Chapter 4
Integrated Approaches for Economic Sustainability of Biofuel Industries



S. Chozhavendhan, G. Karthigadevi, R. Praveen Kumar, D. Karthiga, and A. Magesh

Abstract A modern bioenergy application is a low-carbon energy source and eco-friendly in the conversion of the biomass into bioenergy. The depletion and oscillating prices of fossil fuels greenhouse effect led the researchers to reach the transition from traditional bioenergy to modern bioenergy applications. Bioenergy, especially biofuels economy, is dependent on market supply and demand. The implementation of zero-wastage liquid discharge from the bio-based industries addresses valorization of biomass effectively for the production of other high-value products. In this perspective, the integrated approaches for sustainable development and bio-economic development with the exploration of biomass for biofuel production were assessed. The integrated biorefinery aims at achieving sustainability in energy, economic and environmental aspects with the production of energy and reducing greenhouse gas emissions. This chapter focused on how the production of bioenergy and bioproducts from the biomass feedstock under biorefinery model plays an instrumental role in the development of the technological and socioeconomic aspects. Assessment of circular economy, bioeconomy under green economy with various assessment indicators led to the production of greener products and long-term sustained economic development of biofuel industries.

Keywords Biorefinery · Circular economy · Green economy · Sustainable development · Bioenergy

S. Chozhavendhan (✉)
Vivekanandha College of Engineering for Women, Tiruchengode, Tamil Nadu, India
e-mail: scv.ibt@gmail.com

G. Karthigadevi
Sri Venkateswara College of Engineering, Chennai, Tamil Nadu, India

R. Praveen Kumar
Arunai Engineering College, Tiruvannamalai, Tamil Nadu, India

D. Karthiga
V.S.B. Engineering College, Karur, Tamil Nadu, India

A. Magesh
Department of Chemical Engineering, Annamalai University, Chidambaram, Tamil Nadu, India

© The Author(s), under exclusive license to Springer Nature Singapore Pte Ltd. 2023

P. K. Ramanujam et al. (eds.), *Bioenergy*, Energy, Environment, and Sustainability,
https://doi.org/10.1007/978-981-99-3002-9_4

4.1 Introduction

The uncontrolled population growth and rapid urbanization and industrialization created an exponential demand for non-renewable energy resources (Khalil et al. 2019; Yi et al. 2018). This scenario is expected to be worse in the future since the human inhabitants are projected to increase up to 5 billion by 2050 (Abdul et al. 2018). Similarly, energy consumption is also expected to increase nearly by 50% due to the promising developing nations like India, China, Brazil and other nations. Currently, fossil fuels are commonly used fuel sources and further rising population. The depletion of fossil fuels triggers the common universal ecological issues like greenhouse gas emission and local and regional degradation of air quality. The life form of earth with health threat is persistently looked at and that led the researchers to explore novel sustainable clean energy resources (Shariat et al. 2020; Chozhavendhan et al. 2020). Non-sustainable energy sources are being substituted with 53 forms of sustainable renewable energy for human mankind such as geothermal, marine, solar, hydropower, wind, biomass-derived energies as per the global energy statistics energy book 2020 (Rincon et al. 2019). Among the various renewable source of energy derived from the biomass is considered as bioenergy that is environmentally renewable sustainable energy source which is further used to produce electricity, transportation fuel heat and other products (Karthiga Devi et al. 2019a; Vaez and Zilouei 2020). As per the global energy statistics in 2020, the utilization of renewable energy is increased around 1% when compared with the previous year. The International Energy Agency (IEA) has set a goal for biofuel to contribute 25% of worldwide transportation by 2050 (Pandey et al. 2016). Many of the energy policymakers also set a goal with the strategic expansion in green technology to maximize the utilization of renewable energy. The approach toward socioeconomic development identifying appropriate and sustainable energy sources lead to decrease the reliance on fossil fuels and take the edge off the carbon dioxide emission (Aziz and Hanafiah 2020).

4.1.1 Bioenergy

Bioenergy is a versatile renewable energy source and the oldest among all possible biomass exploitation technologies that can be converted into bioenergy. Biomass is a natural, renewable carbon source derived from either live or dead organism as chemical energy in it (Karthiga Devi et al. 2019b). Sometimes biomass can also be referred to as a wide range of energy crops, residues and other biological resources that generate diverse renewable energy. In traditional, the bioenergy implies the utilization of solid waste for the generation of heat; however, the modern bioenergy was commonly defined by three products, namely bioethanol, biodiesel and biogas. Based on the feedstock used, the biomass is transformed into gaseous energy carriers through direct combustion, thermochemical or biochemical transformation (Perna et al. 2018). Bioenergy is classified as solid bioenergy, liquid bioenergy and

