Chapter 2
Microbiological Aspects of Bioenergy Production: Recent Update and Future Directions

Veer Singh, Ritesh Tiwari, Vivek Kumar Chaturvedi, Nidhi Singh, and Vishal Mishra

Abstract Biofuels are considered as alternative of fossil fuels. Nowadays, conventional fuels like as petrol, diesel, and liquid petroleum gas (LPG) are the major sources of energy. The sources of fossil fuels are limited on the Earth crust and will be finished after a certain period of time. Biofuels like bioethanol, biomethanol, biogas, biohydrogen, and biodiesel are derived from various types of biological sources (plant, algae, microbial biomass) and considered as renewable sources of energy. They are green energy sources and cost-effective and also considered as alternative of fossil fuel in the future. They can be classified into several categories such as first, second, third, and fourth generations based on the source of production. There are several methods that are currently used for the production of biofuels by utilization of several biomasses. The microorganisms such as microalgae, cyanobacteria, and fungi play an important role in the production of biofuels. These microorganisms provide suitable raw materials as well as involved bioconversion of biomass during production of biofuels. This chapter is focused on the brief introduction of biofuels and role of microorganism in the biofuel production.

Keywords Biofuels · Classification of biofuels · Microalgae · Cyanobacteria · Bioconversion

---

V. Singh · V. Mishra (✉)
School of Biochemical Engineering, IIT (BHU), Varanasi, Uttar Pradesh, India
e-mail: vishal.bce@itbhu.ac.in

R. Tiwari
Department of Botany, Patna University, Patna, Bihar, India

V. K. Chaturvedi
Centre of Biotechnology, University of Allahabad, Allahabad, Uttar Pradesh, India

N. Singh
Centre of Bioinformatics, University of Allahabad, Allahabad, Uttar Pradesh, India

M. Srivastava et al. (eds.), *Bioenergy Research: Revisiting Latest Development*, Clean Energy Production Technologies,
https://doi.org/10.1007/978-981-33-4615-4_2

2.1 Introduction

Biofuel research is aimed to the production of eco-friendly and cost-effective fuels which have the ability to replace the need of fossil fuels (Jang et al. 2012; Hjersted and Henson 2009; Sharma et al. 2020). Nowadays, conventional fuels such as petroleum products like petrol, diesel, kerosene, and LPG are the major energy sources. The limited sources of fossil fuels are available on the Earth, and these sources may be finished in the future. Therefore, the alternative of these fossil fuels is an urgent requirement for the energy sector (Singh et al. 2020a). Few demerits of the fossil fuels are also reported; these fuels generate a large number of toxic agents which increase the environmental pollution load (Clomburg and Gonzalez 2010; Vanholme et al. 2010). Carbon monoxide (CO), sulfur dioxide, nitrogen dioxide (NO_2), nitric oxide (N_2O), carbon dioxide (CO_2), and hydrocarbons are produced during the consumption of fossil fuels. These gases are responsible for air pollution as well as greenhouse effect. Greenhouse gases play an important role in maintaining the Earth temperature and provide favorable environment to the living organisms. The level of these gases at above the certain limit causes the increased temperature of Earth known as global warming. Global warming affects the distribution of biodiversity and is also responsible for some other dangerous changes like the increased sea level and melting of glaciers (Singh et al. 2020a; Schmidt et al. 2010). Hence, developing an alternative option of fossil fuels is extremely important for the continuation of fulfilling the need of energy source in the future.

Biofuels are considered as suitable energy sources and may take the place of conventional fuels in the future. They are energy-enriched energy sources derived from eco-friendly green sources such as dead biomaterials of plants, bacteria, and microalgae (Allakhverdiev et al. 2009; Razzak et al. 2013; Voloshin et al. 2015; Dragone et al. 2010). They can be classified into several generations such as first, second, third, and fourth generations (Singh et al. 2020b). First-generation biofuels are derived from starch-rich biomass like wheat, corn, potato, and sugarcane. Mustard, soybean, and fats are considered as good sources for biodiesel production (Aro 2016). Second-generation biofuels like bioethanol and biomethanol are produced from several plant species such as jatropha, miscanthus, as well as wood (Hirani et al. 2018). Third-generation fuels are derived from several species of microbes and microalgae (Gajraj et al. 2018). The fourth-generation category of fuels is considered as the advanced type of biofuels. In this generation, biofuels are produced from the genetically modified organism. Biofuels from this category are derived from microalgae and microbes same as the third-generation biofuels (Abdullah et al. 2019). Fourth-generation biofuels is the more developing field for research as well as biofuel industries, and requirement of more study in this area (Anemaet et al. 2010).

Various production methods are used in biofuel production. Biomasses need to convert simple biomaterials using various biomass conversion processes. There are several microorganisms that produce enzymes which have an important role in the

Table 2.1 Biomass-degrading microorganisms for biofuel production

Microorganism	Application	References
Bacillus aerius CMCPS1	Delignification	Ganesan et al. (2020)
Bacillus tequilensis VCB1	Production of glycosyl hydrolases	Thankappan et al. (2018)
Bacillus tequilensis VSDB4	Production of glycosyl hydrolases	Thankappan et al. (2018)
Bacillus licheniformis KBFB2	Production of glycosyl hydrolases	Thankappan et al. (2018)
Bacillus licheniformis KBFB3	Production of glycosyl hydrolases	Thankappan et al. (2018)
Clostridium cellulolyticum	Cellulose degradation for biofuel production	Tao et al. (2020)
Pseudomonas putida	Biocatalyst for terpenoid productions	Yang et al. (2019)
Hexagonia hirta MSF2	Production of laccase	Kandasamy et al. (2016)
Trichoderma harzianum SNRS3	Production of CMCase and β-glucosidase	Rahnama et al. (2014)
Trametes sp. strain AH28-2	Laccase production	Xiao et al. (2003)
Yarrowia lipolytica	Provide raw starch-digesting factory for the production of ethanol and lactic acid	Gęsicka et al. (2020)
Ganoderma lucidum CBS 229.93	Production of lignocellulosic-degrading enzymes	Sitarz et al. (2013)
Trametes sp. Ha1	Production of laccase isoenzyme and peroxidase for ethanol production	Nakatani et al. (2010)
Trametes trogii	Production of lignin-modifying enzymes	Levin et al. (2002)

biofuel production. The microorganisms and their application have been listed in Table 2.1.

The microbial enzymes have a better capacity to digest biomass and produce different types of biofuels. The microbial enzymes use biomass as substrate and convert it into biofuels. The biomass derived from algae, bacteria, fungi, and plants can be converted into biofuel via several biological and chemical processes. The biological biomass conversion can be done using several microbial substances such as extracellular enzymes (Parmar et al. 2011). The biomass conversion and biofuel production process are mentioned in Fig. 2.1.

These microorganisms produce suitable enzymes for the conversion of biomass as well as are also used as raw materials (Okada et al. 2020; Mostafa 2010). This study focused on the introduction of biofuel, classification of biofuels, as well as role of microorganisms in biofuel production.

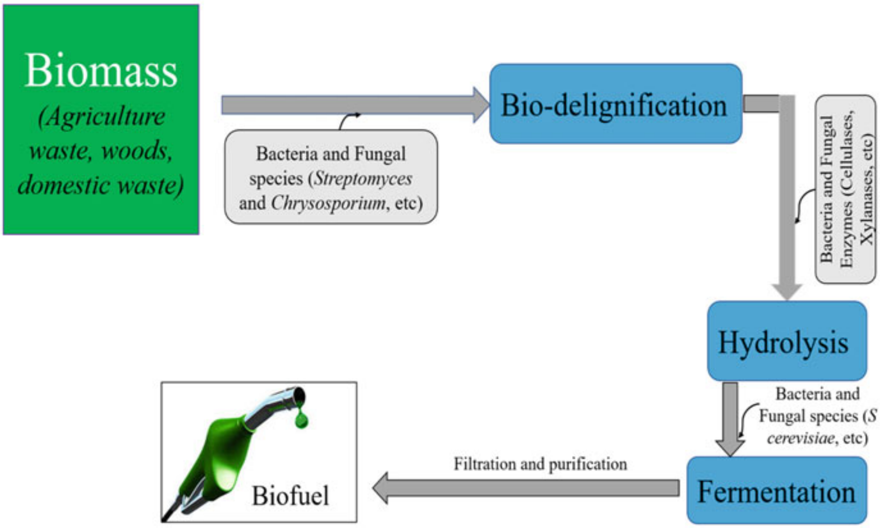

Fig. 2.1 Microbial aspects of biofuel production

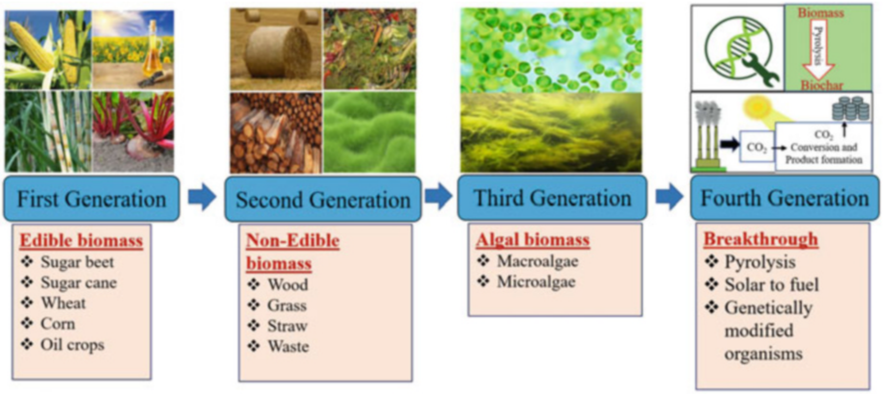

Fig. 2.2 First-generation biofuels are produced from edible biomass, while second-generation biofuels are produced from non-edible biomass. Third-generation biofuels are produced from several species of macro- and microalgae. Modifications in metabolic pathways and genetic materials are the major source of fourth-generation biofuels

2.2 Classification of Biofuels

Biofuels can be classified into four categories, and these categories are named as first, second, third, and fourth generations. The classification is mainly based on the materials used for production purpose. The generation of biofuels and their sources have been shown in Fig. 2.2.

