Chapter 9
Bioenergy: Challenges Ahead and Future

Sandeep Kaur, Loveleen Kaur Sarao, Ankita, and Harmeet Singh

Abstract Increasing population, urbanization, rapid industrialization, fast depleting fossil fuels, environmental degradation, and rising energy demands, have left us with no other means than looking for alternative energy resources. Bioenergy, i.e., energy from renewable resources like biomass, wind, and solar have been looked like promising ventures. Certain crops, resisues from the fields, residues from industries and processing units, algae are some forms of biomass energy which is being explored by the scientists. Biomass energy in the form of crops, residues from industries and fields and processing, algae are explored by scientists. Energy crops can also be a part of highly specialized and diverse agricultural production chains and biorefineries where a variety of bioproducts, in addition to bioenergy can be obtained, which is essential for their economic competitiveness. Land-intensive bioenergy needs too much land and hence cannot be a viable source of energy in future. Hence, we need to look for other options. Solar, wind energy, and bioenergy from algal biomass are the promising ventures. Solar energy and wind energy are not only available in unlimited supply but are also currently the cheapest to harvest, and same scenario is expected to continue in future as well. Algae cultivation can be done on barren lands and hence the competition with food production or occupying of cultivable land for production will be ruled out. The overall cultivation and processing of algae for bioenergy/biofuel is a challenging affair and demands a combination of breakthrough in almost all aspects of cultivation. Bioenergy offers good agricultural market opportunities and has the ability to foster sustainable development of suburban areas, but also has ecological, social, and financial concerns. If not properly developed, bioenergy may have negative effects. There must be adequate environmental and social safeguards to address certain possible negative effects. In order to make available energy which is sustainable and deliver local communities, some finances in addition to GHG emission reductions are important to assess bioenergy on the basis of its overall achievements.

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9.1 Introduction

Increasing population, urbanization, rapid industrialization, and fast depleting of fossil fuels have resulted in an unprecedented rise in energy demands, especially in emerging markets. Almost 80% of world's energy consumed is generated from fossil fuels (International Energy Agency (IEA) 2010). But fossil fuel resources are finite and their use also leads to greenhouse gases (GHG) emissions. And renewable energy resources can be looked upon as solution to the current situation. Being not only environmentally sustainable but also capable of substituting for non-renewable energy resources in all energy requiring markets, biofuels are considered as the most possible replacement of fossil fuels (Bauen et al. 2009). Materials which are inedible and generated from lignocellulosic biomass are gaining popularity as sustainable, cost-effective, and abundant resources for reducing reliance on gasoline and lowering the cost related to its production and feedstock (Iramak 2019). As opposed to the fuels like charcoal, crude oil, and natural gas which are generated from non-renewable resources, these resources make no addition to concentration of carbon dioxide in the environment. Carbon dioxide (CO_2) produced in biomass growth is largely offset by CO_2 released from bioenergy/biofuel production (Fig. 9.1).

Rising global energy demands, the release of emissions from fuels from non-renewable resources and the national security concerns have finally focused attention to sources which are environmental-friendly and are viable replacement too.

Alternative bioenergy not only minimizes reliance on oil trade and decreases uncertainty due to oil price volatility, but it also ensures lower emission levels because of its elevated concentration of oxygen (Huang et al. 2008; Boer et al. 2000). Thus, timber and agricultural energy, the two most available forms of bioenergy, can be the source to fulfill the basic energy requirements as sustainable alternatives.

Agriculture and forestry may be the key sources of feedstock for biofuels like wood pellets, fuelwood, charcoal, bioethanol, and biodiesel in this century, with agriculture and forestry as the main sources of feedstock for biofuels like wood pellets, fuelwood, charcoal, bioethanol, and biodiesel (Agarwal 2007). Energy crops can also be a part of highly specialized and diverse agricultural production chains and biorefineries where a variety of bioproducts, in addition to bioenergy can be obtained, which is essential for their economic competitiveness (United Nations Environment Program 2006). Concerns and questions have been raised on bioenergy as it is energy derived from food (Tilman et al. 2009; Pulighe et al. 2019) and also its effect on GHG emissions (Bosch et al. 2015), this hold true especially when bioenergy will be the main energy supplier as fossil fuels will be depleted. Another issue is the debate of fuel vs food, whether bioenergy resources compete with food

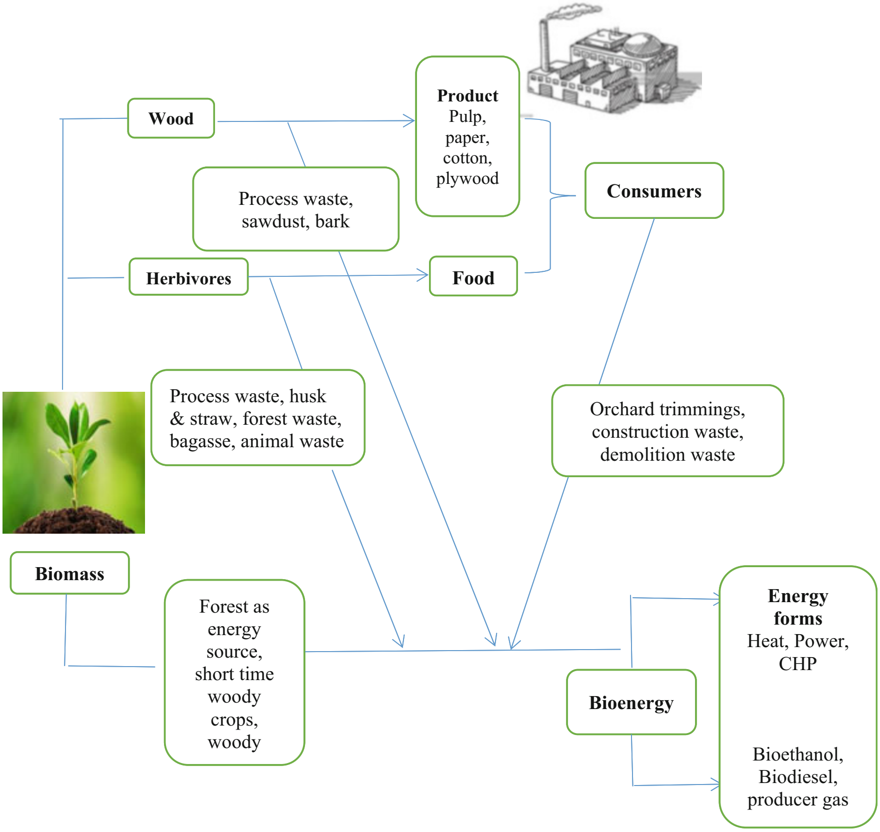

Fig. 9.1 Bioenergy Routes

resources threatening food security and sustainability (Pretty et al. 2010). Noticeable competition has been observed on transformation to bioenergy crops with respect to environmental effects and changes on use of land, water, and ecological preservation (Milner et al. 2015).

One has to find a solution to the problem within the current agricultural scenario and by solving the issues at field scale on which land to use and which to spare (Anderson-Teixeira et al. 2012), and simultaneously conserving and enhancing the ecology in the form of solutions from the nature and based on nature (Nesshöver et al. 2016), so that all challenges are converted to fortuity and answers.

Alternative energy options need to have elevated energy content, thus emitting the minimal GHG possible. Importantly, these fuels' resource extraction and production processes should have no effect on the other parameters as food generation and supply, hydro resources, land use, and climate. These sources, for example, nuclear, solar, geothermal, wind, and biomass are virtually carbon neutral, hence make up as good fuel options (Chung 2013). Also, there has been emphasis from

IEA that infrastructural gains of renewable energy, for example, financial gains, work opportunities along with lesser emissions, and encouraging technology innovation should be kept in mind by the governments while designing plans for the development and use of bioenergy (IEA 2020).

