# Chapter 16
# Biofuel Production: Global Scenario and Future Challenges

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**Abstract** Biofuels have evolved as the fuel of the future. The technology hungry era has resulted in pollution escalation and fossil fuel depletion like never before. The scientific quest for sustainable fuel options finally culminated with the biofuels. The biomasses for biofuel production are the best candidates for carbon fixation. The biomass mediated carbon capture and storage/utilisation is an excellent natural route for reduction of carbon footprint. The substrates for biofuels are food crops, non-food crops, and microalgae. The food-fuel issues have enforced the biofuel producers and policymakers to give up the practice of food crop usage. As of now biofuel production from lignocellulosic and microalgae is the only remaining viable option. Biofuel production methods are necessarily less energy-consuming ones as compared to their fossil fuel counterparts. Fermentation, transesterification, and hydrothermal liquefaction are some of the biofuel production methods. Biofuels like bioethanol, biodiesel, and biobutanol are getting used in transportation sector as flex-fuels. The current blending percentages for flex-fuels are as high as 20%. The physicochemical properties of biofuels mandate engine retrofitting for biofuel usage. Biofuel sustainability is an utmost requirement for its social and economic acceptance. Biofuels productions must not be done at the cost of reduction in food supplies. Simultaneously biofuel production process should not put adverse effects on land quality, water reservoirs, and biodiversity. The biofuel policies all over the globe are more or less the same. They necessarily enforce biofuel blending into petroleum fuels. The producers are provided with lucrative fiscal supports by governments. Tax exemptions, frequent regulation of raw materials prices, and guarantee for biomass sales for over a decade are now attracting many farmers to initiate energy cropping. All these efforts from different stakeholders are gradually transforming the global energy sector scenario.

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## 16.1 Introduction

Energy is a quintessential need for survival. For living beings, it can be in the form of food, and for non-living entities, as fuel. The energy became the most significant necessity for developmental activities all around the globe. Till date, the best possible sources of energy are the conventional fossil fuels. However, the insecurity of a steady-state supply at par with the asking demand, varying prices and last but not the least the considerable adverse environmental impacts have forced us to look beyond fossil fuels for better alternatives (Brito and Martins 2017). The usages of fossil fuels have led to drastic climatic changes, loss of biodiversity, alterations in the quality of ecosystem and rapid exhaustion of fuel reserves (Kumar et al. 2019). These serious issues have rung the alarm to tackle them in the shortest period possible. These concerns have opened the doors for the usage of renewable energy sources and alternative ways for the production of energy and fuels (Renewable Energy Directive 2009; Correa et al. 2019).

Currently, the most debatable topic is how to cater the increasing energy demands while either doing no harm to the environment or even reversing the harmful effects (Heard et al. 2017). Nowadays, about 80% of the global energy demands are getting fulfilled by fossil fuels (coal, petroleum and natural gases) which amount to $5.8 \times 10^{11}$ GJ as of 2016. The transportation sector alone has claimed about ~60% share out of those 80% energy demands (Correa et al. 2019; Joshia et al. 2017). Alternatives to conventional fuels must be renewable and sustainable. The biofuels have emerged as the sustainable fuel source having capabilities like reducing the greenhouse gas emissions, thereby simultaneously improving environmental health (Rauda et al. 2019). The amount of $CO_2$ emitted during the combustion is the amount of $CO_2$ assimilated by the biomass during its growth period (Kour et al. 2019). That is how carbon footprint is balanced via biofuels (Mahapatra and Kumar 2019). Biofuels are gaining lots of attention in the current times because of their extensive number of pros over minimal cons. Some of the striking pros and cons are mentioned in Table 16.1.

**Table 16.1** Advantages and disadvantages of biofuels (Mahapatra and Kumar 2019)

| Advantages of biofuels | Disadvantages of biofuels |
|---|---|
| The usage of biofuels can reduce the biofuel dependency to a large extent | Biofuel production can lead to food scarcity when the feedstocks are used as raw materials |
| Balance in the ecosystem is maintained since the emissions of greenhouse gases are controlled | |
| Reduction of waste handling issues since biomass wastes are used as the raw materials for biofuel production | The genetically engineered microbes and biomasses used for biofuel production can pose a threat to the ecosystem balance unless they are handled effectively |
| Biofuel generation process provides employment opportunities, which eventually helps in socio-economic development | |

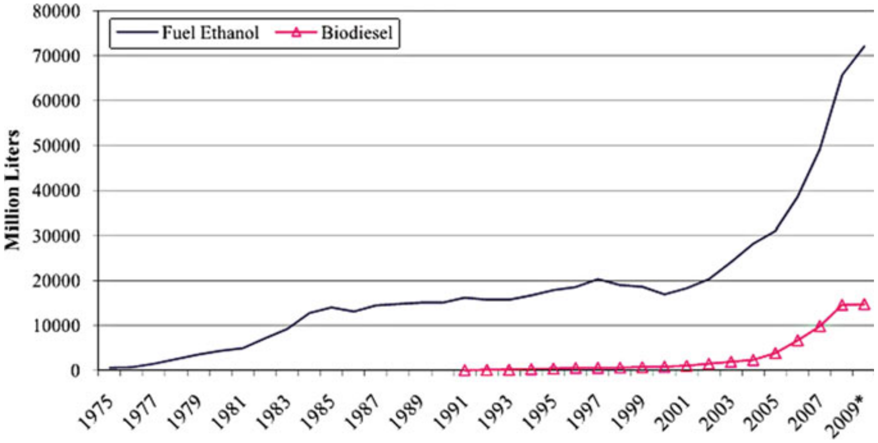

**Fig. 16.1** The pattern of worldwide Ethanol and biodiesel production on an annual basis during 1975–2009 (Sorda et al. 2010)

The governmental interventions in the larger biofuel producing countries have acted as catalysts to enhance biofuel production. The US (global leader in bioethanol production) government provides financial incentives to the biofuel manufacturers. France and Germany have brought the mandates of biodiesel blending with conventional petroleum fuels to use them as transport fuels. This government supports resulted in an escalation of bioethanol production from 16.9 to 72.0 billion litres, while that of biodiesel has grown from 0.8 to 14.7 billion litres during the last decade between 2000 and 2009 (Sorda et al. 2010). The pattern of ethanol and biodiesel productions during 1975–2009 is represented as a plot in Fig. 16.1.

## 16.2 The Biofuels

The reports for the year 2014 of International Energy Agency, have predicted growth in energy demands of about 37% by 2040. However, the limited and fast exhausting fossil fuel reserves would not be able to meet the requirements alone by then. Hence the scientists are trying their best to come up with alternative fuel sources from biomasses, i.e. the biofuels. Although a lot of production methods are invented the commercial-scale productions at large scale are still to be untapped (Schiermeier et al. 2008).

The developed countries use biofuels for the transportation sector. Whereas, the developing nations are targeting in multifold such as maintaining the climatic harmony, creating employment opportunities at large, and last but not the least in the restoration of wastelands to their original state via biomass-energy plantation (Joshia et al. 2017). The global climate change issue is currently posing as one of the primary driving forces for emphasising biofuel production. Recently the International Energy

Agency has proposed a 2 °C scenario (2DS), which says that the global $CO_2$ emissions by the year 2060 should be cut down by a mark of 70% with reference to the 2014 level. The principal sectors which contribute to the $CO_2$ emissions at large are the transportation sector and electricity generation sector, with the former one alone providing to 23% of total emissions all across the globe. Both of these sectors are utilising fossil fuels for their operation (Yabe et al. 2012; Ahlgren et al. 2017). Based on the mobility model outcomes in accordance to the 2DS approach released by IEA, by the year 2060, the quota of biofuel usage in the transportation and electricity generation sectors should be at least 30.7% and 27%, respectively (Ho et al. 2014). The surge of biofuel usage in various areas is considered as favourable approach owing to their either carbon neutral or carbon negative based on their contribution to the $CO_2$ concentration (Naik et al. 2010).

## 16.3 The Generations of Biofuels

The biofuels are categorised into four different generations based on the raw materials used and are as follows,

- First generation (1G) biofuels
- Second generation (2G) biofuels
- Third generation (3G) biofuels
- Fourth generation (4G) biofuels

### *16.3.1 First Generation (1G) Biofuels*

The first-generation biofuels are the biofuels which use edible biomasses as raw materials. Those raw materials can either be starch such as potato, wheat, barley, and corn or the sugars obtained from sugarcane and sugar beet (Alalwan et al. 2019). The first generation of biofuels is easy to produce because of the structural simplicity of biomasses. They hold their promises of cutting down fossil fuel usages considerably while lowering the atmospheric $CO_2$ concentration, which is consumed by the biomass during their growth (Rodionova et al. 2017). Some of the examples of first-generation biofuels are bioethanol, biodiesel, and bio ether, etc. Several criteria are to be looked upon before clearing up the food crops to be used as raw materials for the first-generation biofuel.