2.2.1 First-Generation Biofuel

Bioethanol is derived from the fermentation of carbohydrates such as starch obtained from wheat, barley, corn, rice grain, potato, or disaccharide sugar, acquired from the sugarcane industry. Biobutanol is the second most valuable product; it can be produced by the same process as bioethanol but with different fermenting microbes (Kriger et al. 2020; Lee et al. 2015). Biodiesel is also a well-known first-generation biofuel. It can be obtained from various crops such as soybean, coconut, palm, sunflower, recycled used cooking oils, fat obtained from animals, etc. (Bhatia and Johri 2015). The Brazil government has made the addition of 2% biodiesel to conventional diesel compulsory in 2008; later, this increased up to 5% in 2013. To meet this increasing demand of biodiesel, production capacity has been increased. Agricultural crops cultivated for biomass production need arable agricultural land. Crops cultivated for biofuel production vary based on the climatic condition of different geographical areas. Excessive commercial production of first-generation biofuels through agricultural crops results in low availability of fertile lands being used to cultivate food and fodders for human and animals (Singh et al. 2018). Hence, this category of biofuel is based on economically and environmentally safe. All these issues compelled bio-scientists to focus on second-generation biofuels.

2.2.2 Second-Generation Biofuel

The biofuels that exist in this category are mostly produced from non-food crops like jatropha, cassava, or miscanthus (Robak and Balcerek 2018). Second-generation biofuels are produced through several chemical, physical, and biological biomass conversion processes of lignocellulosic materials from agricultural non-edible crops or their residues (Nigam and Singh 2014). Fuels produced biochemically are called biochemical fuels, such as ethanol and biobutanol. Besides these both fuels, other second-generation fuels are produced from thermochemical method and are known as thermochemical energy source. Some examples are methanol, ethanol, and ether. The Fischer-Tropsch liquid is also produced in the thermochemical reaction which is synthesized from the catalytic reaction of CO and H_2; thus, it can be produced from any biomass that can be made to produce CO and H_2 (Buaban et al. 2010).

Unrefined oils produced thermochemically require extra processing to make them useful for engines (Larson 2008). There are high interests to produce such fuels which have high cetane number and very little or no sulfur or aromatic compounds. It can reduce vehicular exhaust pollution. The entire use of above-ground biomass and cheaper feeding material and judicious use of non-edible crops boost scientists to look forward in the research and production of second-generation biofuel. But the commercial production of second-generation biofuels is not profitable because it requires expensive and sophisticated technologies (Alam et al. 2015). Researchers aimed to focus on enhancing the production and minimizing the production cost of biofuels.

2.2.3 Third-Generation Biofuel

Third-generation biofuel produced from photosynthetic microalgae can be considered as one of the most sustainable, environment-friendly, economically feasible fuels. Various types of third-generation biofuels like methane (Gavrilescu and Chisti 2005), biodiesel, and biohydrogen (Kapdan and Kargi 2006) can be produced from microalgae. Microalgal fuel production does not require arable agricultural land and is photosynthetic which can fix CO_2 of the atmosphere and CO_2 released from industrial sources and from soluble carbonates, thus reducing greenhouse gas emissions and promoting a way leading to carbon neutrality that's why they are being considered superior than first- and second-generation biofuel (Into et al. 2020). Microalgae are more diverse than plants. It consists of more than 3 lakh species which may be found in fresh water and marine habitat (Alam et al. 2015). Microalgae are single-celled microorganisms that grow well in aqueous suspension culture that provides easy access to water, carbon dioxide, and other organic or inorganic nutrients for their growth (Dragone et al. 2010; Anemaet et al. 2010). They are an ideal candidate for fuel production because they may contain lipid contents in the cell up to 85% of dry cell mass and they grow very rapidly in the presence of proper nutrient and double within 24 h (Angermayr et al. 2009). Selection of useful microalgal strain and their cultivation, biomass harvesting, and biomass oil extraction are quite tedious which require expertise and a huge amount of money. Hence, it is not yet sustainable for biofuel production (Grima et al. 2003). All microalgal species can produce triacylglycerols by imposing stressed conditions. *Nannochloropsis* and *Chlorella* microalgae give a high yield of triacylglycerols for biofuel production (Kleinova et al. 2012). Nitrogen-deprived condition is one of the most potent stressed conditions for substantial oil accumulation. TAGS are formed by combining three different fatty acids, and hydroxyl groups of glycerol play an important role in the arrangement of TAGS. The oils can be converted to biofuels by simple transesterification process. Microalgal fuel production can only be increased by combining advanced methods of lipid metabolic process with biotechnological tools (Chisti 2007).

2.2.4 Fourth-Generation Biofuels

This category of biofuel applies the concept of "cell factory" which harnesses the solar energy to convert CO_2 into potential biofuel (Patnayat and Sree 2006). Fourth-generation biofuels can be produced by (1) photosynthetic microorganisms, (2) combining photovoltaics with microbial fuel cells, or (3) synthetic cell components specifically designed for the synthesis of suitable and desired fuels. Fourth-generation biofuels are used to extract lipid extensively using synthetic biology techniques. This technique also aims to harvest high-quality biofuels having high octane number which indicates the quality of fuels (Hays and Ducat 2015). It also enhances carbon dioxide sequestration using bioengineered microalgae (Dutta et al. 2014). Carbon dioxide sequestration is the conversion of inorganic CO_2 to organic compounds by the help of photosynthetic organisms (Stitt et al. 2010). These biofuels are synthesized from inexhaustible raw materials which are inexpensive and easily available worldwide. Unused agricultural lands and water bodies can be used as producing site for this biofuel category without destruction of biomass.

2.3 Role of Microorganism in Biofuel Production

The source of the fossil fuels is declining day by day, and at the same time, the world population is growing, so we can assume that fossil fuels will be finished after a certain time. Hence, biofuels are considered as a better option of energy that can fulfill the need of energy in the future. Biofuels are synthesized from biomasses plant, algae, or microbial cells. There are several mechanisms involved in the transformation of biomass into biofuels. Several microbial species are also used for the degradation of lignocellulosic biomass and production of hydrolytic enzymes as well as in the fermentation process. The role of microorganism has been shown in Fig. 2.3.

Microbial enzymes work as catalyst and play an important role in biomass conversion (Machado and Atsumi 2012; Tabatabai et al. 2019). Microorganisms