9.2 Bioenergy Current Status

Bioenergy makes up 9.5% of main energy supply and accounts for 70% share in currently used energy from renewable resources (IEA 2017a, 2019). More than 50% of this share comes from conventional use of biomass, i.e., fuel for domestic usage and small ventures such as charcoal and brick kilns. Although, conventional biomass has a lot of room for improvement in terms of sustainability, quality, and health protection (Creutzig et al. 2015), we focus on modern bioenergy and its future in coming decades as it has the prospects of substantial growth. The contribution of modern bioenergy (hereafter "bioenergy"), in 2017 was four times the combined share of solar photovoltaic (PV) and wind, thus contributing 50% to the total consumption of renewable energy (IEA 2018). The majority of bioenergy is used to heat buildings and industries, and it is projected that bioenergy will make up for 3% of electricity generation and 4% of transportation requirements in 2023 (IEA 2018). For transportation, there was an increase in liquid biofuel production before 2010, at the rate of more than 10% per year, falling to 4% annual growth from 2010 to 2016. For bioenergy electricity capacity, the annual average growth rate was 6.5% between 2010 and 2016 (IEA 2017a). Along with liquid biofuels, bioenergy is projected to make 30% increase in its contribution to energy generated from renewable resources between 2018 and 2023 (IEA 2018).

9.2.1 Biomass Potential

Biomass has different types of potentials which include theoretical, technical, environmental, economic, and sustainable, with separate scopes and are based on approaches and methodologies different from each other (BEE 2010; WBGU 2009; Scarlat and Dallemand 2019). The total amount of biomass or biophysical limit that which the current resources (land, water) can possibly generate with no addition to energy production constraints is referred to as theoretical potential. With today's technological standards, technical potential refers to a small fraction of theoretical potential (e.g., structure, framework, approachability, reaping, and processing methods) and the limitations of space (e.g., landscape, height, slant). Environmental potential is the part of theoretical potential which is eco-friendly conserving land, water, and atmosphere. The economic viability of technological potential under specified economic conditions makes up economic potential. Sustainable potential

Table 9.1 Classification of biomass resources

Resource	Category	Source
Energy crops	Traditional crops	Yearly crops, cereals, sugar, and fuel crops
	Perpetual power crops	Short-term crops, grasses, and forests
Principal/ basic waste	Woodland/plantation wastes	Logging residues: branches, twigs, tops; low quality stem wood; landscape care residue
	Farming wastes	Crops (straw and others) Waste from trimming of vineyards/orchards; cattle, manures and slurries, pigs, goats, and sheep residues, poultry leftover
Secondary waste	Timber processing	Sawmill coproducts: wood, shavings, sawdust, bark
	Farming wastes	Food industry waste, processing of farming products Slaughterhouse leftovers
Other waste	Urban wood	Construction and demolition generated; contaminated timber; consumer durables
	Organic leftovers	Paper/cardboard, cooking, garden, clothing, and packaging wastes
	Sewage sludge	Wastewater treatment plants
	Landfill gas	Generated by decomposition of organic waste in waste disposal sites

Adapted from: Scarlat N and Dallemand J-F. 2019. Future role of Bioenergy. In: The Role of Bioenergy in Emerging Bioeconomy. Ed. Lago C., Caldes, N.,Lechon Y. Academic press. pp: 435–547

Table 9.2 Some problems and solutions to biomass usage

Problem	Solution
Although present in sufficient quantity, good quality biomass is in short supply and expensive and not always feasible	Agricultural and timberland residues should be used. They are available in plenty and are sustainable
Farming and timber residues are of poor quality and micro-element (K, Ca, Mg) content is high	Different biomass should be mixed to have required composition
Biomass is available in forests only	Cheaper residues are dispersed around and universally available
Fresh biomass has low energy density and bulk volume, hence adding to storage costs and effecting movement efficiency	To enhance biomass energy density and movement efficiency, chipping should be done at first step
Degradable nature of biomass effects long distance transport and extended storage	Agropellets should be produced. They have less moisture, high energy density, lesser degradation, and transportation issues

Adapted from www.eubia.org

is the one meeting the criteria of sustainability in terms of technological, financial, and ecological constraints (Scarlat and Dallemand 2019) (Tables 9.1 and 9.2).

9.2.2 *Limitations of Biomass Potential*

Land availability is the primary constraint to land-intensive bioenergy, which will not be a viable power source for prolonged time because of its extensive land requirement. Being limited in amount, it is in short supply and considering the ever-rising human population along with attention towards conservation of natural resources, land will continue to be a scarce commodity in spite of an increase in agricultural yields. Creutzig et al. (2015) estimated that technological potential for bioenergy development is from 1000 EJ/year to tens of thousands of EJ/year. Perspectives and perceptions regarding availability of land, its sustainability, social and economic constraints add to uncertainty in above figures. Committed plantations on marginal and deteriorated lands have been assumed to provide a biomass potential of up to 100 EJ/year, still the amount of land which is not in use or can be usable is debated upon (Creutzig et al. 2015; Field et al. 2008). Even in the absence of bioenergy land demand will continue to rise. Crop and pastureland will still need to grow 10% by 2050, if the rate of increase in agricultural productivity remains the same as half a century in the past with no fresh area allocation to bioenergy production (Searchinger et al. 2018a, b). Ecology has been harmed because land dedicated to ecosystems, natural reserves have been transferred to farming and housing development, leading one million species on the verge of extinction (Díaz et al. 2019; Reid et al. 2005). Conservation of natural habitats and restoration of destroyed ecological reserves on deteriorated lands or lands no more in use for cultivation is required. Conservation and regeneration cannot go hand in hand with extensive growth of land-based bioenergy (Reid et al. 2020). Land conservation will prevent desert formation and degradation of land, but its impact on food security will not be a positive one and at the same time dedication of land for bioenergy generation and conservation and regrowth of forests will lead to GHG reduction and removal of CO_2 from environment (Arneth et al. 2019).

9.3 Why Bioenergy?

9.3.1 *Reasons*

Despite inefficiently used land and the competition from other processes requiring land, bioenergy has a prominent presence in most energy scenarios for half of the century for three reasons (Reid et al. 2020). First, bioenergy is capable of meeting baseload electric power needs unlike intermittent energy sources. This feature is expected to become increasingly significant as existing non-renewable resource-based thermal capacity moves towards retirement. Secondly, fuels with high energy density are needed for applications in shipping and aviation and biofuels are capable of meeting these criteria at a low cost. Third, Bioenergy with Carbon Capture and Storage (BECCS) can be used to generate carbon-negative energy. The integrated

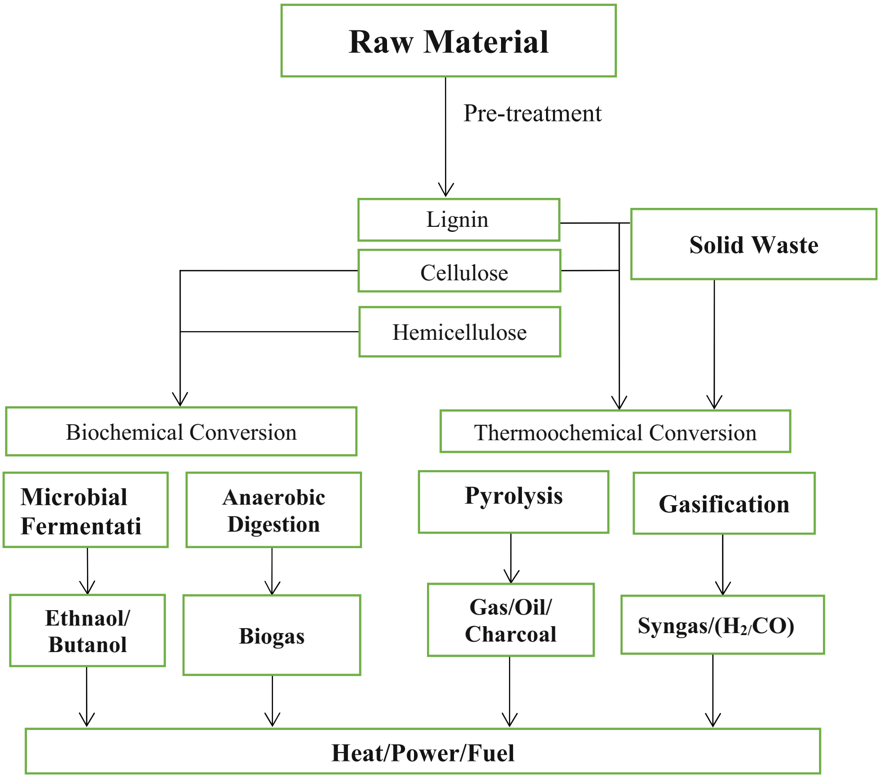

Fig. 9.2 Biomass and solid waste transformation and distribution in different energy pathways (*Source:* Chung, JN. 2013. Grans Challenges in bioenergy and biofuel research:engineering and technology development, environmental impact and sustainability. *Frontiers in Energy Res.* 1: 1–4. https://doi.org/10.3389/fenrg.2013.00004)

assessment models to find negative emission technologies (NETs) are appealing because they are able to effectively delay the much-needed transition from current technologies and also not only offset ceaseless emissions in short term but also removal of GHG in the long run (Field and Mach 2017) (Fig. 9.2).