- Chemical composition of biomass
- Direct or indirect competition with the food crops
- Emission of harmful gases if any
- The extent of pesticide and assorted toxic chemical usage
- Cost of biomass transport and storage
- Employment opportunity creation

### 16.3.2 Second Generation (2G) Biofuels

This generation of biofuels follows an enhanced sustainable approach for their production. The carbon footprint from the utilisation of these 2G biofuels is either neutral or negative. Based on the raw material cost, the 2G biofuels is a cheaper option. Since most of the feedstocks are lignocellulosic biomasses, which are found as agriculture and forestry wastes (Trabelsi et al. 2018). The 2G biofuels include bioethanol, biodiesel, biobutanol, and acetone. Although acetone is a solvent, it gets produced as an outcome of ABE fermentation process (Alalwan et al. 2019).

The raw materials for 2G biofuels are necessarily lignocellulosic biomasses. Which are composed of lignin, cellulose, and hemicellulose (Ravindran and Jaiswal 2016). Figure 16.2 provides the complex chemical structures of these compounds. These compounds are consists of repeating cyclic units with varying functional groups. Cellulose is a homopolymeric carbohydrate consisting of hexose sugar (D-glucose) as the monomers connected by the β-1, 4-glycosidic linkages, and it constitutes the rigid primary cell wall of plants. The hemicellulose is a complex carbohydrate consisting of both hexose and pentose sugars. The glucose, mannose, and galactose are hexose sugars and the xylose, arabinose, and rhamnose are the pentose sugars found in hemicellulose. Apart from sugars, certain uronic acids like 4-o-methylglucuronic, D-glucuronic and D-galacturonic acids are also found in the strands of hemicellulose. The linkages between monomers are β-1, 4-glycosidic linkages and β-1, 3-glycosidic linkages. The lignin is the non-carbohydrate polymer where the monomers are derived from aromatic alcohols. The monomers of lignin are syringyl group, guaiacyl group, and p-hydroxyphenyl group, which are derived from sinapyl alcohol, coniferyl alcohol, and p-coumaryl alcohol, respectively (Mahapatra and Kumar 2019; Sadeek et al. 2015).

### 16.3.3 Third Generation (3G) Biofuels

In the third generation biofuels, the microbes like microalgae, bacteria, yeast, and fungi are the feedstocks. Amidst different type of microbes, the microalgae are the most promising one and are responsible for biodiesel production. The microalgae can be autotroph, heterotroph, and mixotrophs; they can exist in both fresh as well as marine waters. The predominant use of microalgae over other microbes is favoured because microalgae impart higher growth and biomass productivity tendencies and can accumulate lipids in the range of 20–77% (Bajracharya et al. 2017; Chelf et al. 1993). The residual biomass of microalgae is used for producing biomethane, bio-oil, bioethanol, and biohydrogen via separate biorefinery processes (Packer et al. 2016).

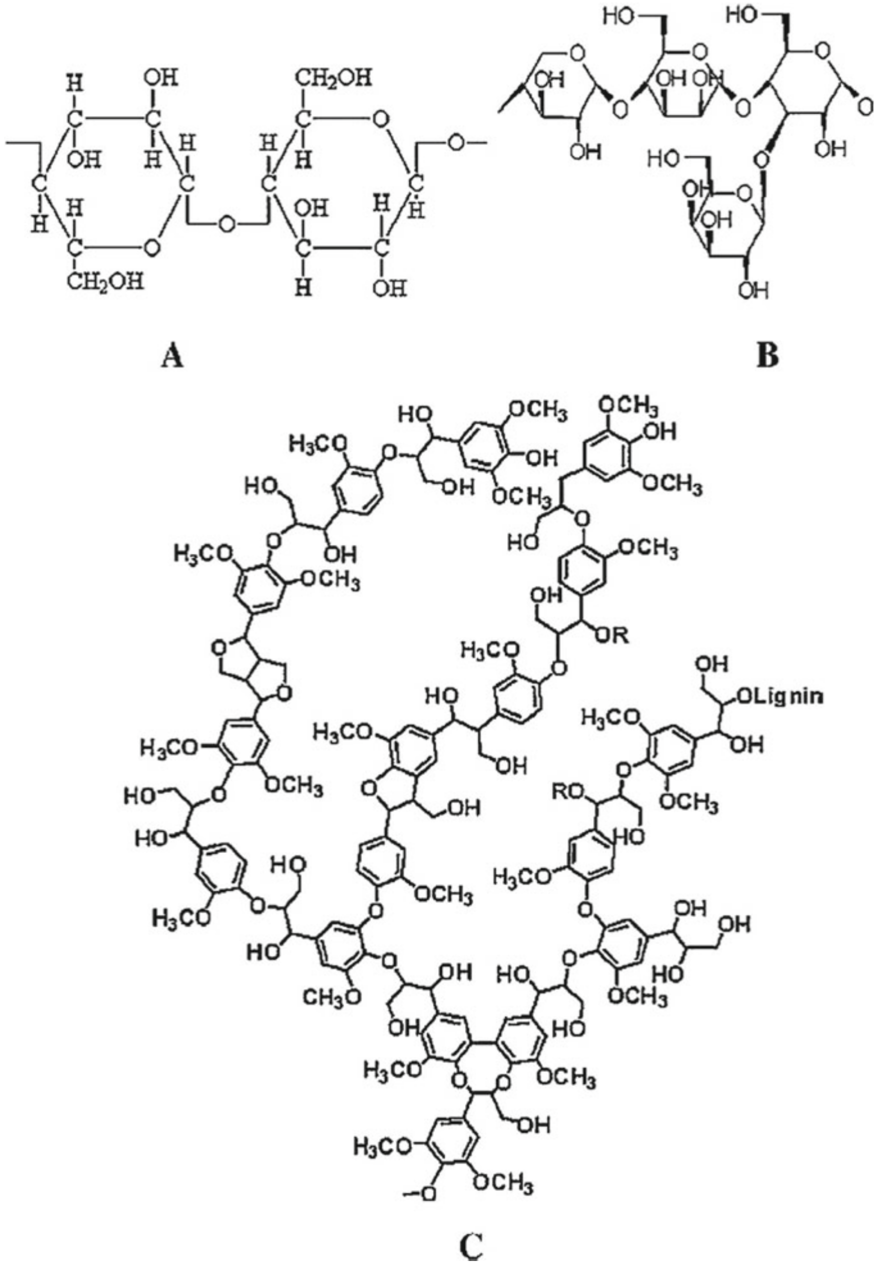

**Fig. 16.2** Chemical Structures of (A) Cellulose, (B) Hemicellulose, and (C) Lignin (Alalwan et al. 2019)

#### 16.3.3.1 Carbon Capture and Storage/Utilisation Approach of Microalgae During Biofuel Production

The microalgae can be autotrophs, heterotrophs, or even mixotrophs based on their mode of carbon source utilisation. The inorganic carbon such as $CO_2$ gets trapped by autotrophic microalgae via photosynthesis to obtain nutrient and energy. While, the heterotrophic microalgae use organic carbon as their nutrient and energy source. The mixotrophic ones as their name suggests utilise both the inorganic and organic carbon as their nutrient and energy sources. The microalgae use atmospheric $CO_2$ for its metabolism, as a result of which carbon concentration in the atmosphere gets reduced (Leong et al. 2018).

The Paris agreement of 2015 by the international community has decided to initiate the $CO_2$ mitigation steps with utmost priority. However, the mitigation if made by creating additional forestation will face the issues of land and food crisis (Dooley and Christoff 2018). Hence a newer concept of BECCS/U, i.e. bioenergy with carbon capture and storage/utilisation was considered to be more fruitful for the same purpose. Among different generations of fuels, the 3G biofuels derived from microalgae is the best candidate for the implementation of BECCS/U approach owing to the characteristic features of microalgae (Williamson 2016). The microalgae have several advantages for both the biofuel and $CO_2$ mitigation purposes (Choi et al. 2019) which are described as follows,

- Higher efficiency of photosynthesis and rapid growth ensures shorter harvest time.
- Microalgae can grow with wastewater, which in turn can serve as a mode of wastewater treatment and do not stress the clean water resources.
- Non-fertile and barren lands are the first choice places for creating algal ponds, hence no problem with cultivable landmass.
- As compared to their forestry equivalent microalgae need much lesser landmass to fulfil the desired objective.
- Microalgae do not need any additional chemicals in the form of fertiliser and pesticides, thus maintains the natural integrity of the ecosystem.
- The algal mass is tolerant to $SO_x$ and $NO_x$; hence, the $CO_2$ laden flue gas stream can be fed to the biomass as the carbon source and mitigating the $CO_2$ simultaneously.

The microalgae biomasses are capable of capturing about 55–65% anthropogenic $CO_2$ emission from the atmosphere (Farrelly et al. 2013). $CO_2$ plays a crucial role in the microalgal photosynthesis process, and the dependency of microalgae on $CO_2$ can be better understood from the composition of carbon in the dried biomass of microalgae which ranges as 36%–65% (Chae et al. 2006). The low concentration of $CO_2$ in the atmosphere as high as 380 ppm and its poor solubility in water keeps the microalgae deprived of a continuous carbon source (McGinn et al. 2011). The compressed $CO_2$ supply will again add up the cost of biofuel production to as high as 41% (Grima et al. 2003). The only solution to this problem is the construction of in situ microalgal ponds at the emission sites of elevated $CO_2$ concentration.

