Chapter 3
Agricultural Residues and Manures into Bioenergy

Shubham Anand, Jashanpreet Kaur, Loveleen Kaur Sarao, and Ajay Singh

Abstract The mandate for energy has upsurged with the increase in population worldwide. Exploiting fossil fuels for energy has directed the exhaustion of fossil fuel assets. Thus, substitute sources of energy are required. Biomass is a renewable source and an alternative feedstock for providing eco-friendly and sustainable energy. Biofuels obtained from different biomass are grouped into three distinct groups: first-generation biofuels (obtained from wheat, sugarcane, barley, potato, soybean, corn, coconut, and sunflower), second-generation biofuels (produced from lignocellulosic materials like cassava, switchgrass, Jatropha, straw, and wood), third-generation biofuels (obtained from algae). The biofuel produced with the help of first-generation energy crops poses threat to biodiversity and food supply. But the use of lignocellulose as a biofuel does not contend with that of food production as it is nondigestible for humans. The principle advantage of algal biomass is higher oil production and it can convert all of the feedstock energy into various kinds of biofuels. Apart from this, it is useful for amputation of CO_2 from the industrial chimney (algae bio-fixation), food products, animal feed, and energy cogeneration after extraction of oil and treatment of wastewater. Thus, it is one of the world's most valuable, renewable, and sustainable source of the fuel which also helps in controlling environmental pollution. Thus, bioenergy crops and biofuels are considered as sustainable sources of energy production as waste products such as forest waste and agricultural residues, manures, industrial waste, and municipal solid waste are used for producing biofuels and bioenergy.

Keywords Bioenergy crops · Biofuels · Lignocellulose · Algae · Agricultural residues

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3.1 Introduction

The world has seen an increase in energy demand due to unceasing rise in the global population. The accomplishment of energy petition is typically done by ignition of fossil gases. But the use of these fuels poses many environmental hazards as the concentration of harmful gases (nitrogen oxide, greenhouse gases, and carbon dioxide) increases. For instance, greenhouse gases such as sulfur-containing compounds, particulate soot, and carbon dioxide are produced due to coal burning which results in acidification of the soil. Moreover, the energy which is produced from nuclear fission needs huge infrastructure and it also leads to hazardous effects on the environment in addition to human health (Gresshoff et al. 2017). Many long-term effects on the environment are related to the use of fossil fuels which include desertification and degradation of fertile soil (Karp and Shield 2008). The consequences of increased usage of fossil fuels are noticeable as diseases associated environmental pollution and drastic changes in climate such as torrential rains.

In addition to this, there has been increasing concern of depleting crude oil resources all over the world. As per the report of the renewable energy policy network (Mohr 2013), it was found that nearly 78% of the energy all over the world comes from fossil fuels, 3% is obtained from nuclear energy while another energy comes from resources which are renewable, i.e., hydrothermal, wind, biomass, and solar. At present, about 85 million barrels of oil from fossil fuels are refined each year. At the current rate, about 116 million barrels of crude oil will be needed every year by 2030. This increase in energy demand may lead to the exhaustion of fossil fuel assets. Thus, there is a need for substitute sources of energy (Lee and Lavoie 2013).

Due to increased concern about climate change all over the world, there is a need to evaluate the crops which are capable of producing higher biomass for the generation of energy (Lemus and Lal 2007). Biofuels and bioenergy crops are sustainable sources for the reason that these decrease carbon releases and dependency on fossil fuels along with providing habitat and ecosystem services (Fargione et al. 2010; Searchinger et al. 2008). Hence, the production of bioenergy will increase globally in near future (OECD-FAO (Organisation for Economic Co-operation and Development and the Food and Agriculture Organization) 2017).

Biomass is a renewable source and an alternative feedstock for providing eco-friendly and sustainable energy. Waste products such as forest waste and agricultural residues, manures, industrial waste, and municipal solid waste are used for producing biofuels and bioenergy. Different kinds of bioenergy can be produced from biomass. However, it is not competitive with respect to cost in comparison to petro fuels and other sources of renewable energy. Biofuels obtained from different biomass are grouped into three distinct groups. The first-generation biofuels are obtained from edible food crops like wheat, sugarcane, barley, potato, soybean, corn, coconut, and sunflower. While the second-generation biofuels are those which are obtained from lignocellulosic substances like cassava, switchgrass, Jatropha, straw, and wood. The third-generation biofuels are attained from algae