9.3.2 Effects

The power system planning earlier consisted of economical combination of baseload electrical power (rigid but economical, for example, coal/nuclear), load-following power (adaptable to variations in demand on daily or periodic basis although expensive), and peaking power (flexible with highest cost, for example, gas turbines) (Reid et al. 2020). For baseload electrical energy, bioenergy is a rational substitute in conventional arrangement taking along nuclear, hydro and geothermal resources. In decarbonization framework, biomass is a befitting option for baseload power source, also it is considered a low-carbon, low-cost fuel. Falling of natural gas, solar, and wind energy costs has changed the overall system of power planning. Cost of solar and wind energy is lowest than any energy source in two-third of the world, it is forecasted to be the most pocket-friendly energy source everywhere by 2030 (Bloomberg New Energy Finance 2019).

According to the CEO of NextEra Energy, United States, solar and wind plus storage energy are cost-efficient than charcoal, oil, and nuclear sources and hence will have a detrimental unsettling effect on traditional resources (Roselund 2019). The need for baseload power which is seldom turned off is being replaced by the need for versatile, dispatchable power as intermittent renewables become prevalent.

9.4 Biomass Conversion Technologies: Problems and Solutions

Biomass pre-treatment and fractionation, enzymatic hydrolysis, saccharification, microbial fermentation, and product separation and purification are among the various steps involved in biomass fermentation and conversion processes (Chung 2013) (Fig.9.1). Improvement of each of these intrinsic processes requires further research and analysis. According to Virkajarvi et al. (2009), the problems are related to availability of the raw materials in sufficient quantities and at affordable prices. Processes like pre-treatment, microbial fermentation, and sugar concentration in manufacturing all need to be improved. To constitute, develop, and raise the biochemical conversion system, which includes a fermentor as well as assisting and auxiliary parts, engineering studies are needed. The primary method of conversion of biomass into synthesis gas (Syngas), in thermochemical approach is gasification. Hydrogen, carbon monoxide, carbon dioxide, methane, water vapor, and trace impurities are main components of Syngas (Chun et al. 2013). Thermochemical gasification is among the most economical and reliable processes for energy conversion being gaseous in nature. Syngas finds its use in combustion furnaces, fuel cells, gas turbines, and internal combustion engines. The process of gasification is accomplished with biomass feedstock reacting at a regulated volume of oxygen with or without steam at higher temperature (above 700 °C but without combustion). The requirement of thermal energy for gasification is fulfilled either internally (partially oxidative autothermal process) or an external heat source, for example, electricity (an allothermal process) in the case of plasma gasifiers. The ability of high temperature to act as heat source and promote the conversion of char to hydrogen through water gas change reaction has drawn attention to allothermic/external gasification (Chang et al. 2011; Umeki et al. 2012). Hence, the focus of the problems associated with advancing gasification technology should be on discovering methods which can enhance the thermic and chemical gasification process, for example, development of effective catalysts and additives. For design, optimization and step up of gasification system including the fermentor/reactor along with supporting and auxiliary components requires development of engineering research. Although a functional fuel, conversion of biosyngas to a liquid hydrocarbon fuel will yield a material that is more energy dense than crude oil-derived diesel and petrol. The most significant chemical reaction in the conversion of Syngas to liquid hydrocarbon is the Fischer-Tropsch reaction (Huber 2013). The feedstocks for biomass and petroleum are different from each other (Huber 2013) as high oxygen content of biomass, make it less thermostable and difficulty in functional control. Effective removal of oxygen from molecules generated from biomass and selectively functionalization petroleum compatible target molecules is among the main challenges faced in gas-to-liquid synthesis (Huber 2013). The overall effectiveness of the conversion process of biomass-derived molecules into fuel is dependent on heterogenous catalysis and chemical engineering. Development of clean catalytic technology and processes to understand and monitor the chemical reactions is critical in the advancement of the biomass-to-biofuel conversion. The effective temperature range for gas-to-gas synthesis is a narrow one and the process is an endothermic reaction. Quick pyrolysis, an anaerobic, rapid thermal means of decomposition of organic compounds for the production of oils, char, and gases in small concentrations at 400–500 °C is also an effective thermochemical conversion method (Chun et al. 2013). Pyrolysis derived bio-oil has the ability to make major contribution to the supply of liquid biofuels as well as source of variety of useful chemicals. But there are many issues like plant scaling, economization, improved stability of oil and efficiency producer and consumer norms and standards along with ecological health and safety concerns in operating, moving, and consumption that need to be addressed (Czernik and Bridgwater 2004).

9.5 Environmental Impact: A Reason to Shift

The transition to cleaner and renewable fuel substitutes has been fueled by the energy crisis, air pollution, and greenhouse gas emissions. Biomass has no effect on its resource extraction and processing methods do not alter food supply, water provisions, use of land or climate, besides being carbon neutral, biomass makes a good option for fuel. But better understanding of energy policy, its impact on environment, pollution, and assessment of life cycle with regard to use of biomass for energy should be prioritized for making it a valid candidate. These can be accomplished through (Chun et al. 2013):

- The thermochemical, biological conversion, and aerobic fermentor plants emissions need to be classified on the basis of their effects on change of climate, global warming, and ecosystem.
- Sampling instruments for generated aerosols should be used in conjugation with chromatography (ion), atomic absorption, and carbon analysis to analyze gaseous emissions and classify aerosols for physical and chemical characteristics.

- The emissions generated during working stage of thermal and biological energy production processes along with those generated during extraction, usage, movement, and disposal of waste should be measured by incorporating data into a broader LCA system.
- Resulting environmental effects such as global warming and depletion of ozone layer should be calculated and equated with current systems based on fossil fuels to ensure minimal negative consequences on environment.

9.6 Future

As we talked in Sect. 9.3, the traditional system consisted of mixture of cost-effective baseload electric power, load-following power and peaking power, bioenergy is the most suitable alternative to the traditional arrangement along with nuclear, hydropower, and geothermal energies. It is an attractive alternative power source as it is considered as low-carbon and low-cost fuel hence favoring current decarbonization scenario (Reid et al. 2020) (Table 9.3).

9.6.1 Alternative Fuels

Solar and wind prices are currently among the lowest leveraged energy costs of any energy source and are estimated to be cheapest by 2030 (Bloomberg New Energy Finance 2019). Decarbonized grids require flexible time frames, minutes to seasons, which can be obtained using a number of technologies and strategies for grid management like flexible electricity supply sources (gas and hydro), storage of electricity (batteries, pumped hydro, compressed air), and chemical bonds (hydrogen production, synthetic fuels) (Pierpont et al. 2017), measures in requirement sector

Table 9.3 An estimate of carbon emissions: bioenergy vs fossil fuels—electricity generation

Fuel and technology	Generation efficiency (%)	Grams of CO_2 per kWh
Generator (Diesel)	20	1320
Coal-based power plants	33	1000
Natural gas combined cycle	45	410
Biogas digester and diesel generator (with 15% diesel pilot fuel)	18	220
Biomass steam cycle (BER[a] = 12)	22	100
Biomass gasifier and gas turbine (BER[a] = 12)	35	60

Source: Kartha S. and Larson ED. 2000. Bioenergy Primer: Modernized Biomass Energy for Sustainable Development (New York: United Nations Development Program, 2000)

[a] Biomass energy ratio: Ratio of the energy content of the biomass produced to the energy of the fossil fuel consumed for the production of given biomass