Moreover, due to their tolerance to $SO_x$ and $NO_x$, the $CO_2$ abundant flue gases can be fed to them as a carbon source (Choi et al. 2019).

Gonçalves et al. (2016) have reported about the involvement carbonic anhydrase and RuBisCo (Ribulose-1, 5- biphosphate carboxylase oxygenase) for $CO_2$ fixation in microalgae. Moreover, microalgae can utilise the bicarbonate and gaseous $CO_2$ as a carbon source. At the pH range of 6.5–10 for microalgae production media, the bicarbonate is the first choice as a carbon source. The flue gas (has a higher $CO_2$ concentration in the range of 0.03-0.05% as compared to the standard air), when fed as the carbon source, has resulted in a higher yield of the biomass (Gonçalves et al. 2016). Choi et al. (2017) have reported that the $CO_2$ when dissolved in media acts as a buffer to bring up the pH value to a favourable range for microalgae growth resulting in enhanced yield (Choi et al. 2017).

The chloroplast is the factory for the biosynthesis of lipid in microalgae. The $CO_2$ initially gets fixed as the endogenous source for Acetyl-CoA, and later becomes the carbon in the fatty acid chain of the lipid (De Bhowmick et al. 2015). Apart from *Chlorella sp.*, a few other species such as *Ostreococcus tauri*, *Phaeodactylum tricornutum*, *Nannochloropsis sp.*, and *Chlamydomonas reinhardtii* have shown promising capabilities for lipid biosynthesis (Zienkiewicz et al. 2016). The various 3G biofuels produced from microalgae via different biorefinery processes are represented in Fig. 16.3.

## *16.3.4 Fourth Generation (4G) Biofuels*

The fourth generation biofuels are the advanced versions of 3G biofuels. Unlike the 3G biofuels, the 4G ones are produced from genetically modified microorganisms for better yield, and to avoid any inhibitory action from solvents. The widely used sources for 4G biofuels are microalgae, yeast, fungi, and cyanobacteria, etc. Additionally, thermochemical techniques such as gasification and pyrolysis in the range of 400–600 °Care also used for biofuel production (Azizi et al. 2018). The intention of using thermochemical conversion routes is to improve hydrocarbon yield and to reduce carbon emissions. However, the 4G biofuels are still in the developmental stage and need a lot of research inputs before hitting the commercial production market (Sikarwar et al. 2017).

### 16.3.4.1 Health and Environmental Issues Related to 4G Biofuels

The 4G biofuels use genetically modified (GM) microalgae as the feedstock for biofuel production. The GM microalgae are prepared for rapid growth and withstand adverse environmental conditions, as a result of which they impart the threat of replacing the native microalgae from the ecosystem. The absence of native microalgae in the ecosystem results in crashing of the biodiversity since GM microalgae are unable to provide natural qualities for biodiversity maintenance.

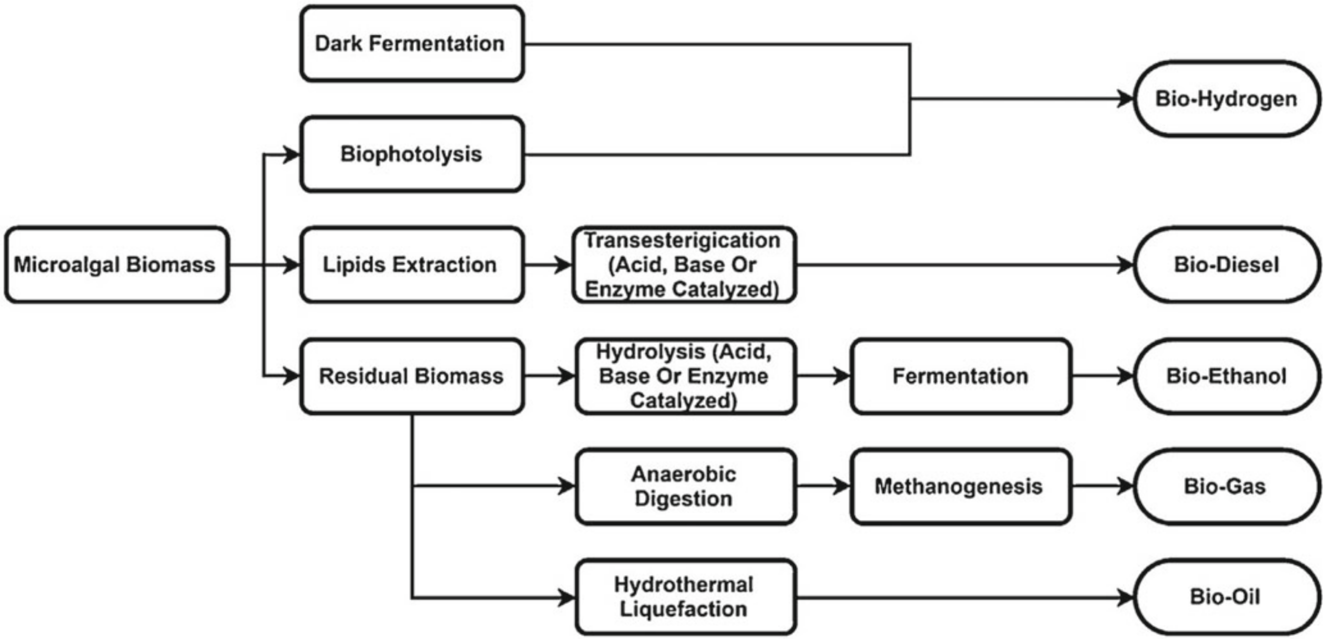

**Fig. 16.3** Various types of third Generation biofuels produced from microalgae via different biorefinery processes (Alalwan et al. 2019)

**Table 16.2** Health and environmental issues associated with the GM microalgae

| Affected area | Type of risk | Brief description of the risk | References |
|---|---|---|---|
| Health hazard | Allergy | Affected areas are the GI tract, respiratory tract, and skin | (Genitsaris et al. 2011) |
| Health hazard | Resistance to antibiotic drugs | The medical treatments become prolonged, might end up with impaired immunity | (Wright et al. 2013) |
| Health hazard | Pathogenicity | The toxic residues are good candidates for imparting pathogenicity, toxicity, and carcinogenicity | (Menetrez 2012) |
| Environmental hazards | Alteration of the natural ecosystem | Depletion of nutrients in the eco-system leading to a sharp decline in biodiversity of flora and fauna | (Tucker and Zilinskas 2006) |
| Environmental hazards | Horizontal gene transfer | Very acute chances of mutation resulting in further deterioration of the natural ecosystem and toxins released from these species are deadly for other flora and fauna, naturally habituated in the ecosystem | (Raybould 2010) |

The primary environmental concerns regarding the uncontrolled exploitation of GM microalgae are the alteration of natural habitats, toxicity, and horizontal gene transfer which pose the threat of mutation of the native microalgae (Abdullah et al. 2019). Apart from imparting adverse effects on the environment, GM microalgae are also responsible for health hazards in human beings. A list of health and environmental issues associated with the GM microalgae is provided in Table 16.2.

## 16.4 Understanding the Key Terms Like Advanced Biofuels and Drop-in Fuels

Specific interesting terminologies like advanced biofuels and drop-in fuels are being used in recent times and are capable of creating a significant amount of confusion in the course of understanding the biofuel concepts.

Advanced biofuels are a synonym to the 2G (second generation) biofuels, which uses non-food crops and their residues as well as waste materials such as animal fat, spent vegetable oil, greases, as the sources for biofuel generation. The biorefinery techniques for advanced biofuels are as follows;

- Hydrolysis of the raw materials and subsequent fermentation
- Thermochemical conversion route like pyrolysis
- Alcoholic fermentation of the syngas.
- Transesterification

The advanced biofuels are of two types, namely drop-in biofuels and the biobutanol. The drop-in biofuels are biodiesel and bioethanol produced either from lipids or lignocellulosic materials. These biofuels are good candidates to replace the conventional fossil fuels in IC engines with negligible revampments (Araújo et al. 2017). The hydrotreated biodiesel production has several advantages over the diesel produced by the transesterification process. The benefits range from zero enhancement of $NO_x$ released to the atmosphere, no residue formation in engine cavity, enhanced life of engine oil, no sulphur contents (zero $SO_x$ emission), and higher cetane number (Department of Energy 2019).

Biobutanol is another type of advanced biofuels produced via the fermentation route. However, unlike ethanol fermentation, biobutanol production employs ABE (acetone-butanol-ethanol) fermentation pathway. As the name suggests, the outcome is not only biofuels rather solvents are too produced. In the entire arena of biofuels, biobutanol is the only biofuel which can directly replace the gasoline in IC engines without any revampment. The physicochemical properties like higher energy density and lower vapour pressure of biobutanol have made it stand out as the ready to use biofuel in gasoline-powered IC engines (Bharathiraja et al. 2017).