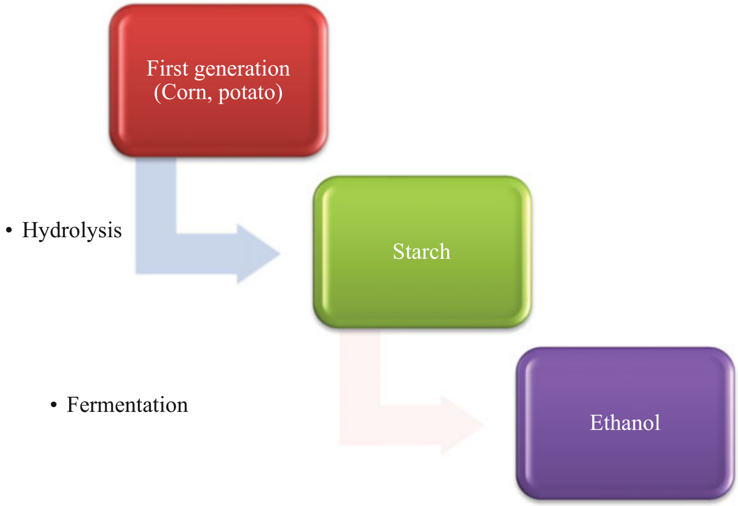


Fig. 3.1 Elementary steps for making of first-generation biofuels

produces huge quantities of lipids that are appropriate for the production of biodiesel.

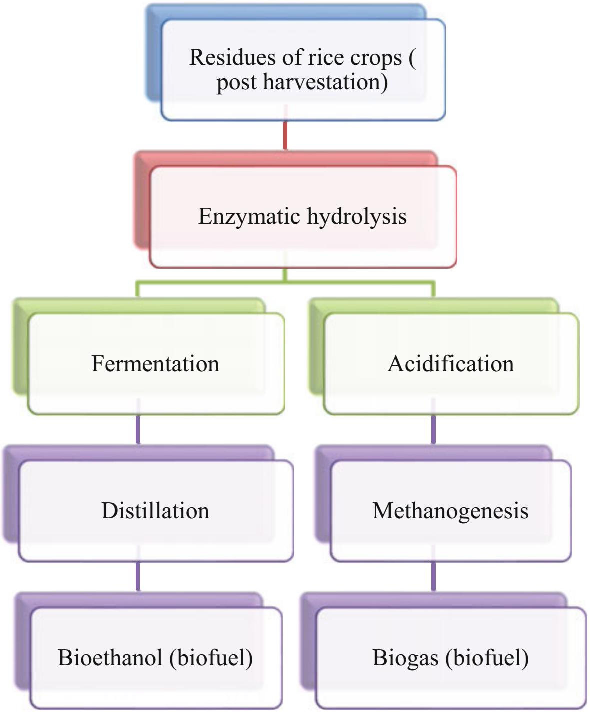
Bioenergy crops provide several advantages over traditional fuels such as decrease in the level of greenhouse gases and emission of CO_2, reduction in soil erosion along with increased transpiration and content of soil carbon (Adler et al. 2007; Wang et al. 2012; Kim et al. 2013). Resultantly, attention of scientific community is being continuously drawn towards the use of bioenergy crops because they are eco-friendly and renewable. However, the use of bioenergy crops results in an increased race for nutrient requirement, agricultural land, and water resources with food crops. Apart from this, the use of bioenergy crops can result in more dispersal of dominant plant species and destruction of wildlife habitat (Dipti and Priyanka 2013). So, in this chapter various kinds of bioenergy crops in addition to their features are discussed in detail (Fig. 3.1).

3.2 First-Generation Biofuels

Biofuel generation was started with first-generation bioenergy crops that are crops of global or local source (Yadav et al. 2019). They are made of starch, vegetable oil, and sugar. Fuels such as propanol, ethanol, and butanol are obtained biologically due to the action of enzymes and microorganisms by the fermentation of cellulose, starch, or sugar.

Production of ethanol is done primarily from cane sugar or corn starch. In 2014, nearly 14 billion gallons of ethanol from corn starch were produced in the US. In the US, around 40% of the corn crop is used for the production of ethanol. Higher than

Fig. 3.2 Using rice postharvest residues for the manufacture of biofuels



90% of the world's ethanol supply is made by the US and Brazil (Renewable Fuels Association 2015).

Rice straw is an abundant lignocellulosic biomass having the potential for use as a feedstock for the production of bioethanol. Enzymatic hydrolysis is important to make ethanol from biomass for degradation of straw of rice into sugars like xylose and glucose. Since each biomass has diverse enzyme going-on therefore enzyme substances appropriate for all biomasses essential should be carefully chosen. Ethanol production can be done from treated straw through the process of simultaneous fermentation and saccharification (SSF) in the presence of xylose-fermenting fungus (*Mucor circinelloides*) and an optimized enzyme cocktail (Takano and Hoshino 2018).

Apart from this, biodiesel is also used as an alternative. Eventhough the cost of biodiesel production is higher, it is a copious source of renewable energy as it is eco-friendly. Producing biodiesel from coconut oil is more in comparison to rapeseed and soybean. Lubrication properties of coconut oil are much better compared to other biofuels (Hossain et al. 2012) (Fig. 3.2).