(costs are used to alter the time of customer requirements), and better integration of electric grid areas (Schaber et al. 2012). Short time frame flexibility (minutes to hours), then decreasing battery prices will make battery storage as cheapest energy source by 2030 for intraday energy shifting than the new combined cycle gas turbine (Polymeneas et al. 2018). But there seem no chances of intermittent renewable engines in conjugation with storage to be the most economic means of providing flexibility over longer periods, at least over the coming decades. We need to overbuild the solar system and make it capable of storage for long term owing to its high penetration and storage to substitute for the natural gas or related constant sources of energy generation (Davis et al. 2018). For example, Ming et al. (2019) drew inference from their study of profound decarbonization for California that in 2050, the requirement of natural gas is 17–35 GW capacity, in spite of significant decrease in number of days in which it is used, it will reduce the emissions of the electricity sector by 90–95%. According to some studies, renewable hydrogen (generated from variable renewables via electrolysis) can be a possible and economic supplier of storage for long duration and a means to further decrease the energy demand of firms (Element Energy 2019) although in current scenario this methodology is not considered an economic means of hydrogen production (Davis et al. 2018). That means, in mid-century bioenergy will emerge as a competitor to other power sources for supply of firm energy with interday and seasonal load balancing, and not an alternative for baseload power production. Bioenergy will not be able to make a large part of energy mix for several reasons. Due to low natural gas cost, gas infrastructure in countries like the United States is more prevalent, and the growth rate is higher than bioenergy infrastructure. Existence of such infrastructure uses natural gas plants (at a reduced capacity), a cheapest option rather than sidelining the assets. The emissions are also relatively low because of online nature and availability for limited period of time and projections say that bioenergy without Carbon Capture and Storage (CCS) or hydrogen will be used by these plants by mid-century. Investment in new carbon capture technologies is already being increased in the United States by providing credit on tax for capturing CO_2 and storage power plants (Reid et al. 2020).

When it comes to firm power, land-intensive biofuel may not be the most attractive source of bioenergy, whereas use of biogas, instead, is likely to expand, which is a fuel with low-carbon content and is obtained from cow dung, municipality wastes and water. Biogas provided only slightly less than PVs with 17.2% of the German electricity being generated from renewable fuel in 2016 (Liebetrau et al. 2017). By 2050, the flexibility needs of future energy grids cannot be fulfilled by large baseload power plants which use combustion of wood pellets for fuels, due to difficulty of ramping up energy production. Above all, the financial incitement for modest, transmittable energy will increase substantially as medium renewables saturate the power trade. As discussed earlier in this section, different types of bioenergy will compete with a variety of options such as demand reaction, battery storage, hydro, solar power focus, power gas, hydro energy, and natural gas with CCS, but will also be combined with same demand. The said scenario will be little like the conventional farming of low-emission fuel that replaced the baseload coal power for baseload energy (Reid et al. 2020).

9.6.2 *Bioenergy Future Vs Current Scenario*

According to IEA (2019), even though bioenergy will make a small part of the power mixture of 2100, conventional and contemporary bioenergy represent 9.5% of main energy supplies and the quantity and the contribution of bioenergy are likely to increase. With coal-powered infrastructure being transitioned between government and power sector owners, the requirement for timber biomass is expected to rise. Between 2006 and 2015, the timber pellets production for biomass energy increased four times to 26 million tonnes (MT) (Thrän et al. 2017). Solid biomass makes up for 44.7% of all renewable energy in the EU, where wood pellet is the main import. East Asia is expanding its biomass merchandise and are expected to compete with European requirements in coming times. For example, the biomass power projects of 11.5 GW were approved by Japanese government with palm oil filling 40% of the total (Obayashi 2017; Watanabe 2017). A major factor in this expansion is that under systems of carbon pricing and for coping up to environmental targets of both national and corporate levels, the legislation of many takes the carbon content of biomass as nil. From climate point of view, this assumption encourages use of bioenergy, as only a segment of obtainable biomass in a 10-year span of time can achieve climate gains (European Academies Science Advisory Council 2019). A decade time period is considered as most applicable to environmental effects, as with the regeneration of fuel source, initial increase in CO_2 with use of bioenergy in a 10-year period will be eventually removed. There is a possibility of creation of a unique “double climate problem” because of an increase in use of forest biomass, as short time emissions are higher than majority of non-renewable fuels with long-carbon return tenures of a decade to longer than a 100 years and hence, degrading, forests’ efficiency to settle carbon (Brack 2017; Buchholz et al. 2016; Cornwall 2017; Sterman et al. 2018). Biofuel generation has risen 82 MT of oil equivalent (MTOE) in world and the estimated growth is up to 142 MTOE by 2040 (BP 2019). It is estimated that an increase in demand for palm biodiesel in Indonesia could increase the demand of palm oil by 18.6 MT by 2030, as Indonesia has expanded its biofuel mandate from 5% in 2006 to 30% by 2020 (Malins 2017). Currently, mere 35% of available palm biodiesel oil refinery is in use in Indonesia, it is yet to achieve its blending targets for biodiesel, and it can be taken that they can achieve their targets without any significant additional investment (Wright and Rahmanulloh 2017). There are chances of increased forest degradation as well as destruction of some of the unchanged ecosystems in the world and also an increase in level of carbon generated from transport sector due to the conjugated requirement of biofuels from these young and up-coming markets (Malins 2018; Meijaard et al. 2018). A number of unique challenges are put forward with the hope of reduced requirement in further times with awkward proximity of near term growth in bioenergy. There are

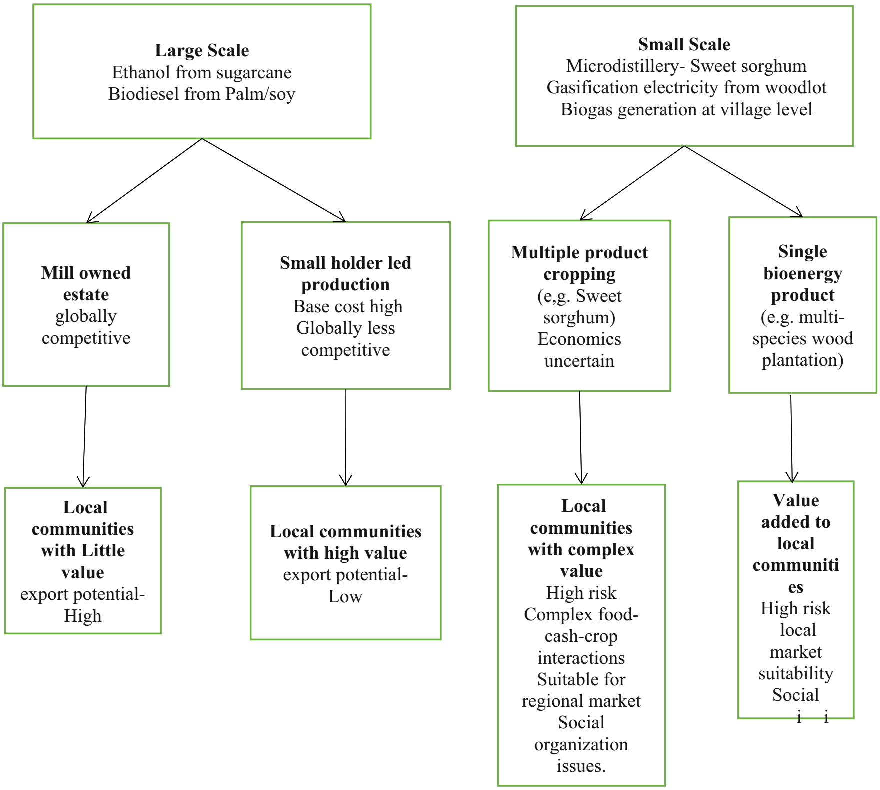

Fig. 9.3 Alternative bioenergy development options (*Source*: Woods, J. 2006. Science and Technology Options for Harnessing Bioenergy. In. Bioenergy and Agriculture: Promises and Challenges. Ed. Hazel LP. and Pachauri RK.)

three different biomass delivery categories, each of which has origin in different ecosystems with different capabilities and schedules for carbon storage, both onsite and offsite. Generation of biomass can be the result of waste produced during activities like timber generation or farming or cooking oil use. With the aim of expanding carbon storage or enhancing the living space, biomass can be removed from the ecosystem, for example, cutting of trees to decrease the wildfire possibility, afforestation, or increase the wood fiber usage in long-term products can all enhance storage of carbon while simultaneously providing a source of bioenergy. Thirdly, biomass can be produced from energy-specific ecosystems. The desirability, sustainability, and prospects for each of these categories are significantly different (Reid et al. 2020) (Fig. 9.3).