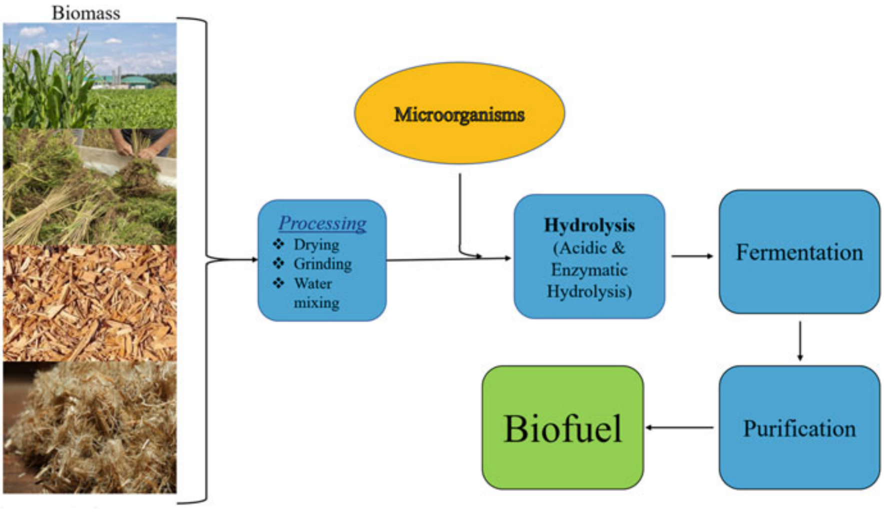

Fig. 2.3 Role of microorganisms in biofuel production

such as microalgae, cyanobacteria, Archeabacteria and some methanogens are good sources of bioenergy (Fu et al. 2016). These organisms produce several types of bioenergy such as bioelectricity, biohydrogen, biomethanol, bioethanol, and methane gas. Microbial fuel cell (MFC) is the better example of bioelectricity production (Singh and Mishra 2020; Jin et al. 2014; Ni and Sun 2009). Microalgae are considered as a good source of bioethanol and biomethanol, and these products are used as additives in the diesel in present days and also considered as an alternative option of fossil fuel in the future (Xue et al. 2017; Lutke-Eversloh 2014; Hou et al. 2013). Biohydrogen is considered as a clean and eco-friendly fuel because it produces zero waste after burning. Various types of microorganisms (microalgae and bacteria) produce biohydrogen during their growth (Azwar et al. 2014; Saifuddin and Priatharsini 2016). Microorganisms such as algae produce bio-oil. Bio-oils also produce various types of plant and agriculture biomass. Microorganisms such as bacteria and fungi produce extracellular enzymes involved in the conversion of biomasses into bio-oils. Biogas is considered as an eco-friendly fuel and has applications in various fields. Biogas is produced during the bioconversion of biomass by methanogenic bacteria (Senger 2010; Gowen and Fong 2010; Himmel et al. 2007). The best alternative for that is microorganism like cyanobacteria and microalgae which are capable to perform the specific function. Some of them have the unique capability to take the sugar and convert it into biofuel, whereas many microalgae contain natural oil content greater than 50% (Zhu et al. 2008). There are several examples of microbial species used in the conversion of biomass. *Echinodontium taxodii* can reduce 30% lignin materials of bamboo tree in 30 days. This fungal species can grow at temperature range from 25 to 35 °C (Philbrook et al. 2013). *Ceriporiopsis subvermispora* has very good biomass degradation properties. It can degrade 45% lignin materials of corn stover in 30 days (Philbrook et al. 2013). Some bacterial species are also used in the biofuel production. There are some examples of ethanol-producing bacterial species such as *Escherichia coli* (Romero-Garcia et al. 2016), *T. reesei* (Huang et al. 2014), and *Caldicellulosiruptor bescii* (Singh et al. 2020d; Chung et al. 2014). There are some examples of biobutanol-producing microorganisms like *Clostridium acetobutylicum* (Lutke-Eversloh and Bahl 2011) and *Pseudomonas putida* (Nielsen et al. 2009). In brief, we can say that engineered microorganisms are the factory for the biofuel production and at the same time it fits to our sustainable energy source (Clomburg and Gonzalez 2010; Fatma et al. 2018). There are several methods to get biofuel from microorganisms, and more research and attention of scientist are required for them to become ready for future use. We also discussed in this chapter about major microbial groups (cyanobacteria and microalgae) and their importance in bioenergy production.

2.3.1 Cyanobacteria

Cyanobacteria belong to the kingdom Monera. The member of cyanobacteria contains a photosynthetic pigment which is a different feature of cyanobacteria from

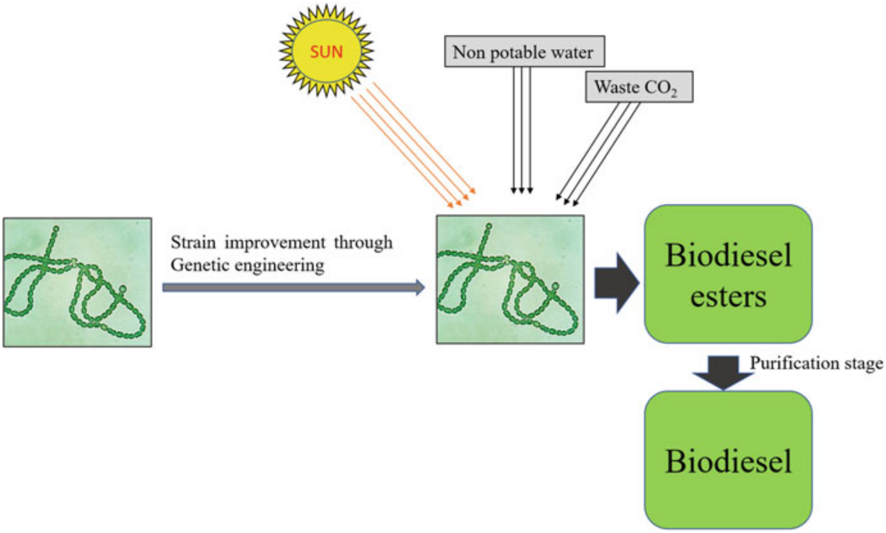

Fig. 2.4 Genetic modification and typical pathways of biodiesel production using cyanobacteria

bacteria (Zhou et al. 2010). Maximum characters of cyanobacteria are very similar to bacteria, and this is the reason why cyanobacteria and bacteria exist in the same kingdom Monera. Cyanobacteria grow very rapidly without the requirement of arable land. Cyanobacteria can uptake CO_2 from the atmosphere and prepare their own food; hence, they are considered as autotrophic organisms (Lu et al. 2010). Due to their photosynthetic properties and being a good source of carbon, cyanobacteria are used for biofuel production (Bandyopadhyay et al. 2010). The biofuel production pathways of cyanobacteria are described in Fig. 2.4.

Cyanobacteria have a genetic disability and have a potential platform for biofuel research. The major challenges in the cyanobacterial biofuels are improvement at genetic level, modification in carbon fixation pathways, metabolic reactions of cyanobacteria, requirement of nutrients for production at industrial level, and enhancement of photosynthetic efficiency of cyanobacteria in natural light (Sakurai and Masukawa 2007; Lindblad et al. 2012).

2.3.2 Microalgae

The yield of biofuel production depends on the source used (Greenwell et al. 2010). Therefore, the selection of biofuel production crops/microorganisms plays an important role in the biofuel research (Moreno-Garrido 2008; Ghirardi et al. 2000). Biofuel production varies with geographical area which provides the optimum condition for the growth of an organism (Medipally et al. 2015; Kumar et al. 2020). Few biofuel-producing crops like soybeans require a large land area for cultivation. But microalgae can grow in a small area with more productivity (Himmel et al. 2007; Sticklen et al. 2006; Olguin 2012). Hence, microalgae can be considered as an attractive material for biofuel production. The process of biofuel production using microalgae has been shown in Fig. 2.5.

Some important features of microalgae are:

1. High productivity in comparison to other biological sources like soybean plant biomasses.
2. These are non-food-based feedstock resources for biofuel production.
3. Microalgae can be easily cultivated on non-arable land.
4. Microalgae can utilize wastewater and fresh, blackish, marine, and saline water for their growth.
5. They produce biofuels and other several valuable products.
6. Excellent recycling potential of CO_2 as well as nutrients present in the waste.

Based on the above points, microalgae are considered as a potential option for biofuel production (Razeghifard et al. 2013). The algal fuel also known as oilgae is derived from triglycerides (triglycerides synthesized by algal cell and called as algal oil) [Simionato et al. 2013; Gimpel et al. 2013]. Triglycerides can be converted into biodiesel by using different processing technologies same as second-generation biofuels. Biogas can also be produced from algae via anaerobically digestion. This process is very advantageous due to the elimination of biofuel drying process. The biomass drying process consumes a large amount of energy and time. The chemotrophic organisms can cultivate in phototrophic fermenters and obtain energy in the presence of sunlight. Phototrophic organisms generally cultivate in the closed photobioreactors as well as open pond system (Anto et al. 2020; Show et al. 2013).

The fermentation tanks are a closed system and need to transfer CO_2 and nutrient from time to time. The pond is an open system and takes CO_2 from the atmosphere. CO_2 works as a fertilizer and increases the growth of algae in the pond. The algal cells make their own food in the presence of sunlight and CO_2 present in the atmosphere. But laboratory photobioreactors are an artificial system, and a suitable condition is maintained with the help of CO_2 supply and artificial LED light. However, a large-scale photobioreactor is placed and directly exposed to sunlight. The production cost of the pond is significantly lower, but due to contamination problem, it cannot be used for the growth of single species. The contamination problem does not appear in the packed photobioreactors. Thereby, it is useful for single species organisms and applicable at industrial scale. Open ponds are considered as the best place for the growth of extremophiles like halophiles and thermophiles (Karemore et al. 2016; Day et al. 2012).