Coconut shell is most commonly used as a source for making charcoal. By using the traditional pit method, nearly 25–30 of charcoal can be produced from dry shells. Calorific value of coconut shell is higher (20.8 MJ/kg) and it is used for the production of biochar, energy-rich gases, bio-oil, steam, etc. Due to high volatile matter content, low content of ash, and cheap cost, coconut shell is more suitable for

Table 3.1 Biofuel production from rice straw

Pretreated source	Biofuel	Outcomes	References
Husk mixture	Pellets of fuel	Combustion properties are better and the quality of pellets of fuel; leading to the production of sustainable biofuel	Rios-Badran et al. (2020)
Straw pretreated with sodium hydroxide (NaOH)	Bioethanol from *Bacillus spp*	Better yield of sugars which are fermentable Capability of replacing enzymes which are traditional	Tsegaye et al. (2019)
Valorized straw	Bioethanol	Production of sustainable and eco-friendly biofuel	Kaur and Chander (2019)
Straw of pretreated rice	Biomethane	Production of biomethane is better and biogas after pretreatment resulting in higher net energy outputs	Elsayed et al. (2019)

pyrolysis process. It can be collected easily from the places where coconut meat is used for food processing. Other crops which are used for the production of first-generation biofuels include Corn, Sugarcane, Vegetable oils, Soybean, rapeseed, wheat, peanuts, and sugar beet (Table 3.1).

3.3 Second-Generation Biofuels

The second-generation biofuels, recognized as unconventional biofuels, refer to those biofuels which are formed from lignin, cellulose, and hemicellulose. Such kind of biofuels are either merged with petroleum-based fuels, ignited in the current engines, or can be used in slightly adapted vehicles such as vehicles for dimethyl ether. These biofuels are used because first-generation biofuels have certain limitations. With the help of first-generation biofuels, enough biofuel cannot be produced without posing threat to biodiversity and food supply. Also, such biofuels are less cost-competitive when compared with the prevailing fossil fuels (Anonymous 2021) (Fig. 3.3).

3.3.1 Characterization of Lignocellulosic Biomass: Components and Structure

Lignocellulose is the most copious natural biomasses in the world with 200 billion tons yield (Zhang and Percival 2008). It is stored in the plant's cell wall and it constitutes 60–80% of the woody tissues in plant stems, 15–30% in plant leaves, and 30–60% in the herbal stems (Moller et al. 2007). Use of lignocellulose as biofuels do

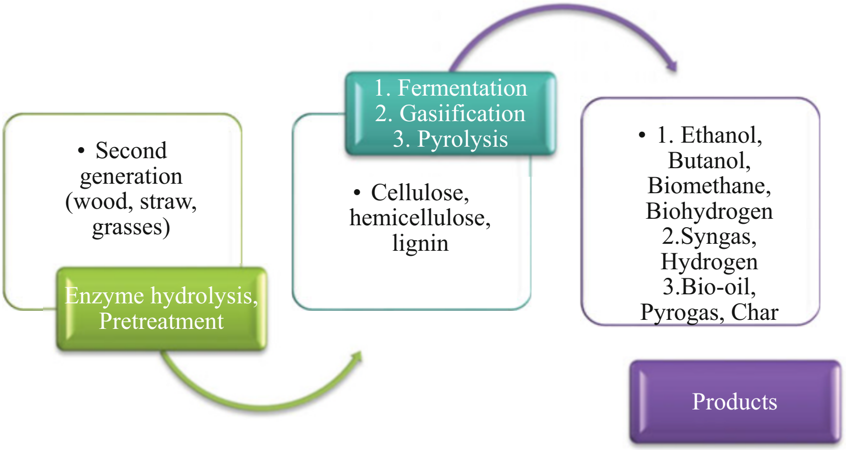


Fig. 3.3 Elementary steps for the manufacture of second-generation biofuels

not contend with that of food production (as in first-generation biofuels) because it is nondigestible for humans. Lignocellulose is made up of three polymeric compounds that are lignin, cellulose, and non-cellulosic carbohydrates (mainly hemicellulose).

Cellulose is a long chain homo-polymer that consists of a unit of glucose with a repeat unit of cellobiose (Zhang et al. 2019). It has 500–1,000,000 D-glucose units linked to β-1,4-glycosidic bonds (Volynets and Dahman 2011). In cellulose, a semi-crystalline structure is created due to interchain H-bonds present between hydroxyl groups (glucose residues) in the radial position and hydrogen atoms (aliphatic) in the axial position. This structure makes cellulose unaffected by enzymatic hydrolysis and the weaker interactions (hydrophobic) between the cellulose sheets promote the formation of a layer of water near the surface which results in production from acid hydrolysis (Bessou et al. 2011). The chemical structure of cellulose built from different plants is identical. However, cellulose molecules derived from different plants differ from each other in interconnections with other biomass molecules and crystalline structure.

Hemicellulose belongs to polysaccharide groups containing chains which are branched and shorter. As hemicellulose accounts for 35% of the biomass weight, these are considered important for biofuel production (Limayem and Ricke 2012). Hemicellulose are not chemically homogenous like cellulose and the chemical structure depends upon the kind of material as the hardwood mainly consists of xylans while the softwood constitutes glucomannans (Agbor et al. 2011; Vidal et al. 2011).

