019). At the same time, through an external circuit, electrons are moved from the anode to the cathode and protons are transported via a polymer electrolyte membrane (Rabaey and Verstraete 2005). In the last step of the process water molecules are produced in the cathode chamber where electrons and protons integrate with oxygen (Sharma and Li 2010). Microorganisms such as C*lostridium, Geobacter, Shewanella,* and *Pseudomonas* act as biocatalysts, oxidizing the substrate and moving electrons to the anode through substrate oxidation thereby generating bioelectricity (Yadav et al. 2017, 2020). Sometimes, microorganisms perform this process without an exogenous electron mediator (Nimje et al. 2012; Zhi et al. 2014). An MFC is shown in Fig. 12.4. Operational conditions in MFCs are associated with pH (He et al. 2006 and Huang et al. 2012) and temperature (Amend and Shock 2001; Logan 2004; Oh et al. 2010; Patil et al. 2011; Tang et al. 2015).

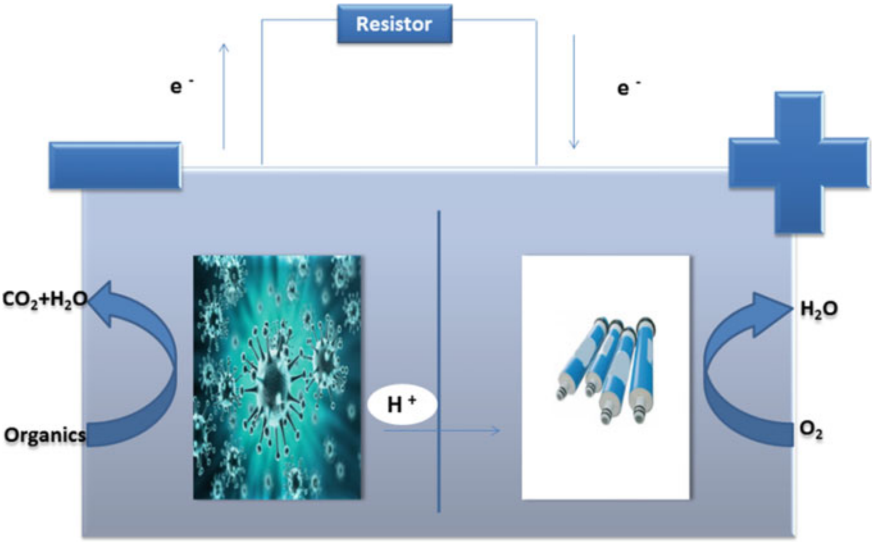

Fig. 12.4 Schematic diagram of a microbial fuel cell

12.3 Potential Applications

The form of bioenergy produced mainly depends on microbial activation (Milano et al. 2016). Bioenergy forms include bioelectricity (Moqsud et al. 2013; El-Chakhtoura et al. 2014; Mekawy et al. 2015; Rahimnejad et al. 2015) and biofuels such as bioethanol (Ballesteros et al. 2002; Najafi et al. 2009a, b; Gelfand et al. 2013; Nitsos et al. 2016, 2017; Achinas and Euverink 2016; Matsakas et al. 2018), biobutanol (Raganati et al. 2012; Jang and Choi 2018), biodiesel, and biohydrogen (Ibrahim 2012; Alavijeh and Yaghmaei 2016).

12.3.1 Bioelectricity

Fermentation processes used to produce bioelectricity (Moqsud et al. 2013) have obtained about 350 mV from MFCs, being significantly influenced by volatile ash, cell tissues, and electrode design. The MFC method is affected by chemical oxygen demand and bioresource loading rate (Jia et al. 2013). Using mixed of organic residues, from paddy or rice, compost and soil the maximum obtained voltage was 700 mV (Moqsud et al. 2015), from stream of wastewater or animal manure the maximum power density were (MFCs 116 mWm^{-2} and 123 mWm^{-2}) respectively (El-Chakhtoura et al. 2014).