The production of third-generation biofuels are based on cyanobacteria and microalgae, but these fuels are not commercially available. The third-generation biofuel production is under development process and to furthermore investigation in this sector. Researchers are trying to enhance the production of third-generation biofuels through various strategies. Some challenges appeared in the third-generation biofuels such as enhancement of the production of biofuel through several methods (Rogers et al. 2014). Biomass of microalgae and macroalgae can

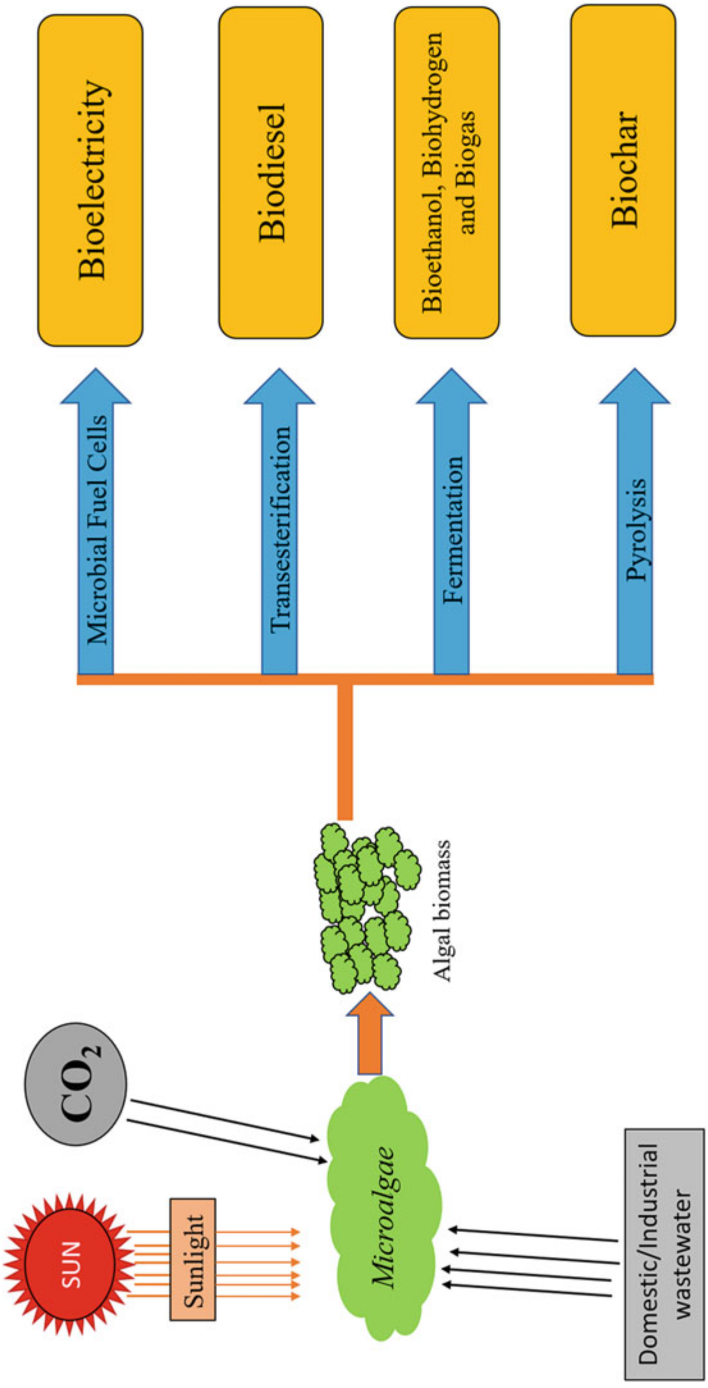

Fig. 2.5 Microalgae and their role in various categories of biofuel production

be digested anaerobically. Other methods are also available such as thermal degradation and gasification method (Show et al. 2013).

2.4 Biofuel Types

Biofuels can be categorized into types such as biohydrogen, bioethanol, biomethanol, biomethanol, and biodiesel. We have discussed few important biofuels in this chapter.

2.4.1 Biohydrogen

Biohydrogen is a clean, environmentally safe, and low-cost-based fuel. It has much more advantages compared to other fuels. Biohydrogen produces high energy which enhances fuel efficiency. The biohydrogen production is still a developing sector in biofuel research. Nowadays, biohydrogen generally produces through conventional methods (Shaishav et al. 2013). There are various conventional methods such as electrolysis as well as gasification of coal, but these methods have some disadvantages. The major disadvantages of these methods are requirement of high thermal energy and generation of some hazardous by-products such as gases and wastewater (Hsia and Chou 2014; Chang and Lin 2004). Electrolysis of water is an environmentally safe process, but it requires a large amount of electricity for hydrogen generation. Hence, this process is only possible in the developed area where regular electricity supply is possible (McKinlay and Harwood 2010). Hence, it is needful to find out a cost-effective and eco-safe method for biohydrogen production. The production of biohydrogen from microbial species is a very inexpensive and eco-safe method (Dincer 2012). Biohydrogen is produced during photosynthetic reaction in the plant, algae, or cyanobacteria. It is also produced via aerobic or anaerobic fermentation process. There are several microbial species that are applicable and used for biohydrogen production (Manish and Banerjee 2008). Some well-known examples of biohydrogen-producing organisms are *Chlamydomonas moewusii*, *Scenedesmus obliquus*, *Enterobacter aerogenes*, and *Rhodobacter sphaeroides.*

2.4.2 Bioethanol

Nowadays, bioethanol is used as an additive in petrol and diesel. Hence, it is considered as an alternative of conventional fuels, and it has the ability to replace the use of petroleum products in the future (Guo et al. 2015; Littlewood et al. 2014; Saini et al. 2015). It is derived from several types of biomasses which are easily available over the Earth. Hence, bioethanol may have a low production value compared to other fuels. It has a high octane number as well as is an eco-friendly fuel (Chang and Lin 2004; Sarkar et al. 2012; Manish and Banerjee 2008; Limayen and Ricke 2012). Nowadays, it can be generated from various types of biomasses such as algal, bacterial, fungal, plant, and agricultural wastes. It is also produced from several types of edible and non-edible oils such as mustard oil, soybean oil, and corn oil (Forte et al. 2017; Whitaker et al. 2018; Gonzalez-Garcia et al. 2019). Microalgae are the major source of bioethanol product. Microalgae produce a large amount of bioethanol and other biofuels (Porth and El-Kassaby 2015). The production of bioethanol can be improved through genetic engineering in the wild microalgal species (Kuhad and Singh 1993; Manish and Banerjee 2008; Balan 2014).

Nanotechnology has an important role in the bioethanol industries. Nanoscale particles provide more areas for chemical and biological reaction. Cherian et al. investigated that MaO_2 enhance the bioethanol generation from biomass of sugarcane leaves at optimum parameters (Cherian et al. 2015). The small size and bigger surface area of the MnO_2 have more binding sites for enzymes and other reactive molecules and increase the production of ethanol.

2.4.3 Biogas

Biogas is a cost-effective and eco-friendly biofuel. Methane is the main component of biogas, and it is produced from the digestion of organic materials. Several microbial species such as methanogens are involved in the biogas production (Romero-Guiza et al. 2016; Aryal et al. 2018). There are several processes involved in the biogas production. Hydrolysis is the main step of biogas production. In the hydrolysis process, the breakdown of substrate takes place in the presence of a suitable digestion system. The hydrolysis step includes the digestion of a large molecule such as protein and carbohydrates into amino acids and simple sugar, respectively (Romero Victorica et al. 2020). The second most important step is acidogenesis. The third main step is acetogenesis. In the acetogenesis acetic acid envolves in several microbial activities. The fourth and important step is methanogenesis. Methanogenesis is the production of methane gas in the biogas production system. The methane gas is produced from several methanogenic bacteria (Mao et al. 2015; Arias et al. 2020; Buitron et al. 2014; Waqas et al. 2020; Sekoai et al. 2016). The acidogenesis process is responsible for the digestion of sugar and amino acids and produces CO2, hydrogen, and alcohol. There are several pathways involved in the acidogenesis process. The biogas is produced from various microbial pathways, and the growth of methanogenic bacteria required low concentration of hydrogen in the growth medium (Hankamer et al. 2007; Rupprecht et al. 2006). Biogas produced from several biological wastes is considered as a safe, clean, and zero waste emission fuel. It is also considered as an alternative option of LPG and can replace the use of LPG in the future.

2.4.4 Biodiesel

It is generated from several biomass as well as vegetable oils. Biodiesel can replace the use of fossil fuel in the future. It is also considered as an eco-safe and low-cost-based source of energy (De Araujo et al. 2013; Mohammadshirazi 2014). Non-edible vegetable oils can be transformed into biofuels using various approaches. Biodiesel production from non-edible vegetable oils is a beneficial process because a large amount of non-edible oils presents as waste worldwide. Nanomaterials have an important role in the biodiesel production. Several investigations suggested that biofuel production can be improved through changing in transesterification reaction by using nanomaterials (Chen et al. 2018; Lee et al. 2015). It has been reported that Fe_3O_4 and ZnMg(Al)O nanoparticles are able to enhance the production of biodiesel.

Biofuels like biodiesel can be produced from several biofuel crops such as jatropha. Jatropha is a flowering plant species and belongs to the plant family Euphorbiaceae. The oil derived from jatropha seed is very useful for biodiesel production. The waste material (cake) resultants of the oil extraction process have been used in feed of fishes and animals. Resultant materials have a large amount of proteins; hence, they have a very high nutrition value compared to other feeds (Peralta-Yahya and Keasling 2010).

2.5 Biofuel Production and Bioconversion

Complex biomaterials are converted into simple biomaterials through several bioconversion processes. Various types of biofuels such as bioethanol, biomethanol, biodiesel, biohydrogen, and biogas are produced from several bioconversion processes. There are several microbial catalytic reactions involved in the bioconversion and biofuel production process.