gas bioenergy based on the final product. The other recovery process in addition to bioenergy production involves waste volume reduction, waste disposal management and minimizing land utilization for discarding the waste. The increased usage of bioenergy may help in stabilizing supply security and reduces the dependence on fossil fuels and decreases the levels of greenhouse gasses that reduce the dangerous atmospheric concentration and mitigating climate change (EC 2018). The conversion of biomass to bioenergy, the biomass composition varies accordingly (variation in biomass species, geographical location and crop growing condition). The lignocelluloses, forestry municipal waste, algal biomass and animal waste are generally reported as biomass (Rathankumar et al. 2020). However, introduction of the biorefinery approach helps the biomass valorization for the effective production of bioenergy and other bioproducts. Thus, it strives to reduce the waste and reuse the waste acquired after recycling for the effective production of bioenergy with zero waste liquid discharges (Taylor 2008). Food and pharmaceutical compounds, platform chemicals, polymers, biofuel and bioenergy are examples of bio-based products that can be coproduced in a multi-process industrial plant called biorefinery.

4.2 Biorefineries

Biorefineries are promising industrial system which aims at the sustainable and nifty deployment of biomass that delivers various useful bioenergy and bioproducts (Budzianowski 2017). The concept of biorefining is to increase the attention for its integral process to achieve sustainable future economy. National Renewable Energy Laboratory (NREL) states that a biorefinery is a facility that integrates the biomass conversion processes and equipment to produce fuels, power and chemicals from biomass (NREL 2015), and the International Energy Agency (IEA) states biorefinery is the sustainable processing of biomass into a spectrum of marketable products (food, feed, materials, chemicals) and energy (fuels, power, heat) (IEA 2014). The biorefinery concept emphasizes the utilization of renewable biomass for the production of bioenergy and biochemicals (Mahmoud and Shuhaimi 2013).

In general, the biorefinery approach involves a multistep process that usually involves the screening and processing of biomass as initial process. The second step comprises pretreatment and saccharification process, involving the extraction of fermentable sugar from biomass. The last and final stage involves the biological or chemical treatment of the reducing sugar for the synthesis of bioenergy products (Hazeena et al. 2019). In particular, biorefinery plays a vital role in bioeconomy in which renewable and bio-based materials replaces fossil products (Sauvee and Viaggi 2016). Biorefinery has the potential to offer sustainability and conquers several markets replacing a current fossil fuel-based industry that acts as a bridge between triple bottom line standards and adequate interaction with the complete value chain including environmental, social and economic (Budzianowski and Postawa 2016). The development of bioenergy, biorefinery and bioeconomy contributes to national socioeconomic growth.

4.3 Types of Biorefineries

The integrated biorefinery model is initiated for the effective usage of biomass including the waste or byproduct generated in various conversion pathways; it converts them in high-value products. Various feedstocks like lignocelluloses, algae, industrial waste and organic fraction of municipal waste are utilized in the biorefinery concept. The biorefineries comprise a range of transfer technologies like biological, biochemical, thermochemical process that are integrated competently to produce sustainable bio-based merchandise streams such as bioenergy, biofuels, biochemicals and more high-value bioproducts (Cherubini 2010). The biorefineries are generally distinguished into two broad groups based on biomass and chemical nature on biomass.

4.3.1 Biomass-Based Model

On the basis of the usage of biomass, it is classified further into Phase I, Phase II and Phase III biorefineries. The Phase I biorefinery utilizes a single feed to produce a single product and has fixed processing. For example, the phase I biorefineries produce bioethanol and other feed product from corn grain (Kamm and Kamm 2004). Phase II is analogous to Phase I and can produce products from the single feedstock that has more processing flexibility. The products like corn oil, ethanol and high fructose corn syrup are produced from corn. Phase III is an advanced model and uses various types of feedstock to produce numerous products employing a choice of combination technologies. This model produced high-value chemicals along with the co-production of ethanol. It follows the principle of high-value low-volume (HVLV) and low-value high-volume (LVHV) products utilizing a series of technologies. Further, Phase III is classified into four types as (i) whole crop biorefinery, (ii) green refinery, (iii) lignocelluloses biorefinery and (iv) two platform concept biorefinery.

(i) **Whole crop biorefinery** uses whole crop as a raw material to attain useful goods. Raw materials such as wheat, rye and maize are used as biomass and converted into bioenergy by various processes.
(ii) **Green biorefinery** is a multi-product system that uses green feedstock like grass, green plants. The green biomass contains nutrient-rich green juice and fiber-rich press cake. The green juice contains protein, amino acids, dyes, enzymes, etc. The press cake contains cellulose, starch, pigment and other organics which are used for chemical's production like levulinic acid and the production of synthetic fuels.
(iii) **Lignocelluloses biorefinery** feedstock consists of dry biomass as a major feedstock and would generate fuels, chemicals, biomaterials and bioenergy.