Lignin is an amorphous hetero polymer which constitutes three phenolic monomers—phenyl propionic alcohols, sinapylalcohol, p-coumaryl, and coniferyl. Covalent cross-linking (lignin with cellulose and hemicellulose) forms a strong matrix which provides protection to the polysaccharide from microbial degradation, thwarts its extraction with aqueous solvents which are neutral, and makes it oxidative stress resistant (Vidal et al. 2011). The highest lignin is present in forest biomass (30–60% in softwoods and 30–55% in hardwoods) while it is present in lesser quantity in agricultural residues (3–15%) and grasses (10–30%) (Limayem and Ricke 2012).

3.3.2 Lignocellulosic Biomass for Liquid Fuels by Thermochemical Conversion

The controlled oxidation or heating of the feedstock for the purpose of generating heat and energy products is defined as thermochemical conversion (Wang et al. 2021). With the help of thermochemical conversion, there is an acceleration of deoxygenation reactions in lignolytic biomass. The basic hypothesis behind thermoregulation is that these reactions can lead to the rearrangement of the fundamental structure of lignocellulosic biomass for producing high-grade biofuels in comparison to petroleum fuels (Jiang et al. 2015). It constitutes several techniques such as

- Pyrolysis
- Gasification
- Combustion
- Liquefication (Tables 3.2 and 3.3)

The process of heating biomass in anaerobic conditions so that the chemical compounds like lignin, cellulose, and hemicellulose that make the material decompose thermally into charcoal and combustible gases is called pyrolysis. When it is performed in the aerobic condition, then gasification takes place at a higher temperature ensuing formation of gaseous fuel along with solid residue termed as ash. Higher temperature during gasification prevents the formation as well as condensation of the liquid products (Wang et al. 2021) (Fig. 3.4).

During gasification, carbon monoxide, methane, carbon dioxide, and syngas are produced. As compared to pyrolysis, it requires lesser posttreatment. Gasification takes place in three stages that are drying (up to the temperature of 120 °C), devolatization, i.e., removal of volatile matter, and creation of char followed by gasification (at the temperature above 350 °C). For complete gasification, a temperature above 500 °C is required (Kuzhiyil et al. 2012). The gases formed throughout gasification are used for the indirect production of liquid fuel. This process differs from pyrolysis as they are performed at the higher pressure of hydrogen gas in the presence of a catalyst. Liquefaction is the process of direct creation of liquid fuel from solid or gas. It takes place at a high temperature (200–370 °C) and pressure of 4–20 MPa (Fig. 3.5).

Table 3.2 Lignocellulosic biomass composition

Biomass	Cellulose	Hemicellulose	Lignin	Reference
Rice straw	32–47	15–27	5–24	Sarkar et al. (2012), Van Dyk and Pletschke (2012), Saha (2003)
Rice hulls	24–36	12–19	11–19	Van Dyk and Pletschke (2012)
Rye straw	30.9	21.5	25.3	García-Cubero et al. (2009)
Straw of wheat	30–49	20–50	8–20	Sarkar et al. (2012), García-Cubero et al. (2009), Van Dyk and Pletschke (2012)
Corn cobs	35–45	35–42	5–15	García-Cubero et al. (2009), Saha (2003)
Corn fiber	15	35	8	Saha (2003)
Straw of corn	42.6	21.3	8.2	Sarkar et al. (2012)
Corn stover	39–42	19–25	15–18	García-Cubero et al. (2009), Saha (2003)
Softwood	40–45	25–29	30–60	Limayem and Ricke (2012), Balat (2011)
Hardwood	45–47	25–40	20–55	Limayem and Ricke (2012), Balat (2011)
Seed hair of cotton, flax	80–95	5–20	0	Balat (2011), Van Dyk and Pletschke (2012)
Bagasse (Sugarcane)	40	24–30	12–25	Sarkar et al. (2012), Van Dyk and Pletschke (2012), Saha (2003)
Switchgrass	30–50	10–40	5–20	Limayem and Ricke (2012), Saha (2003), McKendry (2002)
Bermuda grass	25–48	13–35	6–19	Van Dyk and Pletschke (2012), Saha (2003)

Table 3.3 Composition of other lignocellulosic sources

Biomass	Cellulose	Hemicellulose	Lignin	Reference
Fiber separated from municipal solid waste	49	16	10	Li and Huang (2010)
Municipal sludge (Primary)	29.3	Unknown	Unknown	Champagne and Li (2009)
Thickened waste (activated sludge)	13.8	Unknown	Unknown	Champagne and Li (2009)
Sawdust	45.0	15.1	25.3	Van Dyk and Pletschke (2012)
Waste paper (Chemical pulps)	50–70	12–20	6–10	Limayem and Ricke (2012)
Newspaper	40–55	25–40	18–20	Wang et al. (2012), Limayem and Ricke (2012)
Used office paper	55.7	13.9	5.8	Wang et al. (2012)
Magazine	34.3	27.1	14.2	Wang et al. (2012)
Cardboard	49.6	15.9	14.9	Wang et al. (2012)
Paper sludge	33–61	14.2	8.4–15.4	Peng and Chen (2011), Yamashita et al. (2008)
Chemical pulps	60–80	20–30	2–10	Balat (2011)