2.5.1 Bioconversion of Natural Gaseous Fuel to Liquid Fuel

Biogas is produced during the decomposition of organic materials. There are several types of bacteria responsible for the production of biogas such as several types of methanogens. Methane is the main constituent of biogas and a well-known gaseous fuel (Haibach et al. 2012). The biogas converted into liquid fuel is the emerging approach in the bioenergy sector. The liquid fuel is considered as a high-demand fuel than the gaseous fuel due to its safety and easy transportation. Hence, the conversion of gaseous fuels into liquid fuel is very essential (Fabbri and Torri 2016). The methanogenic bacteria can feed methane as a carbon source and produce methane gas in anaerobic or aerobic environment. The biogas-producing bacteria also produce some vitamins, single cell proteins, a number of antibiotics, and carboxylic acid (Fei et al. 2014). These bacteria also produce a number of biopolymers such as poly-β-hydroxybutyrate. Poly-β-hydroxybutyrate is the alternative option of polypropylene and can replace the use of polypropylene in the future (Fei et al. 2014; Hu et al. 2016).

2.5.2 *Biofuel from Wastewater Treatment Plant*

Wastewater such as industrial wastewater and domestic waste contain enough amount of carbon-containing compound (Zhang et al. 2014; Singh et al. 2020c). These carbon compounds enhance the growth of microorganisms considered as good sources for bioenergy production. The process of biofuel production and wastewater utilization is shown in Fig. 2.6.

Sludge activation is the main stage in wastewater treatment where organic substance oxide into CO_2 and involved in the various metabolic activity of microorganisms (Abdelaziz et al. 2013). In the domestic sludge, lipid content varies from 30 to 40% or the total organic matter. Triacylglycerols are the major component in the lipid content present in the municipal sludge (Shreve and Brennan 2019). Several bacteria have the capability to uptake lipid from municipal sludge or form other carbon sources from them. These bacteria can store lipids in the intracellular space of the cell. Triacylglycerols and wax esters and polyhydroxyalkanoates are the examples of lipids stored by the bacteria in the intracellular space (Pittman et al. 2011; Sriwiriyarat and Randall 2005; Chinnasamy et al. 2010; Singh et al. 2016).

2.5.3 *Microbial Fuel Cells (MFCs)*

MFC is the bioconversion of chemical energy to electrical energy through metabolic reactions of microorganisms (Yu et al. 2012). If devices take energy directly from the plant cells, then they are known as plant microbial fuel cells (PMFC). The microbial fuel cell has potential applications in the field of bioremediation of pollutants, biosensors, wastewater treatment, biowaste conversion, and electricity production. The hydrogenesis is the main source of electricity production. Hydrogen molecules are generated in the microbial cell metabolism. Biohydrogen production in the electron transport chain of microbial cells is the well known example of biohydrogen production. These hydrogen or proton species are captured by the MFC device and used in the generation of electricity (Singh et al. 2020e; Yadav et al. 2019; Mathuriya 2020; Balasubramaniam et al. 2020; Mani et al. 2020; Zhang et al. 2020).

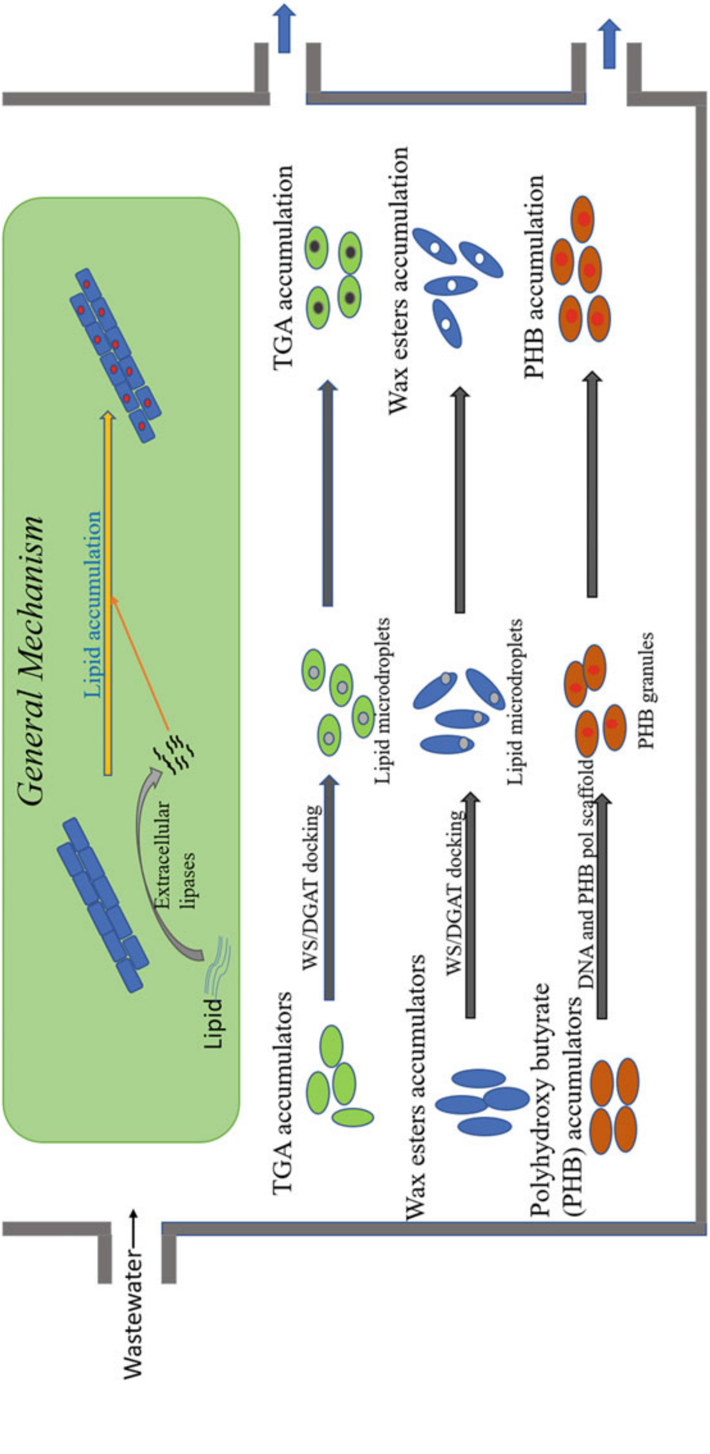

Fig. 2.6 The process of wastewater treatment via biofuel-producing microorganisms

2.6 Conclusion

Biofuels are considered as a clean and cost-effective source of energy. They are produced from various sources such as algae, plants, and bacterial biomass. They can also be derived from edible or non-edible oil and agricultural waste. The limited sources of fossil fuels such as petrol, diesel, and LPG are present on Earth crust and may be finished after a certain period. Hence, it is very needful to develop a suitable and renewable source of energy which can replace the requirement of fossil fuels. Biofuels are considered as renewable sources because they are derived from renewable biological source. They are also considered as an eco-friendly energy source. Based on the raw materials used for their production, biofuels are classified into several classes such as first, second, third, and fourth generations. There are several types of biofuels such as biohydrogen, biogas, bioethanol, and biodiesel produced from various sources such as microalgae, fungal biomass, and several bacterial species. Biomass digestion or biomass conversion is an important method, and it can be done using several biomass conversion approaches. Biomass can be converted using physical, chemical, and biological methods. Biological approaches of biomass conversion are considered as an effective and eco-friendly method. Microbial species such as fungal and bacterial produce extracellular enzymes, and these extracellular enzymes have an emerging role in the digestion of lignocellulosic materials. Microbial system also has the ability to produce electricity through microbial fuel cells. Hydrogen ions generated in the metabolic reaction of microbial cells are involved in the electricity generation. Based on the current research, the authors have concluded that microorganisms have an emerging application in the biofuel production.

Acknowledgments The authors are thankful to the Indian Institute of Technology (IIT), BHU, Varanasi, for providing Internet facility, working place, and instrumentation facilities for this research work.