## 16.5 The Carbon Sequestration Approach with the Biofuels

Carbon sequestration is defined as the method for capturing the carbon either from the atmosphere or from the effluent streams and securely store them rendering the atmospheric carbon levels within the acceptable limits (Jain et al. 2012). The carbon in the atmosphere is found in its oxide forms such as CO and $CO_2$, which are the causative agents of acid rain, global warming via greenhouse gas (GHG) effect, and poor quality of breathable air. The primary sources of carbon into the atmosphere are the combustion of fuels. The fossil fuels are the necessary evils for the overall global development but at the cost of heightened environmental pollution (Mathews 2008).

The most eco-friendly way of carbon capture from the atmosphere is photosynthesis by biomass. In recent times with the concept of biofuels, hope has been kindled for the carbon capture while generating biofuel in the course. Moreover, by taking into account the amount of carbon accumulation and subsequent releases from and to the atmosphere three distinct concepts came to existence namely,

**Table 16.3** Summary of Carbon capture approaches via various fuels (Mathews 2008)

| Type of approach | Carbon input to the atmosphere | Carbon capture from the atmosphere | Additional contribution from fossil fuels for product processing | Examples |
|---|---|---|---|---|
| Carbon positive | Yes | No | Yes | Fossil fuels |
| Carbon neutral | Yes | Yes | Yes, but in lesser quantities, as compared to the fossil fuels | 2G biofuels |
| Carbon negative | Yes | Yes | Yes, the requirement is in a very minimal amount | 3G biofuels |

- Carbon positive approach
- Carbon-neutral approach
- Carbon-negative approach

Carbon positive approach is associated with fossil fuels which are the primary causatives for the enhancement of carbon footprint in the atmosphere. Hence they are also called as the carbon positive fuels (Mathews 2008).

The 2G biofuels are also synonymous as carbon-neutral fuels. Since during the growth of biomass a large amount of carbon gets captured, which is nearly equal to the amount of carbon that gets released while burning the biofuel. However, during transportation, and processing (tedious task) due to the expense of a certain amount of fossil fuels, sometimes these biofuels end up as the carbon positive fuels (Mathews 2008).

The biofuels from microalgae or the 3G biofuels are termed as the carbon-negative biofuels. The microalgae have excellent potential in capturing the $CO_2$ from the atmosphere in large amounts as compared to the forest biomasses. Harvesting and subsequent processing methods are not energy-intensive, resulting in lesser energy consumption for the intended purpose. The spent biomass after oil extraction can be carbonised, and resultant biochar is fed to the soil to produce a natural carbon sequestering agent while improving the soil quality (Mathews 2008; Rakshit et al. 2012). These three different approaches of carbon capture are enlisted in Table 16.3.

## 16.6 The Proven Biofuels Which Will Be the Key Players in Future

During the process of biofuel production, apart from fuels, solvents of industrial importance like acetone, glycerine, and ether are also get produced. However, here we will be discussing the key biofuels which are going to change the image of the fuel energy sector in upcoming times. Based on their production methods and properties three different types of biofuels qualify to gain such status and are as follows;

- Biodiesel
- Bioethanol
- Biobutanol

## *16.6.1 Biodiesel*

Biodiesel is a renewable, eco-friendly, and non-toxic alternative to the petroleum diesel fuel. Due to the sustainable nature, biodiesel found its usage as mainstream fuel in transport sector via road, water bodies (with the ships), and aerial route (with aeroplanes). As of now, biodiesel is being used as blended fuel in the engines. Leading producers of biodiesel like Brazil, EU, and the US are targeting to enhance the blending percentage of biodiesel as 20, 10, and 25 by the year 2020 (Mofijur et al. 2016). The US Naval force is planning to use alternative fuels (primarily with biodiesel) in place of conventional fossil fuels to fulfil 50% of its energy requirement (Mabus 2010). Moreover, the production and usage of biodiesel in a sustainable manner is dependent on certain factors (Ntaribi and Paul 2019; Fazal et al. 2011) namely;

- The availability of better quality feedstocks
- Advanced processing technologies
- Physicochemical properties of biodiesel
- Engine compatibility
- Quantity of production and pricing
- Government regulations and financial support

### 16.6.1.1 The Sources of Biodiesel

The biodiesel is generally produced from two sources, namely; oil-rich food crops, and oil-rich non-food crops. These non-food crops are also called as the energy crops since their cultivation is aimed at biofuel production only. Some of the examples of both categories of sources for biodiesel production are as follows, rapeseed, linseed, rice bran, soybean, sunflower, corn, castor, coconut are a few among the most popular oil-rich food crops from which the 1G biodiesel can be produced, among the non-food crops, animal extracts, and wastes like *Jatropha curcas*, cottonseed, rubber seed, neem seed, apricot seed, desert date, jojoba, *Pongamia glabra*, *Pistacia chinensis*, *Moringa oleifera*, *Shorea robusta*, microalgae, fish oil, leather pre-fleshings, and the waste cooking oils are some of the notable ones for the production of 2G and 3G biodiesels (Alalwan et al. 2019; Karmakar et al. 2010).

#### 16.6.1.2 Different Production Methods of Biodiesel

The various methods for biodiesel production are; blending of oils, micro-emulsification, pyrolysis, and the transesterification (Alalwan et al. 2019).

Blending of oils is a necessary step to reduce the viscosity. The vegetable oils can be preheated to make the blending easier since preheating the vegetable oils result in a reduction of viscosity and atomisation. As reported by Adams et al. (1983), the blending ratio of vegetable oil to diesel should be 1:2, to run the engine without any major modifications (Ghazali et al. 2015; Adams et al. 1983).

Micro-emulsification is another efficient method for biodiesel production. The microemulsions are nano molecules in the range of 1–150 nm in terms of their size and are composed of the oil phase, aqueous phase, and surfactant phase. With the use of butanol, hexanol, and octanol as the aqueous phase in the microemulsion, the desired viscosity limits can be met. A microemulsion with the components and their ratios as soybean oil: methanol: 2-octanol: cetane improver (surfactant), 52.7: 13.3: 33.3: 1 has successfully passed the significant 200 h EMA (engine manufacturers association) test for alternative fuels (Ghazali et al. 2015).

The pyrolysis is a thermochemical conversion process in the absence of oxygen. It is implemented as the alternative to catalytic cracking in the biodiesel production process. The raw materials for pyrolysis with the aim for optimisation of biodiesel are vegetable oils, lignocellulosic biomasses, animal fats, other oil-rich biological wastes, and the FAME (fatty acid methyl ester) (Ghazali et al. 2015). The biodiesel is produced using oils obtained from food crops via *transesterification* or the alcoholysis process. During the transesterification process, one alcohol in the ester is replaced by another desired alcohol in the presence of an alkali catalyst. The replacement of alcohol group from the ester results in a reduction of viscosity (Ghazali et al. 2015).

#### 16.6.1.3 Technical Advantages and Disadvantages of Biodiesel

The molecular chemistry of biodiesel imparts several technical advantages over petroleum diesel; some of such benefits (Gopinath et al. 2010; Knothe et al. 2003; Qi et al. Qi et al. 2009) are enlisted here,

- The long-chain molecules, oxygenated moieties, give *enhanced lubricity* to the biodiesel.
- The long fatty acid chains of biodiesel help in intermolecular sliding, and thereby impart in *non-corrosiveness of the engine cavity.*
- The longer fatty acid chains and saturated molecules render *higher cetane number* to the biodiesel, which in turn result in *complete combustion*, *smoother engine performance*, *negligible carbonation in engine head*, *better fuel efficiency* with *lesser emissions.*

The chemistry of biodiesel gives many significant advantages for biodiesel. Unfortunately, it is the chemistry again which render some of the notable drawbacks to the biodiesel. Some of such disadvantages (Jakeria et al. 2014; Fazal et al. 2018; Tyson 2001) are enlisted below,

- *High viscosity*, this result in deposition of unwanted matter in the engine head, especially around the piston ring, thereby results in improper combustion.
- *Poor oxidation stability* brings in the clogging and sludging of fuel injectors and filters, crankcase, combustion chamber, which results in the below-par performance of the engine.
- *Higher corrosiveness* leads to the leakage in the fuel lines and simultaneous breakage of the seal. Thereby the maintenance costs go high.
- *Short storage period* forces the users to go for produce and use approach. Since when biodiesel is stored for longer durations that can result in loss of calorific value due to moisture accumulation. Moreover, the ester molecules get reverse-engineered via hydrolytic reactions to alcohol and free fatty acids, leaving the biodiesel with only option to discard them, instead of using the same.

### *16.6.2 Bioethanol*

Bioethanol is produced by the fermentation of sugars obtained from the biomasses. This fermentation process is the most common type of fermentation process which commonly employs the yeast (*Saccharomyces cerevisiae*) as the fermenting agent (Rastegari et al. 2019). Although three main types of microbes exist those can bring out the ethanol fermentation, and are yeast (*Saccharomyces spp.*), mold (mycelium), and bacteria (*Zymomonas spp.*) (Yusoff et al. 2015). The industrial-scale production of bioethanol dates back to the year 1894 in France and Germany. Brazil pioneered to use bioethanol as a transport fuel in the year 1925. However, later due to high production costs bioethanol was not considered as a desirable option for any applications. During the oil crisis of 1970 and acute environmental pollutions have renewed the bioethanol production exclusively for its use as a transportation fuel (Alalwan et al. 2019).