12.3.2 Biofuel

The merits of any form of bioenergy include a reduction in greenhouse gas emissions compared with fossil fuels, the ease with which large volumes of bioresources are fermented as biofuels, and from the social point of view the generation of employment (Lin and Tanaka 2006; Kour et al. 2019). Wen et al. (2016) reported the generation of about 12 g m^{-2} per day of biomass using 10 L of high-lipid microalgae like *Graesiella sp.* WBG-1, as well as 5.4 g m^{-2} per day of lipid with 15 mol m^{-2} per day irradiation of artificial light at an optimum temperature and level of natural solar radiation. Also, Schnürer (2016) explained that methane production is the important stage in terms of biogas as a biofuel. Microbial growths with other basic treatments mainly affect the amount of energy obtained from methane.

12.4 Sustainable Development

Sustainable bioenergy mainly depends on crop and food residues. Environmental, social, and economic requirements influence the sustainability of bioenergy. Consequently, bioenergy must be carefully managed (Uwe et al. 2006; Srivastava 2019). Sustainable bioenergy fuels such as biodiesel, biogas, bioethanol, and biohydrogen can be generated from different types of biomass, such as plant and food residue, wastewater, and other waste materials, as well as microalgae grown using advanced techniques (Tan et al. 2015). Saxena et al. (2009) reported the likelihood of there being about 220 × 10^9 Mega-g of available dry biomass globally. Hall and Rosillo-Calle (1998) and Gaurav et al. (2017) calculated available biomass production, with high lignocellulose content, to be about 200 × 10^9 Mega-g per year, of which only about 8–20 × 10^9 Mega-g per year can be converted to energy.

12.4.1 Bioenergy from Sustainable Residues

12.4.1.1 Sustainable Bioelectricity

In sustainable bioelectricity systems the preferred source for the anode is any carbon material, like bamboo charcoal. However, the cathode is made from synthesized fiber to ensure its good design and maximize its bioelectrical power generation (Moqsud et al. 2013). Bioelectricity systems utilize food and agricultural wastewater as bioresources (Mekawy et al. 2015). In addition, there are some innovative technologies that can process bio-residues from food and wastewater to produce bioenergy. These technologies include treatment by means of bioelectrochemistry. The effectiveness electrode of anode which can make from the phyla Firmicutes (67%) in electricity generation (El-Chakhtoura et al. 2014), In addition, Khater et al. (2017) found the bio-film and microbial fuel-cell at act as the anode are effectively showed a high coulombic efficiency of about 65%. Anti-clockwise, they practiced the ability utilize of microbial fuel cell “MFCs” as anode or cathode in biosensor. Moqsud et al. (2015) reported the use of plants as MFCs—producing bioelectricity via soil, compost, or some other organic components. Such a system is considered truly green energy.

12.4.1.2 Sustainable Biofuels

The main bioresources used to produce bioenergy are materials that are rich in lignocellulose (Rashid and Altaf 2008). Therefore, Sun et al. (2016), in a trial using cellulosic agricultural plants, found it difficult to produce biogas especially when using raw materials from wheat and rice—which affected the cells of microorganisms.

12.4.2 Bioenergy from Microbial Substrate

12.4.2.1 Sustainable Bioelectricity

Jia et al. (2013) identified that the more durable the MFC the more effective the electrical power production. Such systems use exoelectrogenic species of *Geobacter* along with organic components in their fermentation cycles. Electrons flowing from anode to cathode can be obtained using different species of bacteria such as *Geobacter*, *Bacteroides*, *Clostridium* (Karluval et al. 2015), and *Clostridium cellulolyticum* (Sun et al. 2016). Helder et al. (2010) used the membrane from *S. anglica* as the surface for their plant associated microbial fuel cell (P-MFC)—it generated a maximum power density of about 222 mW m^{-2}.

12.4.2.2 Sustainable Biofuel

Wang et al. (2017) observed that in many studies there are some obstacles facing high efficiency methane production, such as pH or pectin type of bacteria to help activate the fermentation processes where it was found that CH_4 reduced in minimization, about 37.12% at used H group as, Thermovirga, Soehngenia and Actinomyces, to methane generation. Wirth et al. (2012) cleared that to produce the hydrogen as a biofuel the main importance bacteria in metabolism in biogases synthesizing is Closteria.

12.5 Conclusion

When producing bioenergy it should be noted that a sustainable source of biomaterial is essential, whether terrestrial or marine. Environmental, social, and economic aspects must also be considered at all stages of production and utilization.

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