9.6.3 Dedicated Biomass for Energy

For herbal crops, forest plantations and naturally regenerating forests, sustainability, and perspectives for energy managed ecosystems are very different (Reid et al. 2020). To work in a system that will actually benefit the climate across all of these ecosystems will be difficult, especially over a decade or less. The "carbon opportunity cost" of land diverted to biomass manufacture along with the possibility of extending the age of provisions that consume both non-renewable and renewable resources is loads worse or in line with that of fossil fuels in a time period of 10 years, after adjustment to emissions linked to transport or processing, indirect usage of land, carbon debt, etc. (European Academies Science Advisory Council 2019; Searchinger et al. 2018a, b; Sterman et al. 2018; Zanchi et al. 2012). Land-intensive bioenergy can not only add pressure on food generation (Frank et al. 2017) and preservation of biological diversity (Smith and Torn 2013), it also tips the scale in opposition of the resources which are marginally climate profitable. In the three types of bioenergy ecosystems, the estimates vary widely on how sustainable land-intensive bioenergy can be produced. According to Creutzig et al. (2015), sustainable technology potential of 100 EJ/year was agreed upon by many in literature although the scope covered 1000 EJ/year. Considering the scarcity of land, the requirement of how the ecosystem protects are restores is of utmost requirement. Reid et al. (2020) considered conservative estimates to be more important. Field et al. (2008) estimated that around equivalent of 27 EJ/year could be land which is not competitive to food production (especially the abandoned agricultural land, which is neither converted to forests nor urban areas). Similar bioenergy production estimates have been developed by Canadell and Schulze (2014) from abandoned agricultural lands with high degree of environmental sustainability and concluded that bioenergy production would reach 3–8% of total primary energy by 2050 from 26 to 64 EJ/year, which is 20–40% of mean bioenergy estimates by 2050 (Rogelj et al. 2018) (Fig. 9.4).

9.7 Prevention of Locking-in of Bioenergy

In the history, complete disappearance of primary resources of raw materials were the only reason of closing down of resource-intensive industries, for example, whale hunting and Bison hunting in North America. But there has been unsustainable management of fisheries, forests, and agriculture in many places (Reid et al. 2020). Until recently, the potential to transform the planet in twenty-first century was unimaginable. As the land is fully quantitative, land-intensive bioenergy may transform lands to an essentially unacceptable scales when protections were missing. With assumptions of dissipation of bioenergy demands during this century, types of protections to trust to build a sustainable future is a valid question to ask. There are very few examples of governments or societies in history that have been able to have

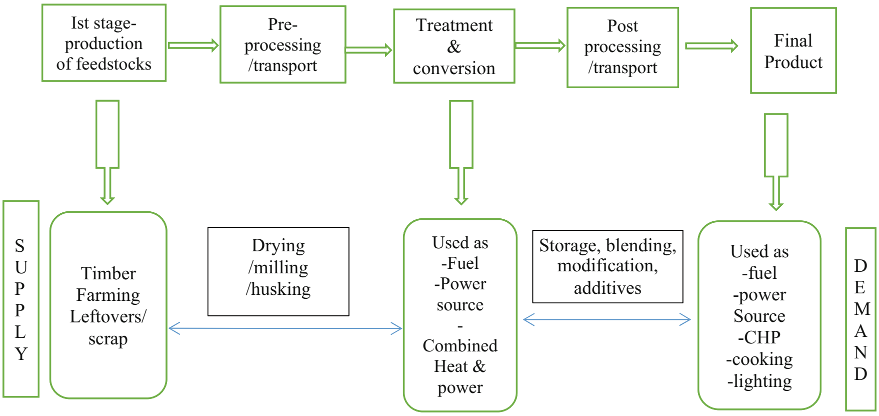

Fig. 9.4 Bioenergy- demand and supply

a successful transition which was trouble free and financially sustainable, in any system or industry on a grand level, not to mention energy system. In general, such systems develop inertial resistance (path dependency) to major systemic changes, which are driven by social and economic initial conditions, along with increased rate of returns (Seto et al. 2016). There are three contributing factors to energy system lock-in: (Seto et al. 2016):

1. An energy system would remain in order for an extended duration than optimum by the lock-ins of physical infrastructures such as power plants of longer duration, pipes, processing plants, establishments, and communication systems.
2. Infrastructure lock-in can be straightened by institutional lock-in, which means financial, political, and social factors seeking to strengthen a trajectory of status quo, favoring their own interests. Industry obtains financial and political weight as it evolves and continues to retain status quo in spite of transition being good for society.
3. Status quo can be further strengthened through lock-in behavior with societal rules and traditional values.

When it comes to bioenergy risks of physical, institutional, and behavioral lock-in are not difficult to recognize. It takes centuries to restore a natural ecosystem if it has been converted because of expansion of energy crop production. Wood pellets have been used in Europe through combined combustion (cofiring) or total switchover to biomass fuel to increase the life of power stations using coal. In Japan, South Korea and the UK-dedicated biomass power plants are under construction, which once complete will slow the transition to more cost-efficient or cost-effective energy systems. Maize ethanol industry in the United States has acquired political power sufficient to promote the growth if ethanol and gasoline mix, even though the benefits of corn ethanol to the climate are questionable, when it comes to liquid biofuels. Talking about financial inferences of lock-in of electricity sector, Kalkuhl et al. (2012) concluded that lock-in of a lower mechanics can remain for several decades, unless specific policies have been applied. To counter lock-in the grants for new techniques, feed-in tariffs and legacy technology quotas were found to be effective. Policies are needed to limit infrastructural, institutional, and behavioral interference ensuring that bioenergy meets short tenure requirements of carbon emission reductions and transformation to energy resources which use land effectively and give better cost. Still, the dependence on path is inevitable. We need effective policies that will not only help industry/large-scale manufacturing level in coming few decades but also help to maintain industry or raising it market contribution beyond that. The appropriate short-term expansion of bioenergy can be facilitated by a number of specific policies, certifications, and standards, while discouraging long-term inefficiencies. There are four broad categories of potentially effective policies: (Scarlat and Dallemand 2019). While some focus on taking proper account of gains and price of bioenergy along with the acknowledgment of the complete restriction on availability of land and possibility of restoration. Others emphasize on feedstocks' features and circumventing those which are endangering the climate in coming times and some encourage the biomass industry to avoid long-term reimbursement infrastructure commitments. And the rest are still promoting substitute technology.

Several attempts have been made to design a future picture of global energy system capable of reducing the carbon emissions required to attain the continuing objective of climate change. A Bioenergy Roadmap was prepared by IEA based on Energy Technology Perspectives modeling framework for supply of energy, structures/establishments, industry, and means of movement perspectives (IEA 2017a). This Roadmap covers three scenarios in a low-carbon energy system with various energy technologies. In each scenario, the Roadmap (IEA 2017b) recognized the part of technology profile in future sustainable global energy systems to control the rise in temperature as accomplishment of the long-term goal. The following scenarios have been analyzed: (Scarlat and Dallemand 2019).

- **Reference Technology Scenario (RTS)—**The basic framework, in line with the global climate deal reached by the 21st COP (CoP21) of the United Nations Framework Convention (UNFCCC) on climate change, which considers both—current and planned climate and energy commitments.
- **2DS—**A power system scenario that allows average global temperature to be limited to 2C by 2100.
- **B2DS scenario—**Speeding up the deployment of clean energy technology to more ambitious climate goal by 2100 by reducing the average global temperature to 1.75 °C.

Based on the assumption if Nationally Determined Contributions (NDCs) are implemented as proposed by Paris Agreement signatories, it will require a change in systems and policies (Scarlat and Dallemand 2019) and owing to this a mean temperature rise of 2.7 °C will take place by 2060. With widespread use of renewable energies, 2DS call for significant energy efficiency improvements across all sectors. Whereas based on an important bioenergy contribution and a greater CCS role to deliver further reductions in emissions, the B2DS scenario examines an ambitious decarbonization pathway. Thus, there is a requirement of a difficult and ambitious energy sector transformation, with B2DS scenario facing more technical and political challenges. There were approximately 34.3 Gt CO_2 emissions globally in 2014, including emissions from industrial processes. It is expected that CO_2 will reduce by 70% from current levels by 2060, in 2DS scenario, with almost 1170 Gt release of CO_2 between 2015 and 2100 which counts emissions from industry as well.