Bioethanol can be used either in pure form or in the blended form with gasoline for Flex-fuel vehicle (FFV) fuel. Currently, bioethanol is blended at a low volume with gasoline at 10% v/v ratio and has obtained the brand name as E10. Bioethanol also acts as a precursor to the ethyl tertiary butyl ether (ETBE), which is mixed with the gasoline to enhance the oxygen content for pollution control purposes (Norkobilov et al. 2017). Like any other biofuels, bioethanol also helps in curbing $CO_2$ from the atmosphere by cutting down the amount of fossil fuel usage and capturing $CO_2$ via biomass during their growth (Li et al. 2017).

The USA leads the global bioethanol market scenario, contributing 47% of the total bioethanol production all across the globe (Balat and Balat 2009). It is estimated that the amount of bioethanol production has reached a value of 93 billion litres as of 2014 (Li et al. 2017). However, excessive usage of food crops for bioethanol production has raised the debate on the food crisis. It was estimated that the extent of food crops used for bioethanol production could have fed 200 million people. Hence the 1G bioethanol option is a strict no type production method (Rulli et al. 2016).

The bioethanol production from lignocellulosic biomasses is a tedious task as compared to the production from the food crops. The lignocellulosic biomasses must be hydrolysed before the fermentation process to release the sugars. 2G Bioethanol can also be produced via a thermochemical route called gasification followed by either of fermentation or enzyme catalysed reaction. The difficulties associated with the 2G bioethanol production are (Vyas et al. 2018) as follows,

- Lack of a remarkably efficient pretreatment method for effective release of sugar from biomasses.
- Release of undesired sugars along with important ones hampers the fermentation process efficacy.
- Presence of oligomers of sugars instead of simple monomers makes the implementation of genetically engineered microbes a must-have thing.
- Release of undesired by-products during hydrolysis leads to a reduction of bioethanol yield to a significant amount.
- Transportation and storage of biomasses at times pose as a costly affair.

As far as the 3G bioethanol is concerned, it is the most preferred bioethanol production process. Since 3G bioethanol, unlike its 1G counterpart, is not creating food scarcity issues, on the other hand, the biomass handling process is easier as compared to that of 2G bioethanol production. In the course of 3G bioethanol production, the algal carbohydrates such as starch and carbohydrates are subjected to hydrolysis to yield monomeric sugars and are subjected to fermentation, subsequently (Alalwan et al. 2019). Moreover, the yield of 3G bioethanol is very high. John et al. (2011) have reported that the Algenol Biofuels Inc. (current alias ALGENOL), a Florida-based company have achieved a production rate of 6000 gallons of ethanol per acre per year. This staggering amount of bioethanol is ~ 15 times higher than those of 2G biofuels (John et al. 2011). Bioethanol has several advantages and disadvantages as well, and those affect its use as a transportation fuel (Rastegari et al. 2020). On the pros side, it has very high octane number of 108, and with higher heat of vaporisation and wider flammability limits, together all these enhance the chances of bioethanol to be used as a reliable transport fuel. On the contrary bioethanol has some significant characteristic flaws associated with it, such as low energy density, corrosive nature, low vapour pressure, and water miscibility, these result in lower calorific value, faster wear and tear of engine parts, problem with cold start of the engine, and improper ignition due to the presence of moisture, respectively (Alalwan et al. 2019). Figure 16.4 represents the production flow sheet of different generations of bioethanol.

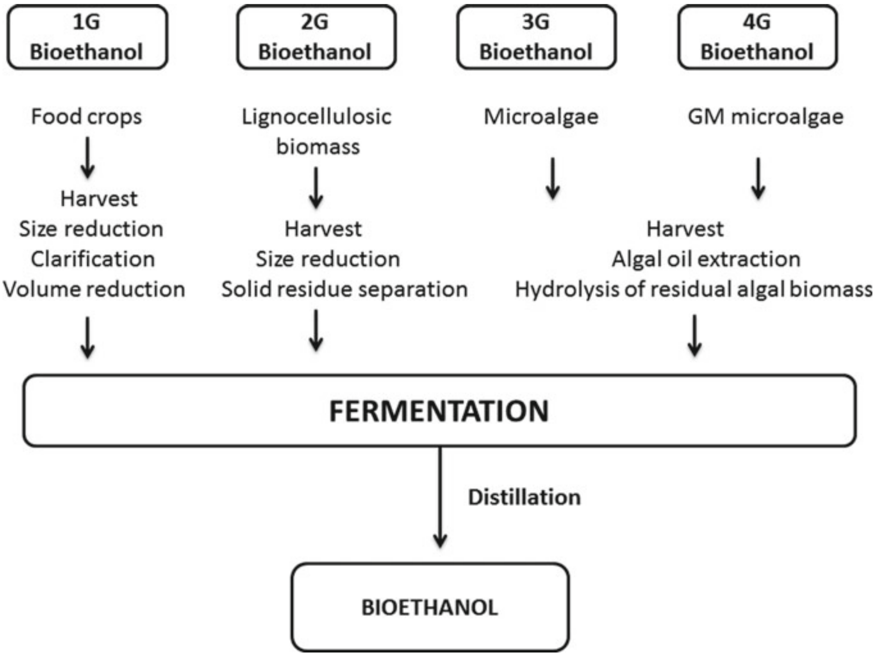

**Fig. 16.4** The production flow sheet of different generations of bioethanol (Alalwan et al. 2019)

### *16.6.3 Biobutanol*

Biobutanol has evolved as one of the most promising biofuels to replace the gasoline as the fuel without retrofitting the engine assembly. The mode of biobutanol synthesis is bacterial fermentation called ABE fermentation mediated by *Clostridium spp*. The raw materials for biobutanol synthesis are food crops and the lignocellulosic biomasses. Butanol is an excellent industrial chemical and has several applications (Mahapatra and Kumar 2017) as follows.

- Butanol is used as a solvent in rubber industries.
- It is also used as quick-drying lacquer for imparting smooth surface finish in the dye industry and printing presses.
- In the pharmaceutical industry, the butanol is used as an extractant for drugs, vitamins, and hormones.
- Butanol is used as a supplement in domestic and industrial cleaners.
- In thin-layer chromatography, butanol is used as eluent.
- It is used as a de-icing agent for gasoline-driven engines.
- Butanol is used as the precursor for the production of acrylic esters, glycol ethers, butyl acetate, butyl amines.

**Table 16.4** The fuel properties of gasoline and butanol

| Properties | Gasoline | Butanol | References |
|---|---|---|---|
| Energy density (MJ/L) | 32.0 | 29.2 | (Mahapatra and Kumar 2017) |
| Air to Fuel ratio | 14.6 | 11.2 | (Mahapatra and Kumar 2017) |
| Heat of vaporisation (MJ/Kg) | 0.36 | 0.43 | (Mahapatra and Kumar 2017) |
| Research octane testing value | 91–99 | 96 | (Mahapatra and Kumar 2017) |
| Motor octane testing value | 81–89 | 78 | (Mahapatra and Kumar 2017) |
| Rate of evaporation or reid value (psi) | 8–15 | 0.33 | (Alalwan et al. 2019) |

The fuel properties, in comparison with gasoline listed in Table 16.4 depicts the ability of butanol to be used as IC engine fuel. The industrial synthesis of biobutanol dates back to 1912–1914 via ABE fermentation using molasses and cereal grains employing the Weizmann's organism (*Clostridium acetobutylicum*) (Jones and Woods 1986). The synthesis of biobutanol in the laboratory was first reported in 1861 by Louis Pasteur (Durre 1998). Apart from Weizmann's organism certain other native *Clostridium sp.* such as *Clostridium beijerinckii*, *Clostridium saccharoperbutylacetonicum, Clostridium saccharoacetobutylicum*, *Clostridium aurantibutyricum*, *Clostridium pasteurianum*, *Clostridium sporogenes*, *Clostridium cadaveris*, *and Clostridium tetanomorphum* are capable of butanol synthesis following the ABE fermentation route (Kumar and Gayen 2011). Among all these species of *Clostridium*, the *C. acetobutylicum*, *C. beijerinckii*, *C. saccharoperbutylacetonicum*, and *C. saccharoacetobutylicum* are the ones for higher biobutanol yield via ABE fermentation (Keis et al. 2001). The ABE fermentation process is strictly anaerobic, and the different products such as acetone, butanol, and ethanol are produced in the ratio 3:6:1 (Alalwan et al. 2019).