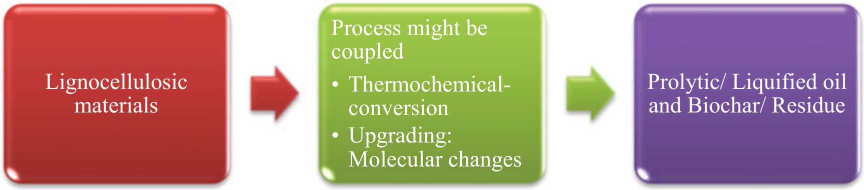
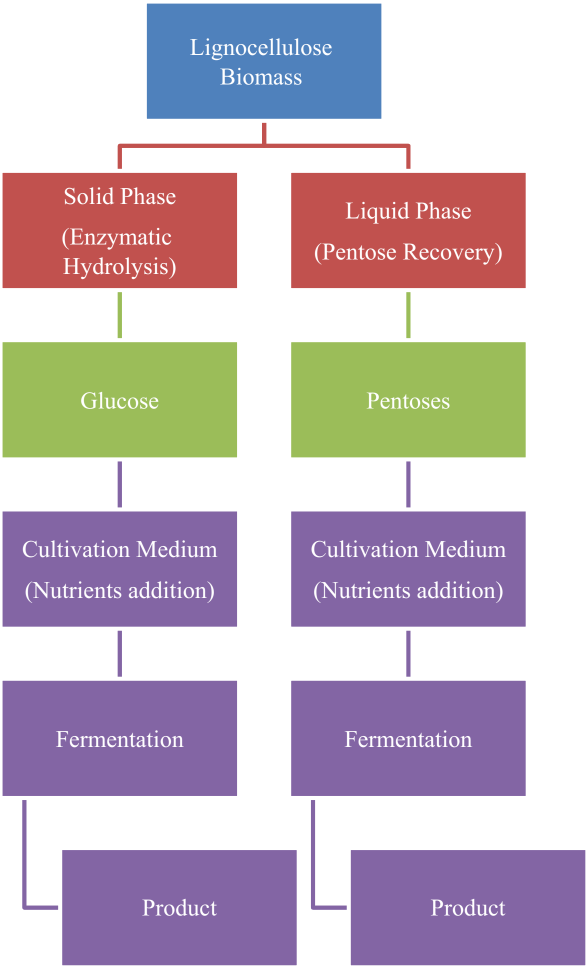


Fig. 3.4 Pathway for thermochemical conversion of lignocellulosic biomass (Jiang et al. 2015)

Fig. 3.5 Using lignocellulose biomass for making of liquid biofuels



3.4 Third-Generation Biofuels

The third-generation biofuels are the fuels that are formed from algal biomass (Brennana and Owendea 2010; Chen et al. 2011). These biofuels are advanced renewable fuels which are obtained from algae through various processes. Algal biomass is rich in oils which are attributed to its ability to photosynthesize abundantly (Anonymous 2014). Algae is an aquatic species with nearly 3000 breeds. Algae possess greater diversity in comparison to land plants because of their ability to reproduce at a faster rate (Suganya et al. 2016). Algae obtain CO_2 from the atmosphere during photosynthesis and convert it into oxygen (Laamanen et al. 2016). Oil from algae is extracted by breakage of the cell structure (Hallenbeck et al. 2016). The principle advantage of algal biomass other than higher oil production is that it can convert nearly all of the feedstock energy into various kinds of biofuels (Suganya et al. 2016). Apart from this, it is useful for the removal of carbon dioxide from the industrial chimney; the process known as algae bio-fixation, animal feed, food products, energy cogeneration after extraction of oil, and treatment of wastewater. Freshwater, brackish water, or even wastewater can be used to grow algae. They can grow at a rapid rate and do not require many nutrients for growth (Guiry 2012) (Fig. 3.6).

Using algae biomass for biofuel production offers several advantages which include:

(a) More tolerance to higher content of carbon dioxide
(b) Lesser consumption of water
(c) No use of pesticides or herbicides for the cultivation of algae
(d) Can be grown throughout the year