In 2DS, CO_2 emissions will decrease further after 2060 in the energy system to reach CO_2 neutrality by 2100. A cumulative carbon budget lower by 40% is expected by 2060 in 2Ds when compared with RTS, which requires and additional 760Gt CO_2 reduction during the period. Most technologies based on renewable energy are motivated by the need of speedy decarbonization in the 2DS and with use of biofuels in transportation, building heating and industry are being deployed in the energy sector. Between 2015 and 2100, the B2DS results in the energy industry emissions of about 750 Gt CO_2 cumulatively and the CCS energy system's carbon neutrality in 2060, backed up by negative emissions using CCS bioenergy. In order to reach net null emissions in 2060, in B2DS the deployment of bioenergy with Carbon Capture and Storage (CCS) is necessary. The negative emissions compensate for very difficult to abate or very expensive emissions in industry and transport (IEA 2017a). It is expected that during 2015–2060 period, the B2DS scenario will control the CO_2 emissions from energy sector to almost 750 Gt, requiring cumulative emission reduction by nearly 60% by 2060 as compared to RTS or about 1000 Gt $CO_{2.}$ It is expected that B2DS will practically decarbonize the power sector by 2060 (IEA 2017a). The B2DS is considered to decrease CO_2 emissions to nil by 2060, where the decarbonization pathway is much faster than 2DS. For energy sector transition, energy efficiency is crucial, accounting for 40% cumulative reductions required to move from RTS to 2DS and additional 34% emission reduction required to move from 2DS to B2DS (IEA 2017a). The expectation of growth in global primary energy is from 576 EJ in 2015 to 843 EJ in 2060 under the RTS scenario. The fossil fuels are still dominating the primary energy supplies although there will be a fall from 82% in 2014 to 67% in 2060, with the hope that biomass and waste, other renewables and nuclear will make up 12%, 14%, and 7% of the remaining share, respectively. It is expected that fossil fuel share will decline from 82% in 2014 to just 35% in 2060 in energy mix and other renewables will make up as primary source contributing 52% (348 EJ) in energy mix. The biomass and waste share will double to 144 EJ by 2060 and will represent 22% of the energy mix. It can be said that the energy industry is approaching carbon neutrality by 2100.

9.8 Biofuels in Aviation Market

Although the aviation industry contributes very little to the global anthropogenic CO_2 emissions (approx. 2.6% per year), commercial aviation growth rate is expected at 5%/year in the next few decades (Scarlat and Dallemand 2019). Thus, by the mid-century, the air traffic share to global CO_2 emissions will increase from 4.6 to 20.2%. To cope with impact of aviation on climate, measures are being taken by states, industry, and international organizations. Ten years after the first commercial flight in 2008 between London and Amsterdam, several airlines were operating commercial flights using aviation biofuels in the beginning of 2018 (Scarlat and Dallemand 2019). In order to comply with jet fuel specifications fit for aircraft that are currently in use, the international standard of ASTM d7566 has been there since 2009. According to Kostova (2017), five conservation processes with different blending levels of 10–50% were approved for March 2018 and number of others were in progress. Aviation biofuels are defined as the fuels with the ability to produce lesser GHG emissions in a life cycle than traditional petroleum-derived jet fuel (Scarlat and Dallemand 2019). Drop-in aviation biofuels are the fuels which are completely replaceable and suitable substitutes of petroleum jet fuels, i.e., it can be used in aircraft in current use, and there is no need for the adaptation of the jet aircraft/engine to the biofuel. GHG emissions in aviation can be reduced by savings during the production of renewable, biological material which will be subsequently converted to biofuels. There is no reduction in emissions in actual combustion stage of drop-in mix of biofuels with conventional petroleum. Hence, although the potential savings in aviation industry can be as high as 80%, but it is dependent of the path taken, i.e., the collaboration of variety and the transformation processes of the feedstock. The possible straight and indirect effects, counting the transformation and use of cultivable land are of crucial significance for biofuels generated from farm crops, similar to situation of road transportation. As bioenergy comes in competition with other possible uses of biomass (food, feed, fiber, biomaterials, and green chemistry) along with feasible waste disposal loads, the scope of producing alternative air fuels from waste are of particular attention. The commercial production of biofuels still remains an unsatisfactory task even though the aviation biofuels are technically operational. There are big expectations from the possibility of aviation biofuels to decrease GHG emissions from aviation industry of Europe and around the world and hence with the aim of enhancing the generation and use of biofuels, numerous initiatives have been introduced. For example, European Advanced Biofuels Flight Path aimed at attaining two million tonnes of aerospace fuel per year by 2020 and US initiative "Farm to Fly" targets to produce one billion gallons of sustainable jet fuel by the end of 2018 (Scarlat and Dallemand 2019). One should not miss that in EU and US regulatory frameworks definitions of sustainable biofuels are different. The EU directive 2009a,b/28/EC (RED) with the aim of supporting development of aviation biofuels in Europe had the target of having 10% share of bioenergy in transport by 2020. In comparison to 2010, the EU Fuel Quality Directive 98/70/EC (FQD) set a mark of decrease in GHG emission from all transport energy by 6% by 2020. Both RED and FQD have harmonized, sustainability requirements acting as exclusion criteria to meet the regulatory objective (Figs. 9.5 and 9.6).

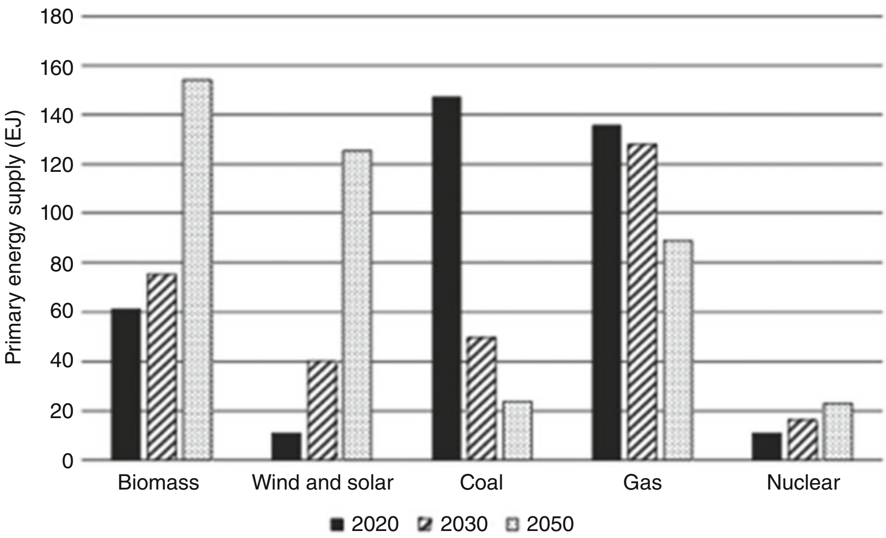

Fig. 9.5 Mean supply of global primary energy based on 85 1.5 °C pathways including all low- and high-energy pathways. The expected CO_2 emissions under these pathways are 38.5 Gt CO_2/year (2010), 29.1 Gt CO_2/year (2030) and 1.0 Gt CO_2/year (2050). (Source: Rogelj et al. 2018)

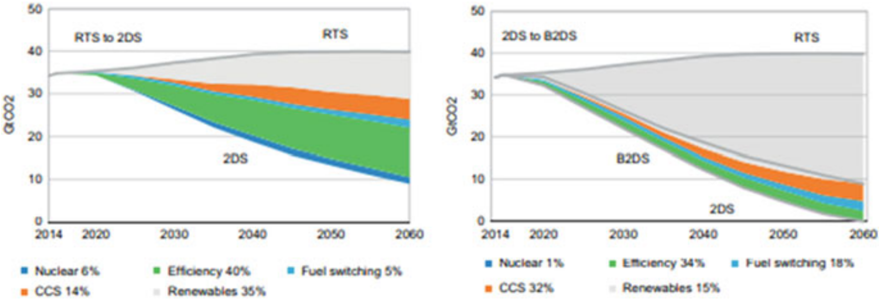

Fig. 9.6 Cumulative global CO_2 reductions in different scenarios until 2060. (*Source*: IEA 2017a. Technology Roadmap. Delivering Suitable Bioenergy. International Bioenergy Agency)

9.9 Algal Systems as Perspectives for Bioenergy

As a potential resource of biomass for multiple uses, algae have been of interest to scientists (Scarlat and Dallemand 2019). So far, around 40,000 to 100,000 algal species with varying morphological, structural, and chemical features besides different lipid, protein, and carbohydrate content have been identified. Almost one and half decade ago, algal biofuel was dubbed as third-generation biofuel, which was supposed to hold several key advantages over previous feedstock-based plant crops of first and vegetable and animal waste of second generation of biofuels (Lo 2020).