#### 16.6.3.1 Biomasses for the Biobutanol Synthesis

Biobutanol production uses two categories of biomasses for their production, namely the food crops for 1G biobutanol production and lignocellulosic biomasses for 2G biobutanol productions. The food crops for biobutanol synthesis are sugarcane, sugar beet, wheat, rice, soybean oil, sunflower, and palm oil. However, utilisation of the food crops for biobutanol production eventually leads to the food scarcity and faces severe criticism with the title of price hikers in the food v/s energy debate (Kumari and Singh 2018). The 2G biobutanol, on the other hand, uses lignocellulosic biomasses such as rice straw, rice hulls, wheat straw, corn cobs, corn Stover, cane bagasse as the raw materials. These agricultural lignocellulosic wastes alone amount to 40 tons per hectare. Frequently, these wastes are either burnt as the most natural way of volume reduction, which is not a sustainable option or used as forage for the farm animals or as organic manures.

Apart from agricultural wastes, the forestry wastes are too good candidates for biobutanol production (Srirangan et al. 2012). The lignocellulosic residues are

**Table 16.5** Inhibitor produced by various pretreatment processes (Baral and Shah 2014)

| Biomass pretreatment process | Inhibitors produced |
|---|---|
| Acid hydrolysis | Furfural, hydroxyl methyl furfural, acetic acid, and phenolics |
| Alkali hydrolysis | Soluble salts (extremely difficult to separate them from the broth) |
| Steam explosion | Furfural, acetic acid, formic acid, and phenolics |

the best candidates for the production of cost-effective 2G biobutanol. Although the lignocellulosic biomasses are significantly cheaper in their worth, their chemical composition is capable of bringing out a significant reduction in the efficiency of the fermentation process in terms of product yield. The pretreatment step produces certain toxic chemicals called 'inhibitors' which are capable of ceasing the metabolism of microbes leading to low yield (Baral and Shah 2014). Table 16.5 enlists the inhibitors produced by various pretreatment methods. Figure 16.5 represents the schematics of biobutanol production pathway from different biomasses.

The separation of inhibitors from fermentation media is called detoxification. A variety of detoxification methods are available which can be used based on the nature of hydrolysate. Mahapatra and Kumar (2019) have reported that the alkali treatment, LLE (liquid-liquid-extraction), membrane filtration, adsorption, microbial degradation, and enzymatic catalysis are some of the noteworthy detoxification methods for hydrolysate inhibitors. The details are reported elsewhere by the investigators (Mahapatra and Kumar 2019).

#### 16.6.3.2 A Brief Discussion About the ABE Fermentation Process

The ABE fermentation is the second-largest industrial process after ethanol fermentation process. However, this fermentation process has seen its ups and downs over time. Before the inception of petrochemical solvents, butanol and acetone produced via ABE fermentation process during the early part of the twentieth century were in demand. Until the late twentieth century and early twenty-first century that dormant scenario prevailed, but with the invention of butanol's biofuel potential, the so-called fermentation process again raised to its previous glory. ABE fermentation yields acetone-butanol-ethanol simultaneously in the ratio 3:6:1. Like any other chemical/biochemical processes, the ABE fermentation can be carried out by any of the three modes, such as; batch, fed-batch, and continuous. The continuous method of fermentation has many advantages to make the process more favourable and efficient. A single inoculum batch is sufficient to carry out the process for a prolonged duration. Limited sterilisation and microbial inoculation steps enhance the productivity and process economy (Baral and Shah 2014).

The entire ABE fermentation is divided into two categories, namely, acidogenesis phase and solventogenesis phase. The microbes are in their log (exponential)

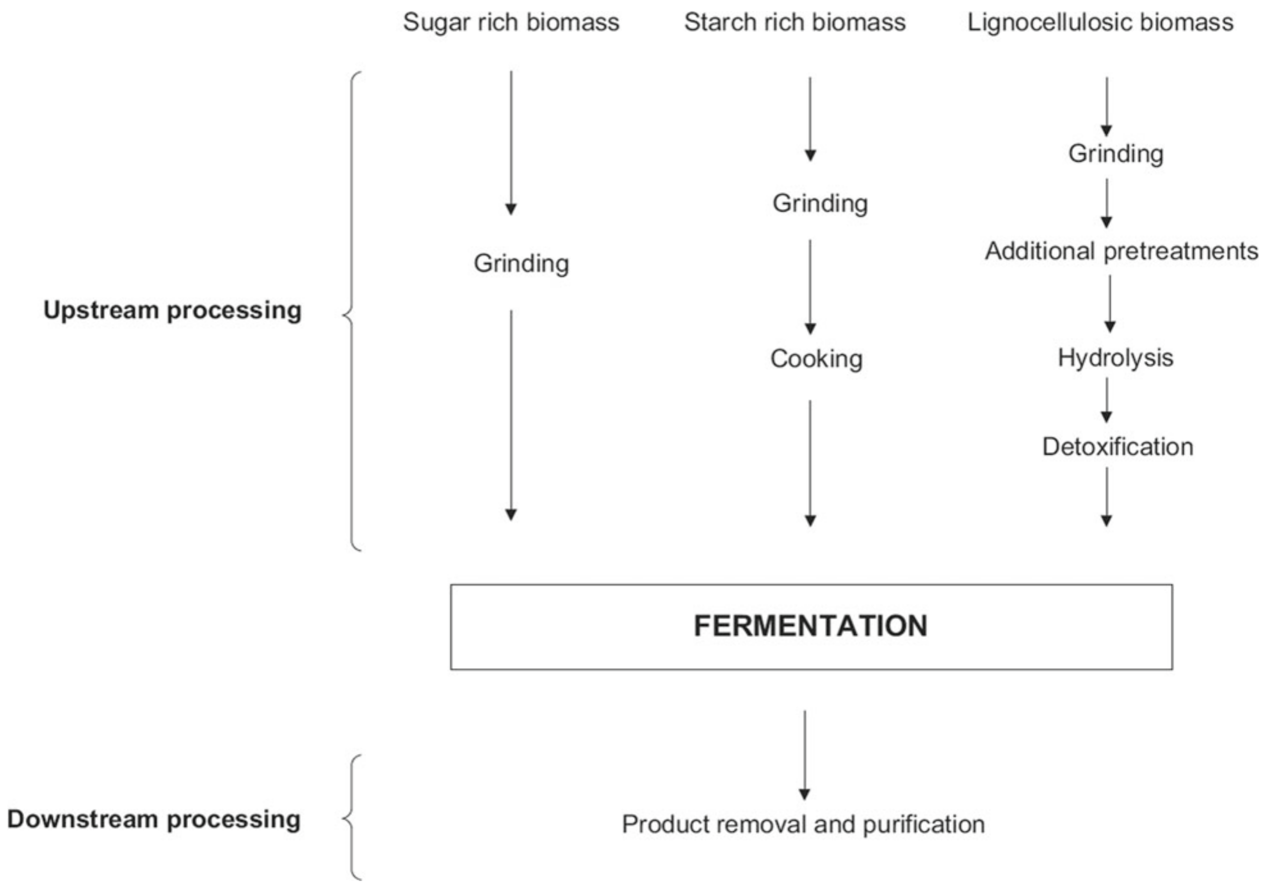

**Fig. 16.5** Schematic representation of biobutanol production pathway from various biomasses (García et al. 2011)

phase of growth acidogenesis part. The synthesis of acids has led to the fermentation media pH declinement to ~4.5. The Glycolysis produces pyruvate from glucose, which eventually yields Acetyl-CoA. The Acetyl-CoA is the prime precursor for the synthesis of acetate, butyrate, ethanol, butanol, and acetone in an anaerobic mode. During the solventogenesis phase, which kicks in immediately after the acidogenesis phase, the acid production ceases due to low media pH. During this phase, the microbes have attained a stationary phase of their growth cycle. The acetaldehyde, acetate, and butyrate are depleted to yield ethanol, acetone, and butanol, respectively (Kumar and Gayen 2011).

The fermentation efficiency is evaluated based on the ABE yield and ABE productivity, respectively (Jin et al. 2019). The ABE yield and productivity can be assessed using the formula given by Eq. 16.1 and 16.2, respectively.

$$\text{Yield of ABE} = \frac{\text{g/L of Total ABE}}{\text{g/L of Total sugar utilised}} \tag{16.1}$$

$$\text{Productivity of ABE (g/L/h)} = \frac{\text{g/L of Total ABE}}{\text{h Duation of fermentation}} \tag{16.2}$$

Figure 16.6 depicts the pictorial representation of the biochemical pathway of ABE fermentation involving all the enzymes and intermediate.