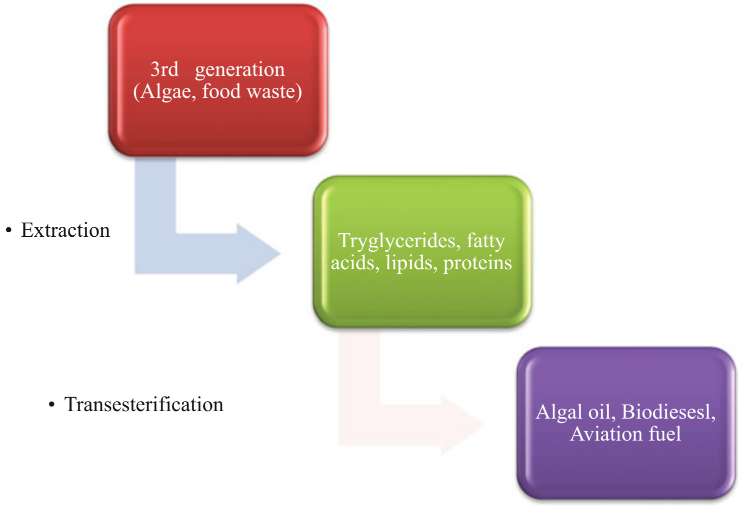
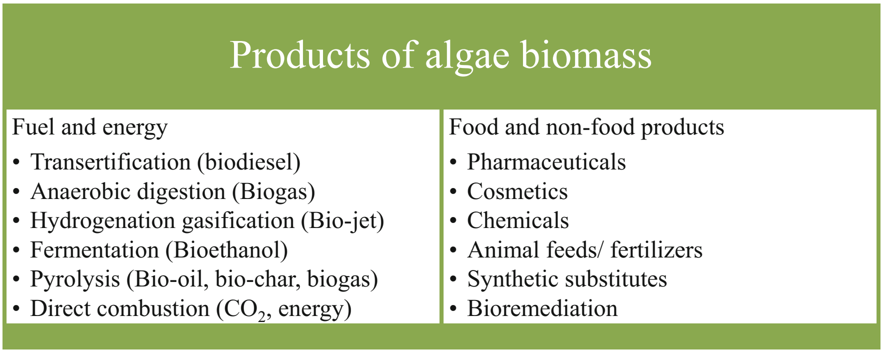


Fig. 3.6 Elementary steps for production of third-generation biofuels



Products of algae biomass

Fuel and energy	Food and non-food products
• Transertification (biodiesel)	• Pharmaceuticals
• Anaerobic digestion (Biogas)	• Cosmetics
• Hydrogenation gasification (Bio-jet)	• Chemicals
• Fermentation (Bioethanol)	• Animal feeds/ fertilizers
• Pyrolysis (Bio-oil, bio-char, biogas)	• Synthetic substitutes
• Direct combustion (CO_2, energy)	• Bioremediation

Fig. 3.7 Products of algal biomass

(e) Can be grown under adverse environmental conditions such as coastal seawater, saline, or brackish water
(f) Grown in wastewater (Spolaore et al. 2006, ‘Dismukes et al. 2008, Dragone et al. 2010).

On the contrary, algae cultivation has many demerits like more cost of cultivation in contrast to conventional fuel crops. Also, for the making of algal biomass, there is the obligation of more energy which constitutes nearly 20–30% of the cost of production. Various methods are used for concentrating the algal biomass which include flocculation, sedimentation, filtration, centrifugation, and floatation (Demirbas 2010a, b; Ho et al. 2011) (Fig. 3.7).

Growth rate of algae varies under different growing conditions such as temperature, nutrients, and acidity. Many products can be obtained from algal biomass which includes jet fuel, syngas, bio-oil, butanol, ethanol, and natural fertilizers (Joshi and Nookaraju 2012). Although the conversion methods of algal biofuel production (fermentation, transesterification, and hydrotreatment) are expensive and complex in comparison to fossil fuels and biofuels of other generations. However, there is a potential basis for optimism with regard to this biofuel due to its sustainability and ability to produce more products because of its diversity (EIA 2016). From all the positive features of the algal biomass, it is found that it is one of the world’s most valuable, renewable, and sustainable source of fuel which also helps in controlling environmental pollution (Suganya et al. 2016).

3.4.1 Classification of Algae

Algae is the group having eight divisions, which can be unicellular or multicellular termed as microalgae (microphytes) and macroalgae (seaweeds), respectively (Suganya et al. 2016). Roots, leaves, and stems are absent in microphytes. It can be grown upto hundreds of micrometers and is found in fresh as well as marine water

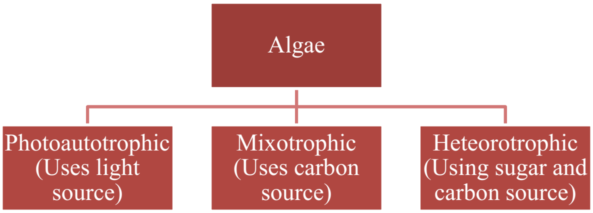


Fig. 3.8 Classification of algae under varied environmental conditions

bodies (Lee and Lee 2016). However, macroalgae has body-like structure. It is found near the sea beds and grows upto hundreds of meters (Suganya et al. 2016). Structure of macroalgae is in such a way as to store and convert the energy without development outside their cells. The easiness in the growth, as well as development of algae, has made them a sustainable source of energy in comparison to any other renewable source of energy (Kandiyoti et al. 2017). Various environmental conditions for the growth of algae is as shown in the figure (Fig. 3.8).

3.4.1.1 Technique of Algal Oil Extraction

For energy production, oil can be produced from algal biomass or these can be transformed into biofuels directly. Oil is usually extracted via various methods which include mechanical and solvent removal (Demirbas 2010a, b). Algae can be converted to biofuel through various options which include change of algal biomass to energy goods, extraction of metabolites, and processing of algal secretions (Ganguly et al. 2021). Steps tangled in the manufacture of biofuels are harvesting followed by dewatering, then extraction, and finally dispensation to energy goods and co-products (Lardon et al. 2009).