Algal biofuels are advantageous with higher biofuel yields against previous systems and the option of providing a variety of biofuels as biodiesel, butanol, and jet fuelPlus that fact that land unsuitable for food crops can be easily utilized for algal cultivation and hence removing the major concern of competition of biofuel feedstock crops with food producer crops. There are different types of algae with photoautotrophs fixing atmospheric inorganic carbon through photosynthesis and heterotrophs using organic carbon substrate as carbon source are the main types (Rocca et al. 2015). Algae are of two types—microalgae and macroalgae on the basis of their size. Algal biomass has high photosynthesis efficiency and is high yielding and also possesses the ability to grow in non-fertile soils in a variety of aquatic habitats (saline, fresh, brackish), plus the advantage of additional CO_2 capturing. Thus, using algae as an energy source is advantageous as compared to biomass crops cultivated on land. Within a biorefinery concept, algae offers extraction of variety of marketable coproducts, for example, chemicals and nutrients besides biofuel production (FAO 2009; van der Velde et al. 2017). Macroalgae, for example, green (Chlorophyta), red (Rhodophyta), and brown (Ochrophyta), depending on the species have various lipid, protein, and carbohydrate proportions and using microbiological conversion processes that can be used to produce biomethane, biobutanol, and bioethanol (Jiang et al. 2016). Asia accounts for 99% of world seaweed production of about 28 million tonnes, but that is mainly for food and food additives, pharmaceuticals, cosmetics, and the chemical industry. Algae industry is in initial growth stages in Europe and seaweed for industry use is supplied almost exclusively from harvesting (FAO 2016). Marine waters offshore are used to cultivate macroalgae, attached to specific growth structures, such as anchored networks and for onshore farming land-based farm systems have been used. Land-based farms can achieve higher productivity (up to 50 tonnes of dry matter per year) either in single cultivation farms or combined crop and aquaculture farming (FAO 2009; van der Velde et al. 2017). Algae harvesting needs various steps, including drainage and drying, in order to reduce water levels in algae from 80 to 20% and from 85 to 30%. Microalgae cultivation is mainly for food, pharmacy, cosmetics, and chemical products additives and large open ponds or lagoons are used for the process in Asia (Vigani et al. 2015; Scarlat et al. (2015)). Commercial cultures of microalgae having high-value, low-volume foods, feed and nutraceuticals are cultivated in Asia, the United States, Israel, and Australia since 1980s. These mainly include green algae (chlorophyte), blue-green algae or cyanobacteria (cyanophyta), golden brown algae (chrysophyta), and diatoms (bacillariophyta) (Rocca et al. 2015; Scarlat et al. (2015)) (Table 9.4).

9.9.1 Biology and Adaptation

Microalgae are quick growers and the oil content is high in comparison to land crops, having a maximum of 5% dry weight of soil (Chisti 2007). Microalgae gets doubled

Table 9.4 Minimum fuel selling price: Technical and economic analysis

Transformation system	Feedstock	MFSP bio-jet produced in multiple plants EUR per tonne
Hydroprocessed Easters and Fatty Acids (HEFA)	UCO	1350 (USD 1518)
Gasification through Fischer-Tropsch (FT)	Timber waste/ wheat straw	1800–2650 (USD 2204-2098)
Hydrothermal Liquefaction (HTL)	Timber waste/ wheat straw	900–1300 (USD 1460-2080)
Pyrolysis	Timber waste/ wheat straw	1300–1850 (USD 1460-2080)
Alcohol to Jet (ATJ)	Timber waste/ wheat straw	2400–3500 (USD 2700-3935)
Direct Sugars to Hydrocarbon (DSHC)	Timber waste/ wheat straw	4,80–6400 (USD 5397-7196)

Source: De Jong, S., R. Hoefnagels, A. Faaij, R. Slade, R. Mawhood, M. Junginger 2015. "The feasibility of short-term production strategies for renewable jet fuels – a comprehensive techno-economic comparison." Biofuels, Bioproducts and Biorefining, 9: 778–800

Table 9.5 Technologies: Status and estimated capital costs as aviation biofuels

Transformation system	Standing	Financial inputs-M EUR_{2013}
HEFA	Commercial	200–644 (USD 265–855)
Gasification—FT	Demonstration	327–1186 (USD 434–1575)
Pyrolysis and upgrading	Pilot/demo	156–482 (USD 207–640)
ATJ (from ethanol; excluding ethanol production)	Demo	68–72 (USD 90–96)
Advanced fermentation of sugars to hydrocarbons (farnesene)	Small commercial	292 (USD 388)
Alcoholic fermentation from farming waste (including pre-treatment, enzymatic hydrolysis)	Commercial	215–426 (USD 285–566)
Sugar extraction from farming residues (includes pre-treatment and enzymatic hydrolysis)	Commercial	206 (USD 274)

Source: De Jong, S., R. Hoefnagels, A. Faaij, R. Slade, R. Mawhood, M. Junginger 2015. "The feasibility of short-term production strategies for renewable jet fuels – a comprehensive techno-economic comparison." Biofuels, Bioproducts and Biorefining, 9: 778–800

[a] Values are based on normalized reported values from literature for 500 t of fuel/day with figures based on 2013 values

in magnitude every 24 h. This time period can decrease to three and half hours during peak growth phase (Chisti 2007). Microalgae oil content is between 20 and 50% dry weight (Table 9.5), which can reach 80% in some strains (Metting 1996; Spolaore et al. 2006).

9.9.2 Cultivation

Mostly microalgae are photoautotrophic, i.e., light and CO_2 are used as energy and carbon sources. To make minimum investment, biofuel production from algae normally uses photoautotrophic cultures. Besides photoautotrophs, algae can be heterotrophs (use organic substrates) and mixotrophs (extracting energy for growth from phototrophic and heterotrophic processes) (Mehrabadi et al. 2015; Judd et al. 2015). Mixotrophic algae are useful in low light and low nutrient environment. Heterotrophs although rich in lipids and biomass productivity, need organic carbon feed and energy, besides which they are at high risk of contagion by other organisms (Mehrabadi et al. 2015; Judd et al. 2015).

As said earlier photoautotrophic system is the preferred system of cultivation, many photoautotrophic algal systems are available (Zhiyou 2019). Suspension based open ponds and closed photo-bioreactors have been in use for the production of biofuel from algae presently. An open pond is a series of ponds in open, whereas a photo-bioreactor is an advanced reactor, adaptable to both indoor and outdoor conditions. Although inexpensive and giving the ease to operate Open Racing Ponds (ORP) have several disadvantages of low potency, below power usage of light, high water evaporation losses and excessive contagion. In comparison PBRs giving high productivity and low contamination potential are closed and controlled systems, but their dependence on complex designs and requirement of high investment and maintenance costs add to disadvantages (Scarlat and Dallemand 2019). Harvesting of microalgae also requires a series of steps like thickening (flocculation), removal, and dewatering to increase algal mass concentration from 0.1 to 1025% and drying after that. The current ORP and PBR plans are small-scale experiments and their production on large scale and commercialization are quite far away (FAO 2009; Vigani et al. 2015; Milledge and Heaven 2013; Rocca et al. 2015) (Table 9.6).

Table 9.6 Microalgae oil content

Microalga	Oil content (% dry weight)
Botryococcus braunii	25–75
Chlorella spp.	28–32
Crypthecodinium spp.	20
Cylindrotheca spp.	16–37
Nitzschia spp.	45–47
Phaeodactylum spp.	20–30
Tetraselmis suecica	15–23

Source: https://farm-energy.extension.org/algae-for-biofuel-production/

9.9.3 Future

Bioenergy, biofuel production from algal biomass faces many challenges in the form of identification of best suited species, conditions of growth, output, and chemical configurations, identifying and developing energy efficient and cost-efficient biofuel pathways to name a few (IEA 2017c). Besides this, many parameters like methods of reaping, ensiling suitability of algae spp. used, carbon balance along with cost of the seaweed and finished product price-bioenergy/biofuel need to be adequately assessed (IEA 2017c). The overall cultivation and processing of algae for bioenergy/biofuel is a challenging affair and demands a combination of breakthrough in almost all aspects of cultivation. In particular, developing collection and dewatering technology is a prime question and a crucial point in terms of energy demands and price given the microscopic dimension and characteristics of microalgae strains. Production of bioenergy from algae is not expected to be financially possible in coming future as algal biomass production costs are still the most important obstacle to trade viability in algal-focused production (IEA 2017c). The complete working demonstration of pre-treatment/hydrolysis processes (e.g., ultrasound and enzyme utilization), extraction of oil, biological, chemical (anaerobic, fermenting), and thermochemical conversion technologies (Pyrolysis, HTL) are also required (Rocca et al. 2015; Scarlat et al. (2015)).