References

Abdelaziz AE, Leite GB, Hallenbeck PC (2013) Addressing the challenges for sustainable production of algal biofuels: I. algal strains and nutrient supply. Environ Technol 34:1783–1805

Abdullah B, Muhammad SAFS, Shokravi Z et al (2019) Fourth generation biofuel: a review on risks and mitigation strategies. Renew Sustain Energy Rev 107:37–50

Alam F, Mobin S, Chowdhury H (2015) Third generation biofuel from algae. Procedia Eng 105:763–768

Allakhverdiev SI, Kreslavski VD, Thavasi V, Zharmukhamedov SK, Klimov VV, Nagata T et al (2009) Hydrogen photoproduction by use of photosynthetic organisms and biomimetic systems. Photochem Photobiol Sci 8:148–156

Anemaet IG, Bekker M, Hellingwerf KJ (2010) Algal photosynthesis as the primary driver for a sustainable development in energy, feed, and food production. Mar Biotechnol (NY) 12:619–629

Angermayr SA, Hellingwerf KJ, Lindblad P, de Mattos MJ (2009) Energy biotechnology with cyanobacteria. Curr Opin Biotechnol 20:257–263

Anto S, Mukherjee SS, Muthappa R et al (2020) Algae as green energy reserve: technological outlook on biofuel production. Chemosphere 242:125079

Arias A, Behera CR, Feijoo G, Sin G, Moreira MT (2020) Unravelling the environmental and economic impacts of innovative technologies for the enhancement of biogas production and sludge management in wastewater systems. J Environ Manage 270:110965

Aro EM (2016) From first generation biofuels to advanced solar biofuels. Ambio 45:24–31

Aryal N, Kvist T, Ammam F, Pnat D, Ottosen LDM (2018) An overview of microbial biogas enrichment. Bioresour Technol 264:359–369

Azwar MY, Hussain MA, Abdul-Wahab AK (2014) Development of biohydrogen production by photobiological: fermentation and electrochemical processes: a review. Renew Sustain Energy Rev 31:158–173

Balan V (2014) Current challenges in commercially producing biofuels from lignocellulosic biomass. ISRN Biotechnol 2014:1–31

Balasubramaniam A, Adi P, Do Thi TM, Yang JH, Labibah AS, Huang CM (2020) Skin bacteria mediate glycerol fermentation to produce electricity and resist UV-B. Microorganisms 8:E1092

Bandyopadhyay A, Stockel J, Min H, Sherman LA, Pakrasi HB (2010) High rates of photobiological H_2 production by a cyanobacterium under aerobic conditions. Nat Commun 1:139

Bhatia L, Johri S (2015) Biovalorization potential of peels of Ananas cosmosus (L.) Merr. For ethanol production by Pichia stipitis NCIM 3498 & Pachysolen tannophilus MTCC 1077. Indian J Exp Biol 53:819–827

Buaban B, Inoue H, Yano S et al (2010) Bioethanol production from ball milled bagasse using an on-site produced fungal enzyme cocktail and xylose-fermenting Pichia stipitis. J Biosci Bioeng 110:18–25

Buitron G, Kumar G, Martinez-Arce A, Moreno G (2014) Hydrogen and methane production via a two-stage processes (H_2-SBR+CH_4-UASB) using tequila vinasses. Int J Hydrogen Energy 39:19249–19255

Chang FY, Lin CY (2004) Biohydrogen production using an up-flow anaerobic sludge blanket reactor. Int J Hydrogen Energy 29:33–39

Chen Y, Liu T, He H, Liang H (2018) Fe_3O_4/ZnMg(Al)O magnetic nanoparticles for efficient biodiesel production. Appl Organomet Chem 32:1–10

Cherian E, Dharmendirakumar M, Baskar G (2015) Immobilization of cellulose onto MnO_2 nanoparticles for bioethanol production by enhanced hydrolysis of agricultural waste. Chin J Catal 36:1223–1229

Chinnasamy S, Bhatnagar A, Hunt RW, Das KC (2010) Microalgae cultivation in a wastewater dominated by carpet mill effluents for biofuel applications. Bioresour Technol 101:3097–3105

Chisti Y (2007) Biodiesel from microalgae. Biotechnol Adv 25:294–306

Chung D, Cha M, Guss AM, Westpheling J (2014) Direct conversion of plant biomass to ethanol by engineered *Caldicellulosiruptor bescii*. Proc Natl Acad Sci U S A 111:8931–8936

Clomburg JM, Gonzalez R (2010) Biofuel production in Escherichia coli: the role of metabolic engineering and synthetic biology. Appl Microbiol Biotechnol 86:419–434

Day JG, Thomas NJ, Achilles-Day UEM, Leakey RJG (2012) Early detection of protozoan grazers in algal biofuel culture. Bioresour Technol 114:715–719

De Araujo CDM, De Andade CC, De Souza E, Silva E, Dupas FA (2013) Biodiesel production from used cooking oil: a review. Renew Sustain Energy Rev 27:445–452

Dincer I (2012) Green methods for hydrogen production. Int J Hydrogen Energy 37:1954–1971

Dragone G, Fernandes B, Vicente AA, Teixeira JA. Third generation biofuels from microalgae in Current research, technology and education topics in applied microbiology and microbial biotechnology. In: Mendez-Vilas A (eds). Formatex, Badajoz (2010). 1355–1366

Dutta K, Daverey A, Lin JG (2014) Evolution retrospective for alternative fuels: first to fourth generation. Energy 69:114–122

Fabbri D, Torri C (2016) Linking pyrolysis and anaerobic digestion (Py-AD) for the conversion of lignocellulosic biomass. Curr Opin Biotechnol 38:167–173

Fatma S, Hameed A, Noman M et al (2018) Lignocellulosic biomass: a sustainable bioenergy source for the future. Protein Pept Lett 25:148–163

Fei Q, Guarnieri MT, Tao L, Laurens LML, Dowe N, Pienkos PT (2014) Bioconversion of natural gas to liquid fuel: opportunities and challenges. Biotechnol Adv 32:596–614

Forte A, Zucaro A, Fagnano M, Fierro A (2017) Potential environmental impact of bioethanol production chain from fiber sorghum to be used in passenger cars. Sci Total Environ 598:365–376

Fu Y, Chen L, Zhang W (2016) Regulatory mechanisms related to biofuel tolerance in producing microbes. J Appl Microbiol 121:320–332

Gajraj RS, Singh GP, Kumar A (2018) Third generation biofuel: Algal biofuels as a sustainable energy source. In: Kumar A, Ogita S, Yau YY (eds) Biofuels: greenhouse gas mitigation and global warming. Springer, New Delhi. https://doi.org/10.1007/978-81-322-3763-1_8

Ganesan M, Mathivani Vinayakamoorthy R, Thankappan S, Muniraj I, Uthandi S (2020) Thermotolerant glycosyl hydrolases-producing *Bacillus aerius* CMCPS1 and its saccharification efficiency on HCR-laccase (LccH)-pretreated corncob biomass. Biotechnol Biofuels 13:124. https://doi.org/10.1186/s13068-020-01764-2

Gavrilescu M, Chisti Y (2005) Biotechnology- a sustainable alternative for chemical industry. Biotechnol Adv 23:471–499

Gęsicka A, Borkowska M, Białas W, Kaczmarek P, Celinska E (2020) Production of raw starch-digesting Amylolytic preparation in *Yarrowia lipolytica* and its application in biotechnological synthesis of lactic acid and ethanol. Microorganisms 8:717

Ghirardi ML, Zhang L, Lee JW, Flynn T, Seibert M, Greenbaum E, Melis A (2000) Microalgae: a green source of renewable hydrogen. Trends Biotechnol 18:506–511

Gimpel JA, Specht EA, Georgianna DR, Mayfield SP (2013) Advances in microalgae engineering and synthetic biology applications for biofuel production. Curr Opin Chem Biol 17:489–495

Gonzalez-Garcia S, Bacenetti J (2019) Exploring the production of bio-energy from wood biomass. Italian case study. Sci Total Environ 647:158–168

Gowen CM, Fong SS (2010) Exploring biodiversity for cellulosic biofuel production. Chem Biodivers 7:1086–1097

Greenwell HC, Laurens LML, Shields RJ, Lovitt RW, Flynn KJ (2010) Placing microalgae on the biofuels priority list: a review of the technological challenges. J R Soc Interface 7:703–726

Grima EM, Belarbi EH, Fernandez FGA, Medina AR, Chisti Y (2003) Recovery of microalgal biomass and metabolites: process options and economics. Biotechnol Adv 20:491–515

Guo M, Li C, Facciotto G et al (2015) Bioethanol from poplar clone Imola: an environmentally viable alternative to fossil fuel? Biotechnol Biofuels 8:134. https://doi.org/10.1186/s13068-015-0318-8

Haibach MC, Kundu S, Brookhart M, Goldman AS (2012) Alkane metathesis by tandem alkane-dehydrogenation-olefin-metathesis catalysis and related chemistry. Acc Chem Res 45:947–958

Hankamer B, Lehr F, Rupprecht J, Mussgnug JH, Posten C, Kruse O (2007) Photosynthetic biomass and H2 production by green algae: from bioengineering to bioreactor scale-up. Physiol Plant 131:10–21

Hays SG, Ducat DC (2015) Engineering cyanobacteria as photosynthetic feedstock factories. Photosynth Res 123:285–295

Himmel ME, Ding SY, Johnson DK et al (2007) Biomass recalcitrance: engineering plants and enzymes for biofuels production. Science 315:804–807

Hirani AH, Javed N, Asif M, Basu SK, Kumar A (2018) A review on first- and second-generation biofuel productions. In: Kumar A, Ogita S, Yau YY (eds) Biofuels: greenhouse gas mitigation and global warming. Springer, New Delhi. https://doi.org/10.1007/978-81-322-3763-1_8

Hjersted JL, Henson MA (2009) Steady-state and dynamic flux balance analysis of ethanol production by Saccharomyces cerevisiae. IET Syst Biol 3:167–179