3.4.1.2 Harvesting and Drying of Algal Biomass

The cell wall of unicellular microalgae contains fatty acids and lipids that are higher plants and animals. Before mechanical and solvent extraction, harvesting and drying algal biomass is an important step. The harvesting of macroalgae is done with nets which needs lesser energy but for the harvesting of microalgae, conventional methods are used which include flocculation, centrifugation, filtration, foam fractionation (Liu et al. 2013; Prochazkova et al. 2013; Heasman et al. 2008; Csordas and Wang 2004; Rossignol et al. 1999), ultrasonic separation (Bosma et al. 2003), froth floatation, and sedimentation. Type of harvesting methods depends upon the species of algae.

For the extension of algal shelf life, drying is an important method as it prevents postharvest decay (Munir et al. 2013). For drying of microalgae, various approaches are considered to be efficient such as freeze drying (lyophilization), drum-drying, sun-drying, and spray drying (Richmond 2004; Leach et al. 1998; Williams and

Laurens 2010). Due to the presence of a higher amount of water, sun-drying is not an effective method (Mata et al. 2010). Furthermore, the effectiveness of drying method is contingent upon temperature during the extraction of lipids from algal biomass (Widjaja et al. 2009).

3.4.2 Production of Biodiesel

Biodiesel is mono alkyl esters of the long chain fatty acids, which is extracted from biomass and renewable lipid feedstocks (Demirbas 2009; Clark and Deswarte 2008,). Extraction of lipid (diatoms) has been initially done by German scientist during second World War (Cohen et al. 1995). Since the yield of oil from algal biomass is higher in comparison to oilseeds, it can be economically converted into biodiesel with the help of various techniques. Various species of microalgae are used for the manufacture of biodiesel which includes *Ankistrodesmus fusiformis*, *Ankistrodesmus falcatus, Chlamydocapsa bacillus*, and *Kirchneriella lunaris* (Nascimento et al. 2013). The content of oil from microalgae is quite high which usually exceeds 80% by weight of the dry biomass. From an acre nearly 5000–15,000 gal of biodiesel can be produced annually from algae thus reflecting its potentiality for use as biofuel (Spolaore et al. 2006; Chisti 2007) (Tables 3.4 and 3.5).

3.4.3 Production of Bioethanol

Production of bioethanol from algal biomass has been reported by many researchers. Algae are considered to be more appropriate for the manufacture of bioethanol due to the lower content of lignin and hemicellulose in algae as compared to lignocellulosic biomass (Chen et al. 2013). Numerous species of algae are used for the manufacture of bioethanol which includes *Gelidium amansii*, *Laminaria sp*., *Spirogyra sp*.,

Table 3.4 Comparison of algal biomass for the manufacture of biodiesel

Algae			
Feedstock	Biodiesel	Conditions	References
Nannochloropsis sp.	99 g/kg lipid	Oil extraction (n-hexane), transesterification with acid	Susilaningsih et al. (2009)
Spirulina platensis	60 g/kg lipid	Reaction temperature (55 °C), 60% catalyst concentration, 1:4 algae biomass to methanol ratio, 450 rpm stirring intensity	Nautiyal et al. (2014)
Nannochloropsis salina	180.78 g/kg lipid	Freeze drying, extraction with chloroform–methanol (1:1 ratio), alkali transesterification	Muthukumar et al. (2012)
Scenedesmus sp.	321.06 g/kg lipid	NaOH, temperature (70 °C)	Kim et al. (2014)

Table 3.5 Comparison of terrestrial plants for the production of biodiesel (Behera et al. 2015)

Terrestrial plants			
Feedstock	Conditions	Biodiesel	References
Soybean	189.6 g/kg lipid	Hydrotalcite (basic catalyst), methanol/oil molar ratio of 20:1, reaction time (10 h)	Martin et al. (2013)
Madhuca indica	186.2 g/kg lipid	0.30–0.35 (v/v) methanol-to-oil ratio, 1% (v/v) H_2SO_4 as acid catalyst, 0.25 (v/v) methanol, 0.7% (w/v) KOH as alkaline catalyst	Ghadge and Raheman (2005)
Azadirachta indica	170 g/kg lipid	Reaction duration (60 min), 0.7% H_2SO_4 (acid catalyst), temperature (50 °C), and methanol: oil ratio—3:1	Awolu and Layokun (2013)
Pongamia pinnata	253 g/kg lipid	Transesterification with methanol, NaOH as catalyst, temp. 60 °C	Mamilla et al. (2011)