Current requirement is the development of harvesting and conversion of large-scale growing systems, along with developing economic methods for offshore and farm/land pond farming, improving yields, and proving economic output. Proper marine farming technologies and infrastructure for macroalgae cultivation should be developed on the basis of existing macroalgae cultivation experience in food, drug, cosmetics, and chemical additives. There have been insufficient evaluations of the available algae potential for energy production. The quantity of natural harvestable algae is still not quantified although the combination of nutrients and light for the offshore algae system can measure the ecosystems' capacity to guarantee algal growth. There is a need to understand and properly address the ecological impact of harvesting natural resources (Scarlat and Dallemand 2019). It is also doubted if it is possible to harvest algae to a scale required to produce significant amounts of bioenergy.

After fading in 2005, there is a fresh interest developed in algal biofuel in recent years (Zhiyou 2019). With a target of being able to get a commercial algal biofuel production research is being done by both educational and entrepreneurs to develop new methods for improving the overall efficiency of algal biofuel production process. These efforts can be classified as: (Zhiyou 2019).

1. Methods to increase oil concentration of current strains or looking for new options having high oil content.
2. Increased algal growth rate.
3. Development of a strong growth system for algae in any of the environments—open or enclosed.
4. Development of side products along with oil.

5. Use of algae in bioremediation.
6. Development of an efficient oil extraction method.

Genetic and metabolic engineering of algal species is one way to achieve these goals, or we can look towards developing new or improved growth technologies. Besides being used for bioenergy/biofuel production, use of algae as fertilizer and in pollution control can also be explored. Many species can be used as organic fertilizer either in raw or semi-decomposed forms (Thomas 2002). Algae can help reduce CO_2 emissions from power plants, as through photosynthetic metabolism, microalgae can purify air with efficiency.

9.10 Sustainability of Bioenergy

9.10.1 Sustainability Directives

New EU sustainability criteria for bioenergy are included in the proposal for a new directive on the promotion of renewable energy sources ([(COM (2016a, b, c) 767 final)], extends their area to include all bioenergy resources and forms for cooling, heating, and electricity generation. The criteria of sustainability for farm biomass is being organized to decrease the bureaucratic constraints; as already discussed under the CAP, the criterion of cross-compliance is removed. There is a new requirement for ensuring that the timber used in power production is adequately carbonized according to LULUCF sector rules. Forest biomass sustainability criteria aims at minimizing the possibility of unendurable logging, requiring that timber biomass both domestic and imported be subject to the following minimum requirements: (1) legitimacy of harvests, (2) afforestation, (3) security of high-value regions counting wetlands and peatlands, (4) reduce the impact of harvesting on soil and biodiversity, (5) harvest is within the capacity of forests to manufacture long-term (Scarlat and Dallemand 2019). Forest biomass must meet the following LULUCF requirements with the aim of limiting the chance of negative impacts on timberland carbon stocks (Scarlat and Dallemand 2019).

1. Country/place of biomass origin (1) is a member of Paris convention (2) submitted an NDC to the UNFCCC on agricultural, forestry, and land use (LUCF) emissions and disposal accounts (3) have a national reporting system.
2. Woodland administrative frameworks are put in to ensure the retention of stock and sink of forest carbon (Table 9.7).

Table 9.7 Policy changes by countries effecting bioenergy after 2021

Nation	Change in policy	Year of impact
Brazil	2020 electricity auctions have been postponed indefinitely	2023–2025
Chile	Auctions delayed from June 2020 to December, 2020	2024–2026
China	Subsidy free project application postponed from Feb 2020 to April 2020	2022–2023
France	Few solar PV auctions delayed by half year	2021–2022
Germany	Selection of bidders in previous auctions delayed	2022–2023
Portugal	700 MW solar PV auction delayed	2022

Adapted from: IEA (2020), Renewable energy market update, IEA, Paris https://www.iea.org/reports/renewable-energy-market-update

9.10.2 Beyond 2021

All biofuel/bioliquid and biogas plants which have fuel capacity same as or more than 0.5 MW shall be subject to sustainability and GHG criteria and to solid biomass facilities with fuel capacity equivalent to or above 20 MW. The processing of waste/leftovers as soot, wood chips, dung, black liquor, etc. is helpful in saving GHGs. For plants which have been operational since October 2015, the performance of GHG in respect of biofuels was raised to 60% and to 70% for plants which started working after January 1, 2021. Biomass-based heating/cooling and electricity (plants operational since Jan 1, 2021) are subject to an 80% saving requirement, while those plant start-ups after January 1, 2026 receive 85% saving requirement. Electricity generation in big extensive plants of equal to or more than 20 MW capacity should be through the use of highly efficient co-generation technology from biomass and must meet the criteria of longevity (sustainability) and GHG. The draught RED sets out a European Union obligation for providers of fuel to make available 6.8% share of low-emission and renewable fuels in 2030 (including renewable electricity and advanced biofuels). For iLUC issues, 7% of total energy consumed in transport by road and railways is to be limited by biofuels and bioliquids obtained from the farming (both food and feed); by 2030, this will be limited to 3.8%. For advanced biofuels, a specific, increasing submandate is introduced, which by 2030 should reach 3.6% or higher. An important step forward are the new legal sustainability requirements for all bioenergy routes. On a larger scale of an economy based on biofuels, ensuring biomass sustainability is a key issue. Energy biomass can be produced in different categories of feedstock, which can be used also for foodstuffs, feed fibers, and biomaterials. Only in respect of the use of biofuels and bioenergy have sustainability requirements been established. Similar commodities do not need to comply with those requirements with other applications that have similar environmental, social, and GHG impacts. A dual-standard policy is most likely to result in indirect movement effects between the production of biomass for bioenergy generation and food, forage, fiber, or materials of biological origin since biomass providers need to ensure sustainable production of the portion of biomass required for bioenergy (Scarlat and Dallemand 2011). It has been observed from experience that voluntary certification, aimed exclusively at forest certification, will unlikely end unsustainable timber production and use and avoid LUCs and deforestation. Consequently, sustainable biomass production and non-biomass use of GHG emission requirements should be addressed in order to prevent leakage. Further points like resources efficiency for differentiation between pathways for a variety of biomass could also be included in sustainability criteria. Global sustainability concerns, either direct or indirect can be addressed through certificates provision for the production of biomass and hence capable of achieving more efficiency (with a constant land administration standards or rules applicable to timber and farming governance practices, directives for protection of nature and environment and planning and use of land). The labeling of biobased products can play a major role by making clear information about product features and environmental effects available to customers. We need a world-wide initiative with determined participation from nations to construct a world-wide governing infrastructure based on universal accord on sustainability (Scarlat and Dallemand 2011; Pelkmans et al. 2014).

9.11 Conclusion

The problems of decreasing fossil fuels reserves and energy security, the negative effects of fossil fuel consumption and change in climate have created a modern bioenergy. Besides, climate and energy targets, bioenergy generation opens notable options for a range of social, ecological, and financial benefits (IEA 2016). Bioenergy offers good agricultural market opportunities and has the ability to foster sustainable rural development. At the same time, usage of biomass for bioenergy has environmental, social, and economic concerns. If not properly developed, bioenergy may have negative effects. The real emissions of GHGs from certain bioenergy routes, food safety, LUCs and ecological diversity, and higher contention for resources are key issues (food, forage, fiber, or materials). The discussion of biofuel longevity, food against fuel, and LUC has many times ignored possible useful results as sustainable development of suburban areas. The gains and effects of biofuels or the generation of bioenergy relies heavily on this particular context. Bioenergy alliance can generate several gains, if properly worked out and administered, with farming, hydro systems, ecological systems, well-being, and security. There must be adequate environmental and social safeguards to address certain possible negative effects. In order to make sustainable energy available and contribute to residential populations' prosperity plus GHG emission reductions, it is important to assess bioenergy on the basis of its overall achievements (Osseweijer et al. 2015; Fritsche et al. 2017).

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