## 16.7 Sustainability Parameters for Biofuels

Sustainable biofuel is the one which has satisfied all the parameters for evaluation. A few essential parameters are,

- The conflict between Food and fuel
- The Emission potentials
- Issues with the land, water, and biodiversity
- Performance of the biofuel

### *16.7.1 The Conflict Between Food and Fuel*

The dispute arises with the food commodity price hikes. These conflicts were fueled by the fact that during the period of food price hikes, the biofuel production intensities were too at their peak. In G20 summits of 2008 and 2011, the agendas were focused primarily on the food prices, and biofuels were the ones to take the blame. The conclusions were, firstly the biofuels are leading to food price hikes and eventually, poor people will be affected at large. Secondly, the energy cropping is rendering the food croplands unusable for their intended purpose, forcing them to displacement (De Gorter and Drabik 2015; Tomei and Helliwell 2016). However, a thorough analysis

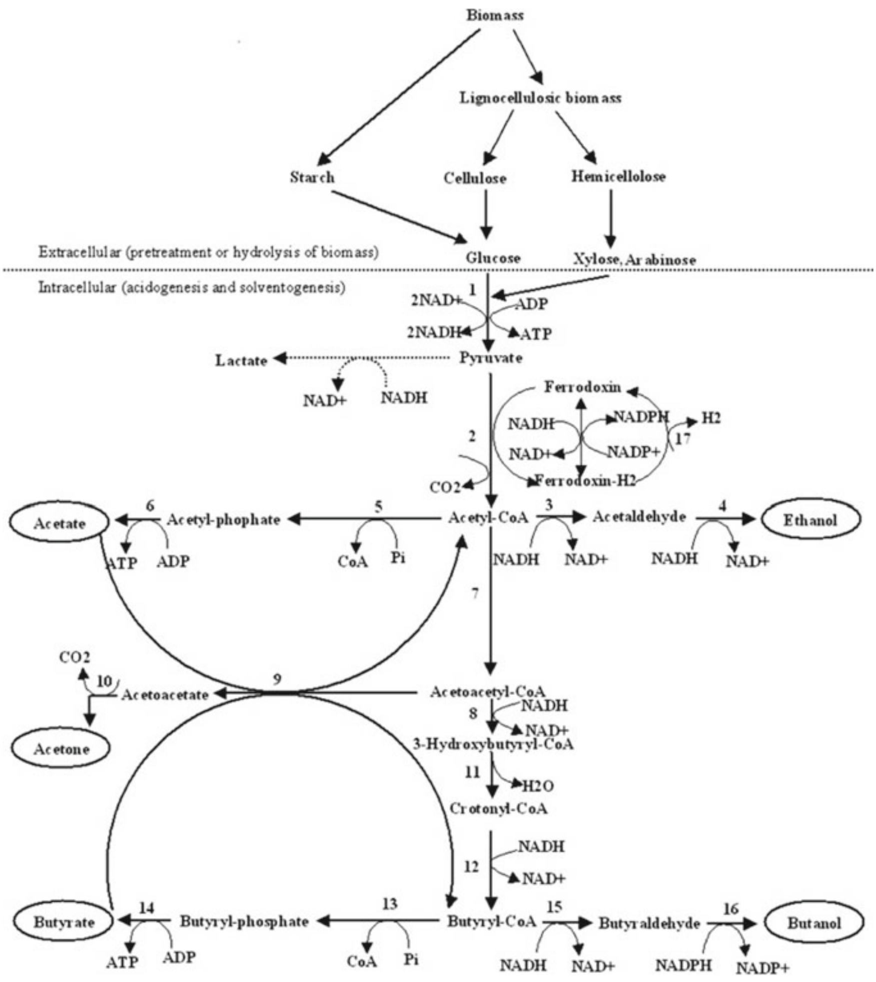

**Fig. 16.6** Biochemical pathway of ABE fermentation (Kumar and Gayen 2011). The enzymes involved are the numbers depicts enzymes involved and are as follows (1) Enzymes of glycolysis process (2) Pyruvate ferredoxinoxidoreductase (3) Acetaldehyde dehydrogenase (4) Ethanol dehydrogenase (5) Phosphate acetyltransferase (phosphotransacettylase) (6) Acetate kinase (7) Thiolase (acetyl-CoA acetyltransferase) (8) 3-hydroxybutyryl-CoA dehydrogenase (9) Acetoacetyl-CoA: acetate/butyrate:CoA-transferase (10) Acetoacetate decarboxylase (11) Crotonase (12) Butyryl-CoA dehydrogenase (13) Phosphate butyltransferase (phosphotransbutyrylase) (14) Butyrate kinase (15) Butyraldehyde dehydrogenase (16) Butanol dehydrogenase

of the issue has concluded that apart from biofuel production, certain other factors such as transportation fuel price hikes, unpredictable weather conditions, and stock market performance at large play the key role for the conflict between food and fuel (Araújo et al. 2017).

### 16.7.2 The Emission Potentials

The staggering rise in global pollution has restrained the energy sectors to operate within the specified limits, and if that option is not possible, then switch over to a more eco-friendly option. Due to the detrimental effects of fossil fuel combustion, now the focus is on the biofuels. Several scientists have reported that biofuels are altogether an eco-friendly approach and are capable of reducing GHG emissions by 60–94% as compared to their fossil fuel counterparts (Highina et al. 2014). The life cycle assessment studies of the biofuels on climatic effects have revealed that they are astoundingly higher GHG emission contributors as compared to petroleum fuels (Searchinger et al. 2008). Extensive investigations on the biofuel sustainability on emission front have surfaced the involvement of inferior technologies behind heightened GHG release by biofuels (Ji and Long 2016). Xue et al. (2011) have reported an interesting fact about the biofuels, which can produce mixed outcomes in terms of sustainability. E.g. biodiesel is capable of cutting down particulate emissions by 88%, whereas, the same biodiesel releases additional amounts of $NO_x$ as compared to the petroleum diesel bringing harmful effects on the ecosystem (Xue et al. 2011).

### 16.7.3 Issues with the Land, Water, and Biodiversity

Due to continuous population growth, there will be an ever-increasing demand for food supply. Fischer et al. (2002) have reported that in the last five decades, the amount of cultivable land area has increased by 12% equivalent to 159 million hectares (Mha). Apart from land area increment, extensive usage of pesticide and fertilisers, doubling the irrigation altogether resulted in an increase in food by a factor of 2.5–3 times (Fischer et al. 2002). Doornbosch and Steenblik (2007) have reported that only 5% of the total landmass of the globe is available for energy crop cultivation by the year 2050. Moreover, from that 5%, approximately 63% of the landmass is technically suitable for energy cropping (Doornbosch and Steenblik 2007). The availability of a meagre amount of land for energy crop cultivation discards the debate that energy crop cultivation is leading to the reduction of food croplands (Popp et al. 2014; Borras and Franco 2012). It is estimated that 80% expansion of cultivable landmass possibilities is there in the African, South American continents, and Central America (Araújo et al. 2017).

Biofuel production will stress out the freshwater resources since currently about 70% of freshwater is used for agriculture purposes (Fischer et al. 2002). The water quantity and quality as well will be affected by biofuel production. The runoff stream containing high concentrations of pesticides and chemical fertilisers will render the water resources unusable. Such contaminated areas will gradually become a dead zone (Solomon and Bailis 2014). However, the biosorption process comes as a rescue option to mitigate the contamination problem. Bransby et al. (1998) have reported about the prevention of nitrogen contamination to the water bodies via biosorption using switchgrass (Bransby et al. 1998).

The deforestation has devastating effects on biodiversity. This act of disruption brings imbalance to the ecosystem and pushes many species towards extinction (Cowie et al. 2016). The life cycle assessment of biofuels for biodiversity disruption is still in the rudimentary state. The assessment parameters are biodiversity damage potential and account of lost endemic species should be made more stringent (De Baan et al. 2013).

### *16.7.4 Performance of the Biofuel*

Biofuels have a significantly higher octane rating, which indicates their capacity to withstand the pre-ignition compression process. However, the low energy density results in lesser fuel mileage as compared to their petroleum counterparts, bioethanol has shown a reduction in mileage by 25%–30% as compared to gasoline. The blending percentages like 20–40% (medium blending) the energy penalty gets lessened (Theiss et al. 2016). The biodiesel, on the other hand, is a superior fuel as compared to the bioethanol. Biodiesel, when used as sole fuel, has shown a reduction in hydrocarbons, particulate matter and CO, and $NO_x$ by 70%, 50%, and 10%, respectively. Apart from the above reductions, the $SO_x$ concentration also got reduced remarkably as compared to petroleum diesel. The lifecycle assessment of bioethanol and biodiesel shows carbon emissions as 2–69 kg $CO_2$-eq/GJ and 20–49 kg $CO_2$-eq/GJ, respectively, indicating that the biodiesel has a better sustainable fuel performance than bioethanol (Araújo et al. 2017).

## 16.8 The Biofuel Policies

In recent times the biofuel productions are undergoing an exponential escalation. However, to keep the ecological, economic, and social balances intact, while undertaking a sustainable route for biofuel production, specific guidelines are to be followed. These mandatory guidelines are also synonymous to policies made by the governing authorities (a group of politicians, bureaucrats, and scientists). This portion of the chapter will be dedicated to the various strategies for biofuels in action in some countries.

### *16.8.1 Canadian Biofuel Policies*

The Environmental Protection Act Bill C-33 of Canada has mandated the biofuel blending content by 5% in gasoline and 2% in diesel fuel and heating oil by 2010 and 2012, respectively. These blending mandates have set a target of bioethanol and biodiesel productions counting to 1.9 billion litres and 520 million litres, respectively by the year 2012 (Sorda et al. 2010). While the bioethanol produced was strictly 1G, i.e. from the cereal grains, the biodiesel, on the other hand, got produced from animal fat hence qualifying to 2G category. Interestingly the biofuel production has positively boosted the Canadian economy by the mark of 2 billion Canadian dollars (Sorda et al. 2010).