Hou X, Peng W, Xiong L et al (2013) Engineering clostridium acetobutylicum for alcohol production. J Biotechnol 166:25–33

Hsia SY, Chou YT (2014) Optimization of biohydrogen production with biomechatronics. J Nanomater 2014:1–11

Hu P, Chakraborty S, Kumar A et al (2016) Integrated bioprocess for conversion of gaseous substrates to liquids. Proc Natl Acad Sci U S A 113:3773–3778

Huang J, Chen D, Wei Y, Wang Q, Li Z, Chen Y et al (2014) Direct ethanol production from lignocellulosic sugars and sugarcane bagasse by a recombinant *Trichoderma reesei* strain HJ48. Sci World J 2014:798683

Into P, Pontes A, Sampaio JP, Limtong S (2020) Yeast diversity associated with the Phylloplane of corn plants cultivated in Thailand. Microorganisms 8:80

Jang YS, Park JM, Choi S, Choi YJ, do Seung Y, Cho JH, Lee SY (2012) Engineering of microorganisms for the production of biofuels and perspectives based on systems metabolic engineering approaches. Biotechnol Adv 30:989–1000

Jin H, Chen L, Wang J, Zhang W (2014) Engineering biofuel tolerance in non-native producing microorganisms. Biotechnol Adv 32:541–548

Kandasamy S, Muniraj IK, Purushothaman N et al (2016) High level secretion of laccase (LccH) from a newly isolated white-rot basidiomycete, Hexagonia hirta MSF2. Front Microbiol 7:707. https://doi.org/10.3389/fmicb.2016.00707

Kapdan IK, Kargi F (2006) Bio-hydrogen production from waste materials. Enzyme Microb Technol 38:569–582

Karemore A, Nayak M, Sen R (2016) Recent inventions and trends in algal biofuels research. Recent Pat Biotechnol 10:30–42

Kleinova A, Cvengrosova Z, Rimarcika J, Buzetzkia E, Mikulecb J, Cvengrosa J (2012) Biofuels from algae. Procedia Eng 42:231–238

Kriger O, Budenkova E, Babich O et al (2020) The process of producing bioethanol from Delignified cellulose isolated from plants of the Miscanthus genus. Bioengineering (Basel) 7:61

Kuhad R, Singh A (1993) Lignocellulose biotechnology: current and future prospects. Crit Rev Biotechnol 13:151–172

Kumar R, Ghosh AK, Pal P (2020) Synergy of biofuel production with waste remediation along with value-added co-products recovery through microalgae cultivation: a review of membrane-integrated green approach. Sci Total Environ 698:134169. https://doi.org/10.1016/j.scitotenv.2019.134169

Larson ED (2008) Biofuel production technologies: status, prospects and implications for trade and development. Report No. UNCTAD/DITC/TED/2007/10. In: United Nations conference on trade and development, New York and Geneva

Lee Y, Lee K, Oh Y (2015) Recent nanoparticles engineering advances in microalgal cultivation and harvesting processes of biodiesel production: a review. Bioresour Technol 184:63–72

Levin L, Forchiassin F, Ramos AM (2002) Copper induction of lignin-modifying enzymes in the white-rot fungus Trametes trogii. Mycologia 94:377–383

Limayen A, Ricke S (2012) Lignocellulosic biomass for bioethanol production: current perspectives, potential issues and future prospects. Prog Energy Combust Sci 38:449–467

Lindblad P, Lindberg P, Oliveira P, Stensjo K, Heidorn T (2012) Design, engineering, and construction of photosynthetic microbial cell factories for renewable solar fuel production. Ambio 41:163–168

Littlewood J, Guo M, Boerjan W, Murphy RJ (2014) Bioethanol from poplar: a commercially viable alternative to fossil fuel in the European Union. Biotechnol Biofuels 7:113. https://doi.org/10.1186/1754-6834-7-113

Lu X (2010) A perspective: photosynthetic production of fatty acid-based biofuels in genetically engineered cyanobacteria. Biotechnol Adv 28:742–746

Lutke-Eversloh T (2014) Application of new metabolic engineering tools for clostridium acetobutylicum. Appl Microbiol Biotechnol 98:5823–5837

Lutke-Eversloh T, Bahl H (2011) Metabolic engineering of *Clostridium acetobutylicum*: recent advances to improve butanol production. Curr Opin Biotechnol 22:634–647

Machado IM, Atsumi S (2012) Cyanobacterial biofuel production. J Biotechnol 162:50–56

Mani P, Fidal VT, Bowman K, Chandra TS, Keshavarz T, Kyazze G (2020) Development of an electroactive aerobic biocathode for microbial fuel cell applications. Environ Microbiol Rep. https://doi.org/10.1111/1758-2229.12871

Manish S, Banerjee R (2008) Comparison of biohydrogen production processes. Int J Hydrogen Energy 33:279–286

Mao C, Feng Y, Wang X, Ren G (2015) Review on research achievement of biogas from anaerobic digestion. Renew Sustain Energy Rev 45:540–555

Mathuriya AS (2020) Development of trickling bio-electrochemical reactor (TrickBER) for large scale energy efficient wastewater treatment. Environ Technol 2:1–35

McKinlay JB, Harwood CS (2010) Photobiological production of hydrogen gas as a biofuel. Curr Opin Biotechnol 21:244–251

Medipally SR, Yusoff FM, Banerjee S, Shariff M (2015) Microalgae as sustainable renewable energy feedstock for biofuel production. Biomed Res Int 2015:519513

Mohammadshirazi A, Akram A, Rafiee S, Kalhor EB (2014) Energy and cost analyses of biodiesel production from waste cooking oil. Renew Sustain Energy Rev 33:44–49

Moreno-Garrido I (2008) Microalgae immobilization: current techniques and uses. Bioresour Technol 99:3949–3964

Mostafa SE (2010) Microbiological aspects of biofuel production: current status and future directions. J Adv Res 1:103–111

Nakatani M, Hibi M, Minoda M, Ogawa J, Yokozeki K, Shimizu S (2010) Two laccase isoenzymes and a peroxidase of a commercial laccase-producing basidiomycete, *Trametes* sp. Ha1. N Biotechnol 27:317–323

Ni Y, Sun Z (2009) Recent progress on industrial fermentative production of acetone-butanol-ethanol by *Clostridium acetobutylicum* in China. Appl Microbiol Biotechnol 83:415–423

Nielsen DR, Leonard E, Yoon SH, Tseng HC, Yuan C, Prather KLJ (2009) Engineering alternative butanol production platforms in heterologous bacteria. Metab Eng 11:262–273

Nigam PS, Singh A (2014) Production of liquid biofuels from renewable resources. Prog Energy Combust Sci 37:52–68

Okada K, Fujiwara S, Tsuzuki M (2020) Energy conservation in photosynthetic microorganisms. J Gen Appl Microbiol 66:59–65

Olguin EJ (2012) Dual purpose microalgae-bacteria-based systems that treat wastewater and produce biodiesel and chemical products within a biorefinery. Biotechnol Adv 30:1031–1046

Parmar A, Singh NK, Pandey A, Gnansounou E, Madamwar D (2011) Cyanobacteria and microalgae: a positive prospect for biofuels. Bioresour Technol 102:10163–10172

Patnayat S, Sree A (2006) Screen of bacterial Associates of Marine Sponges for single cell oil and PUFA. Lett Appl Biol 40:358–363

Peralta-Yahya PP, Keasling JD (2010) Advanced biofuel production in microbes. Biotechnol J 5:147–162

Philbrook A, Alissandratos A, Easton CJ (2013) Biochemical processes for generating fuels and commodity chemicals from lignocellulosic biomass. In: Environmental biotechnology. InTech Open, London. https://doi.org/10.5772/55309

Pittman JK, Dean AP, Osundeko O (2011) The potential of sustainable algal biofuel production using wastewater resources. Bioresour Technol 102:17–25

Porth I, El-Kassaby YA (2015) Using Populus as a lignocellulosic feedstock for bioethanol. Biotechnol J 10:510–524

Rahnama N, Foo HL, Abdul Rahman NA, Ariff A, Md Shah UK (2014) Saccharification of rice straw by cellulase from a local Trichoderma harzianum SNRS3 for biobutanol production. BMC Biotechnol 14:103. https://doi.org/10.1186/s12896-014-0103-y