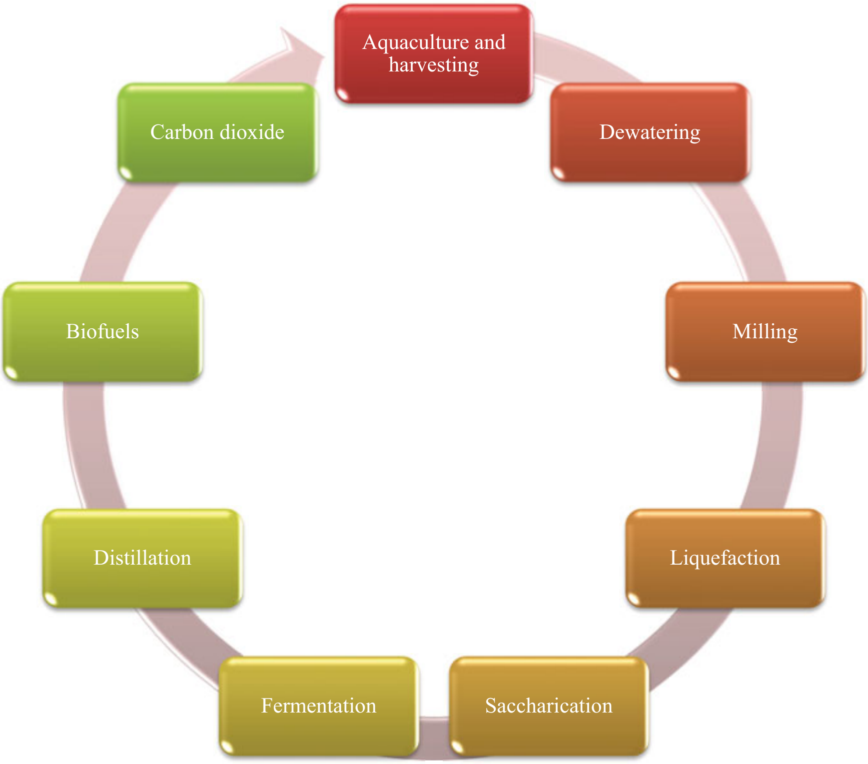


Fig. 3.9 Production of bioethanol from algal biomass through fermentation process

Sargassum sp., *Gracilaria sp.*, and *Prymnesium parvum* (Eshaq et al. 2011; Rajkumar et al. 2014) (Fig. 3.9; Tables 3.6 and 3.7).

Table 3.6 Comparative analysis of bioethanol production from algae

Algae			
Feedstock	Bioethanol	Conditions	References
Chlorococcum infusionum	260 g ethanol/kg algae	Alkaline (pretreatment), temperature (120 °C), *S. cerevisiae*	Harun et al. (2011)
Spirogyra	80 g ethanol/kg algae	Alkaline pretreatment, synthetic media growth, saccharification of biomass by *Aspergillus niger*, fermentation by *S. cerevisiae*	Eshaq et al. (2010)

Table 3.7 Comparative analysis of bioethanol production from terrestrial plants

Terrestrial plants			
Feedstock	Bioethanol	Conditions	References
Manihot esculenta	189 ± 3.1 g ethanol/kg flour	Amyloglucosidase, Enzyme termamyl 1 N HCl	Behera et al. (2014)
Rice straw	93 g ethanol/kg pretreated rice straw	Cellulase, solid-state fermentation, strain, β-glucosidase *Aspergillus niger* MTCC 7956	Sukumaran et al. (2008)
Sugarcane bagasse	165 g ethanol/kg bagasse	Acid (H_2SO_4) hydrolysis, Fermentation at 50 °C	Kumar et al. (2014)

3.4.4 Production of Biogas

As there is a presence of high polysaccharides in algal along with lower content of cellulose and zero lignin, the production of biogas from algal biomass can be done through the process of anaerobic digestion (Yen and Brune 2007; Ras et al. 2011; Zhong et al. 2012; Saqib et al. 2013).

However, for biofuel extraction from algae, there is a requirement of energy-efficient and cost-effective techniques. Use of standard harvesting techniques, design of photobioreactor, biorefinery concept, and other technologies are required which will further decrease the cost of biofuel production from algae.

3.5 Conclusion

Usage of bioenergy crops for energy production can help in employing these alternative sources of renewable energy. Commercial production of these fuels could make us sovereign for fossil transportation fuels using existing engine technologies. The most sustainable sources of energy production are bioenergy crops and biofuels. With the help of first-generation biofuels, enough biofuel cannot be produced without posing threat to biodiversity and food supply. But the use of lignocellulose as a biofuel does not contest with that of food production as these are nondigestible for humans. Also, such biofuels are cheaper than existing fossil fuels. For energy production, oil can be mined from the algal biomass or these can be converted into biofuels directly. Also, algae can convert nearly all of the feedstock energy into various kinds of biofuels. Apart from this, it is useful for the removal of carbon dioxide from the industrial chimney (algae bio-fixation), food products, animal feed, energy cogeneration after extraction of oil, and treatment of wastewater. Hence, it is one of the world's most valuable, renewable, and sustainable source of fuel which also helps in controlling environmental pollution. Thus, bioenergy crops and biofuels are considered to be sustainable sources of energy production as waste products such as forest waste and agricultural residues, manures, industrial waste, and municipal solid waste are used for producing biofuels and bioenergy.

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