### *16.8.2 The United States Policies on Biofuels*

The updated version of Renewable fuel standard (RFS2) came into action on July 2010, according to which a staggeringly high amount of 36 billion gallons of biofuels to be used as transport fuels by the year 2022. The RFS2 has given preferences to 2G biofuels to curb the food-fuel issues, by mandating the cellulosic biofuels (2G biofuels) surge from 0.1 billion gallons to 21 billion gallons in a span of little over a decade. The Environmental protection agency (EPA) supervises RFS, which has a projection of 36 billion gallons of biofuel usage by 2022, against that of 9 billion gallons as of 2008 (Bramcourt 2016). RFS also mandates implementation of advanced technologies which will account for a reduction in the GHG emissions by 50% during lifecycle assessment. Moreover, the biofuels must practise the act of not surfacing the food crisis and land usage issues (Sorda et al. 2010; Araújo et al. 2017).

The biofuel usage needs retrofitting in the engine. Owing to the frequent evaluation and amendments on biofuel policies, all the gasoline-driven vehicles in the US, produced since 1970 are capable of using E10 as fuel. Biofuels due to their lesser energy densities are prone to give low mileage. It was challenging to meet the guidelines of Corporate Average Fuel Efficiency Requirements (CAFE) due to the low mileage received from biofuels. But the Alternative Motor Fuels Act (AMFA) enacted in 1988 in the US has resolved the problem (Koplow 2006).

### *16.8.3 Argentinian Policies on Biofuels*

The biofuel blending enforcements came up in February 2007 have mandated a 5% biofuel blend composition in gasoline and diesel fuels. Interestingly the quality requirement policies came up after the blending enforcement, i.e. in November 2008 for bioethanol and February 2010 for the biodiesel.

The Argentinian biofuel manufacturers are more focused on producing biofuels for use in Argentina only. The background reasons are firstly stringent technical requirements of the biofuel importing countries, which the Argentinian biofuels are unable to comply. Secondly, the tax incentives and financial benefits for biofuel manufacturers who are providing their products for use in Argentina only. The government of Argentina has given assurances for the purchase of biofuels from the manufacturers in the country for 15 years with reimbursements for taxes and depreciation costs (Sorda et al. 2010).

### *16.8.4 Colombian Biofuel Policies*

The government of Colombia had mandated E10 fuel usage in all the cities with a population of above 500,000 in the year based on law 963 (Sorda et al. 2010). This blending enforcement had resulted in an increment of 75% E10 fuel sale from the gasoline fuel market of 100% by the year 2009 (Sorda et al. 2010). The bioethanol in Colombia is obtained from sugarcane, and the government regulates the bioethanol prices based on international sugar prices.

As far as biodiesel is concerned the resolution 1289 of the year 2005 had mandated 5% biodiesel blend by 2008, with a projection of increment to 20% by 2012. Palm oil is the raw material used in Colombia. The government provides tax exemptions for palm oil production and any crop-based oil productions intended to use them as biodiesel. The automobile manufacturers were given stringent directives to make the vehicles capable of running on E85 flex-fuel after 2012, and on 100% biofuel by 2016 (Sorda et al. 2010).

### *16.8.5 Biofuel Policies of Brazil*

The biofuel policies of Brazil are the most developed ones, and they are in existence since the 1970s. In the year 1975 National Alcohol Program ‘Proàlcool’ was introduced by the government, which had the focus of bioethanol production from sugarcane (Walter and Cortez 1999). The current scenario of biofuel blending in Brazil state that bioethanol blending has come up to 27% and that of biodiesel is 10% (Brazil Biofuels Annual 2016). Regional subsidy plans by the government help in balancing benefits from the energy crop cultivation in the underdeveloped region at par with those of developed regions. However, subsidies were not given in 2015, owing to the financial crisis in the country (Harto et al. 2010). From the vehicular point of view, tax incentives were provided to the flex-fuel run vehicle, with no such benefits for vehicles running on pure petroleum fuels. To attract small farmers and family farm producers of vegetable oil, the National Biodiesel Production Program (PNPB) launched in 2004 compelled suppliers to buy raw materials from them (Araújo 2017).

The Proàlcool program has played an important role in Brazil’s economy by providing 3.6 million jobs and 3.5% of the GDP. The aggressive regulations for biofuel production have led Brazil to gain the most price-competitive biofuel status with a price tag of 0.23 US dollars per litre of bioethanol (de Almeida et al. 2008; Sorda et al. 2010).

### *16.8.6 Biofuel Policies of the EU*

In 2009 the European Union energy and climate change package (CCP) had formulated regulations for the use of biofuels in the transportation sector. The CCP regulations have enforced 20% energy quota to be fulfilled by the renewable energies in 2020 (Sorda et al. 2010). The EU Directive 2009/28/EC on renewable energies has specified that the GHG emissions must be reduced by 35% at a minimum in their lifecycle. Apart from GHG emission norms, land management, social and economic compliances are also to be taken care of. To mitigate the food v/s fuel issues, the European Union in 2015 have enacted a cap for maximum 7% contribution will be from 1G biofuels till 2020. Beyond that only non-food crop-based biofuels will be used (EU Biofuels Annual 2016).

### *16.8.7 Biofuel Policies of China*

China's bioenergy policies are very strategic and yet plausible enough to fulfil the goals of maximal usage of biofuels with the solutions to the crucial issues simultaneously. China has already discontinued the subsidies on the 1G biofuel production and utilisation, which began in 2000. China had targeted to produce 4 million tons of bioethanol and 1 million tons of biodiesel by 2015 as a part of their 12th fifth-year plan. China has planned 15% of total energy requirements to be fulfilled by biofuels with a mandate of minimum 10% by 2020 (Araújo et al. 2017; Lane 2016).

### *16.8.8 The Indian Biofuel Policies*

The Indian National Policy on Biofuel has approved for 20% blending of bioethanol and biodiesel into gasoline and petroleum diesel, respectively by 2017. The same policy also enforced non-edible oil crop cultivation in wastelands for biodiesel production. To attract the farmers for the biodiesel cropping government of India has guaranteed the revision of minimum support price (MSP), and minimum purchase price (MPP) for the bioethanol and biodiesel over the time (Altenburg et al. 2009).

Another policy, named as Ethanol Blended Petrol (EBP), came into act in 2003 had mandated the 5% bioethanol blending requirement into gasoline in four union territories and nine states. The E10 implementation plans in 2008 got delayed due to a fluctuation in the supply of sugar molasses. The National Mission on Biodiesel which was begun in 2003 with targets of Jatropha cultivation on 11.2 million hectares (Mha) of wasteland and a 10% blending target by the year 2012. However, this mission had faced failure when the production cost was found to be surpassing the purchase price (Sorda et al. 2010).

Unlike other countries in India, financial support from the government is almost non-existent. E.g. the central government have exempted central excise tax of (4%) for biodiesel production, but the state governments have refused to do so. Amidst all these shortcomings government of India is providing subsidised loans to the sugar mills, which are setting up ethanol production units alongside (Sorda et al. 2010).

## 16.9 Conclusions and Future Prospect

Biofuel is turning out to be a global phenomenon with petroleum fuel reserve depletion and escalation of environmental pollution. The industrial-scale production of biofuels is in existence for over a century. The industrial-scale bioethanol and biobutanol began in 1894, and 1912, respectively. Although the biofuels have been in production since long, their applications as an energy source are untapped only in recent times. Biofuels are categorised into different generations based on the substrates used for their production. Due to the food scarcity issues, the 1G biofuel is now getting axed from production all over the globe.

The 2G biofuels although are very promising in terms of economy and yield, but their complex structures are making the production process a tedious affair. Although the 3G and 4G biofuels from are in the research and developmental stage, many scientists have already reported that the microalgae will eventually become the answer to a sustainable biofuel production approach. The biofuels are capable of carbon capture as compared to their petroleum counterparts since the biomass during its growth assimilates a significant amount of $CO_2$ from the atmosphere. It is estimated that biofuel usage follows either carbon neutral or carbon-negative approach during their life cycle. Biofuels are mostly ending up as transportation fuels, and three potential candidates such as biodiesel, bioethanol, and biobutanol have shown their abilities to cater to the need.

The effectiveness of any biofuel is evaluated based on specific sustainability parameters such as food-fuel issues, emission and engine performance, effects on land, water, and biodiversity. It is noteworthy to mention that none of the biofuels in use till date have scored a 100% on the sustainable efficiency front. To maintain a smooth operation for production, and utilisation of biofuels, the biofuel policies exist in every biofuel producing nations. Currently, the biofuel policies all over the globe have mandated biofuel blends to petroleum fuels in the range of 5–25%. Financial incentives like tax exemption, subsidised loans, and monetary rewards for following the sustainable approach of production are offered to the biofuel manufacturers. The biofuel production is still at a nascent stage and is in dire need of further inputs from cutting edge technologies, more stringent regulations for production and usage. The future of biofuels is definitely bright and they will definitely change the scenario of energy sector in near future. At last we can say public awareness has to play the greatest role in overall acceptance of biofuels sector and subsequently their usage at larger scales.

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