Razeghifard R (2013) Algal biofuels. Photosynth Res 117:207–219

Razzak SA, Hossain MM, Lucky RA, Bassi AS, de Lasa H (2013) Integrated CO_2 capture, wastewater treatment and biofuel production by microalgae culturing-a review. Renew Sustain Energy Rev 27:622–653
Robak K, Balcerek M (2018) Review of second generation bioethanol production from residual biomass. Food Technol Biotechnol 56:174–187
Rogers JN, Rosenberg JN, Guzman BJ, Oh VH, Mimbela LE, Ghassemi A, Betenbaugh MJ, Oyler GA, Donohue MD (2014) A critical analysis of paddlewheel-driven raceway ponds for algal biofuel production at commercial scales. Algal Res 4:76–88
Romero Victorica M, Soria MA, Batista-García RA et al (2020) Neotropical termite microbiomes as sources of novel plant cell wall degrading enzymes. Sci Rep 10:3864
Romero-Garcia JM, Martínez-Pati C, Ruiz E, Romero I, Castro E (2016) Ethanol production from olive stone hydrolysates by xylose fermenting microorganisms. Bioethanol 2:51–65
Romero-Guiza M, Vila J, Mata-Alvarez J, Chimenos J, Astals S (2016) The role of additives on anaerobic digestion: a review. Renew Sustain Energy Rev 58:1486–1499
Rupprecht J, Hankamer B, Mussgnug JH, Ananyev G, Dismukes C, Kruse O (2006) Perspectives and advances of biological H_2 production in microorganisms. Appl Microbiol Biotechnol 72:442–449
Saifuddin N, Priatharsini P (2016) Developments in bio-hydrogen production from algae: a review. Res J Appl Sci Eng Technol 12:968–982
Saini J, Saini R, Tewar L (2015) Lignocellulosic agriculture waste as biomass feedstocks for second-generation bioethanol production: concepts and recent development. 3. Australas Biotechnol 5:337–353
Sakurai H, Masukawa H (2007) Promoting R & D in photobiological hydrogen production utilizing mariculture-raised cyanobacteria. Mar Biotechnol (NY) 9:128–145
Sarkar N, Ghosh S, Bannerjee S, Aikat K (2012) Bioethanol production from agriculture waste: an overview. Renew Energy 37:19–27
Schmidt BJ, Lin-Schmidt X, Chamberlin A, Salehi-Ashtiani K, Papin JA (2010) Metabolic systems analysis to advance algal biotechnology. Biotechnol J 5:660–670
Sekoai PT, Yoro K, Daramola MO (2016) Batch fermentative biohydrogen production process using immobilized anaerobic sludge from organic solid waste. Environments 38:1–10
Senger RS (2010) Biofuel production improvement with genome-scale models: the role of cell composition. Biotechnol J 5:671–685
Shaishav S, Singh RN, Satyendra T (2013) Biohydrogen from algae: fuel of the future. Int Res J Environ Sci 2:44–47
Sharma S, Kundu A, Basu S, Shetti NP, Aminabhavi TM (2020) Sustainable environmental management and related biofuel technologies. J Environ Manage 273:111096. https://doi.org/10.1016/j.jenvman.2020.111096
Show KY, Lee DJ, Chang JS (2013) Algal biomass dehydration. Bioresour Technol 135:720–729
Shreve MJ, Brennan RA (2019) Trace organic contaminant removal in six full-scale integrated fixed-film activated sludge (IFAS) systems treating municipal wastewater. Water Res 151:318–331
Simionato D, Basso S, Giacometti GM, Morosinotto T (2013) Optimization of light use efficiency for biofuel production in algae. Biophys Chem 182:71–78. https://doi.org/10.1016/j.bpc.2013.06.017
Singh V, Singh MP, Verma V, Singh P, Srivastava R, Singh AK (2016) Characteristics of cold adapted enzyme and its comparison with mesophilic and thermophilic counterpart. Cell Mol Biol 62:144
Singh S, Goyal A, Moholkar VS (2018) Synthesis of bioethanol from invasive weeds: process design, optimization, and intensification with ultrasound. In: Bhaskar T, Pandey A, Mohan SV, Lee DJ, Khanal SK (eds) Waste biorefinery: potential and perspectives. Elsevier, Amsterdam, pp 445–485
Singh V, Mishra V (2020) Coronavirus disease 2019 (COVID-19): current situation and therapeutic options. Coronaviruses 1:1–11

Singh V, Yadav VK, Mishra V (2020a) Nanotechnology: An application in biofuel production. In: Srivastava M, Srivastava N, Mishra P, Gupta V (eds) Nanomaterials in biofuel research. Clean energy production technology. Springer, Singapore, pp 143–160

Singh V, Singh MP, Mishra V (2020b) Bioremediation of toxic metal ions from coal washery effluent. Desalin Water Treat 197:300–318. https://doi.org/10.5004/dwt.2020.25996

Singh V, Singh N, Tabassum N, Mishra V (2020c) Microbial system: an emerging application in the bioenergy production. In: Srivastava N, Mishra PK (eds) Microbial strategies for techno-economic biofuel production. Springer, Singapore

Singh N, Rai S, Singh V, Singh MP (2020d) Molecular characterization, pathogen-host interaction pathway and in silico approaches for vaccine design against COVID-19. J Chem Neuroanat 110:101874. https://doi.org/10.1016/j.jchemneu.2020.101874

Singh N, Singh V, Mishra D, Singh MP (2020e) An introduction of metagenomics and its application in microbial fuel production. In: Srivastava N, Srivastava M, Mishra P, Gupta VK (eds) Microbial strategies for techno-economic biofuel production. Clean energy production technologies. Springer, Singapore. https://doi.org/10.1007/978-981-15-7190-9_10

Sitarz AK, Mikkelsen JD, Højrup P, Meyer AS (2013) Identification of a laccase from Ganoderma lucidum CBS 229.93 having potential for enhancing cellulase catalyzed lignocellulose degradation. Enzyme Microb Technol 53:378–385

Sriwiriyarat T, Randall CW (2005) Performance of IFAS wastewater treatment processes for biological phosphorus removal. Water Res 39:3873–3884

Sticklen M (2006) Plant genetic engineering to improve biomass characteristics for biofuels. Curr Opin Biotechnol 17:315–319

Stitt M, Lunn J, Usadel B (2010) Arabidopsis and primary photosynthetic metabolism- more than the icing on the cake. Plant J 61:1067–1091

Tabatabai B, Fathabad SG, Bonyi E, Rajini S, Aslan K, Sitther V (2019) Nanoparticle-mediated impact on growth and fatty acid methyl ester composition in the cyanobacterium *Fremyella diplosiphon*. Bioenergy Res 12:409–418

Tao X, Xu T, Kempher ML, Liu J, Zhou J (2020) Precise promoter integration improves cellulose bioconversion and thermotolerance in clostridium cellulolyticum. Metab Eng 60:110–118

Thankappan S, Kandasamy S, Joshi B, Sorokina KN, Taran OP, Uthandi S (2018) Bioprospecting thermophilic glycosyl hydrolases, from hot springs of Himachal Pradesh, for biomass valorization. AMB Express 8:168. https://doi.org/10.1186/s13568-018-0690-4

Vanholme R, Van Acker R, Boerjan W (2010) Potential of Arabidopsis systems biology to advance the biofuel field. Trends Biotechnol 28:543–547

Voloshin RA, Kreslavski VD, Zharmukhamedov SK, Bedbenov VS, Ramakrishna S, Allakhverdiev SI (2015) Photoelectrochemical cells based on photosynthetic systems: a review. Biofuel Res J 6:227–235

Waqas S, Bilad MR, Man Z et al (2020) Recent progress in integrated fixed-film activated sludge process for wastewater treatment: a review. J Environ Manage 268:110718

Whitaker J, Field JL, Bernacchi CJ et al (2018) Consensus, uncertainties and challenges for perennial bioenergy crops and land use. Glob Change Biol Bioenergy 10:150–164

Xiao YZ, Tu XM, Wang J et al (2003) Purification, molecular characterization and reactivity with aromatic compounds of a laccase from basidiomycete Trametes sp. strain AH28-2. Appl Microbiol Biotechnol 60:700–707

Xue C, Zhao J, Chen L, Yang ST, Bai F (2017) Recent advances and state-of-the-art strategies in strain and process engineering for biobutanol production by clostridium acetobutylicum. Biotechnol Adv 35:310–322

Yadav VK, Singh V, Mishra V (2019) Alkaline protease: a tool to manage solid waste and its utility in detergent industry. In: Tripathi V, Kumar P, Tripathi P, Kishore A, Kamle M (eds) Microbial genomics in sustainable agroecosystems. Springer, Singapore. https://doi.org/10.1007/978-981-32-9860-6_14

Yang J, Son JH, Kim H et al (2019) Mevalonate production from ethanol by direct conversion through acetyl-CoA using recombinant Pseudomonas putida, a novel biocatalyst for terpenoid production. Microb Cell Fact 18:168

Yu D, Wang G, Xu F, Chen L (2012) Constitution and optimization on the performance of microbial fuel cell based on sulfate-reducing bacteria. Energy Procedia 16(Part C):1664–1670

Zhang TY, Wu YH, Hu HY (2014) Domestic wastewater treatment and biofuel production by using microalga Scenedesmus sp. ZTY1. Water Sci Technol 69:2492–2496

Zhang J, Liu Y, Sun Y, Wang H, Cao X, Li X (2020) Effect of soil type on heavy metals removal in bioelectrochemical system. Bioelectrochemistry 136:107596

Zhou J, Li Y (2010) Engineering cyanobacteria for fuels and chemicals production. Protein Cell 1:207–210

Zhu LY, Zong MH, Wu H (2008) Efficient lipid production with T. fermentas and its use for biodiesel preparation. Bioresour Technol 99:7881–7885