(iv) **Two platform concept biorefinery** consists of sugar and syngas platform and uses several conversion technologies to reduce the overall cost; it has more flexibility in product generation.

4.3.2 Based on the Chemical Nature of Biomass

The biorefinery models are further distinguished based on chemical nature and compositions of the feedstocks are as follows:

(i) **Triglyceride biorefinery** utilizes vegetable oil, animal fat, algal oil and waste cooking oil as a feedstock for biofuel production. The triglycerides are converted into biofuel in the presence of alcohol and catalyst via the transesterification process and produce glycerol as byproduct (Chozhavendhan et al. 2015).
(ii) **Sugar and starchy biorefinery** well-developed industrial fermentation technologies for ethanol production. The feedstocks like sugar beet, corn, maize are reduced to monomers to produce ethanol (Demirbas and Demirbas 2011).
(iii) **Lignocellulosic biorefinery** includes wood, straw, grasses, etc., to produce a broad spectrum of products by utilizing various advanced technologies.

4.4 Lignocellulosic Biorefinery

Lignocellulosic biomass is popularly known as second-generation feedstock and generally acknowledged as plant-based biomass and eliminates the potential competition with edible crops (Ma et al. 2019). Lignocelluloses generally composed of three polymers, namely cellulose (35–50 wt%), hemicelluloses (20–35 wt%) and lignin (10–25 wt%). The abundant presence of C_6 (cellulose) and C_5 (hemicelluloses) in the lignocelluloses materials made it utilized in the biorefinery industries. Lignin acts as a protective sheet and as an effective precursor for several extraction processes of C_6 and C_5 compounds to produce value-added products (Ubando et al. 2020). Lignin will also inhibit microbial growth and mask the availability of C_6 and C_5 compounds during a fermentation process. Hence, the lignin should be digested by either chemical or enzymatic hydrolysis for the effective utilization and conversion of polymeric carbon sugar into simple monomeric sugar. To capitalize on, complete utilization of lignocelluloses biomass material, numerous technologies of biorefinery concept is adopted for the generation of biofuels and multiple products with zero waste discharge. Various technologies like milling, grinding, chemical hydrolysis (acid or alkali), biological hydrolysis (enzyme or whole cell), ionic liquid extraction, ultrasonication, microwave irradiation are used for biomass decomposition (Faba et al. 2015).

For the liberation of glucose from cellulose, hemicelluloses pretreatment is carried out to release hemicelluloses from lignin and cellulose and followed by breakage of β

(1–4) glycosidic linkages from cellulose. The C_6 and C_5 compounds have numerous applications. The hydrolysis of cellulose to glucose produces ample useful products like biofuels (ethanol, butonal) and other biological products (acetic acid, succinic acid) by a microbial fermentation process. The xylose from hemicelluloses can be converted into furfural an important starting material for nylon (Kamm and Kamm 2004). Otherwise, cellulose and hemicelluloses undergo thermochemical process like pyrolysis, gasification or liquefaction for the energy products, and the waste is converted into activated carbon, biochar (Foong et al. 2020). If Lignin is isolated efficiently in an economical way, it has a significant perspective to produce a wide variety of monoaromatic hydrocarbons and restricted usage of fuel in the direct incineration process. The use of cellulose, hemicelluloses and lignin could significantly add value to the lignocelluloses refinery process.

4.5 Microalgae/Triglyceride Biorefinery

Microalgae are the simplest photosynthetic living organism in an aquatic environment and are capable of converting CO_2 and H_2O into biomass in the presence of sunlight (Ozkurt 2009; Chozhavendhan et al. 2021). The biological inert matrix for microalgal cell structure used to store high energy molecule incorporating solar energy and carbon sequestration mechanism to produce high-value products from the biomass. Algal biomass is renewable, non-toxic, cheap and generally considered as third-generation biomass for the production of carbon–neutral biofuel providing more productivity and yield when compared with lignocelluloses biomass. Various factors like light intensity, temperature, pH, nutrients, salinity influence the growth of microalgae. Microalgae are able to grow in wastewater, freshwater with various nutritional modes (Devi et al. 2013; Chandra et al. 2014). The expansion of microalgae-based biorefinery assists the high-value bioproducts production from seaweeds (Ingle et al. 2018). Various biorefinery pathways are proposed using microalgae as biomass and are converted to produce numerous value-added products like biofuels and biochemical sustainably (Chew et al. 2017). Thus, the photosynthetic organism provides a sustainable life for mankind through the development in multi-dimensions of biofuel and renewable energy province.

Biofuel production from the algae requires implementation of an enormous integrated upstream and downstream process. Introducing the integrated biorefinery conception of utilization is wastewater for the growth of algal biomass that reduces the enduring waste components; it leads to sustainable economic growth. Besides, algae produce biodiesel, bioethanol, biobutanol, biogas, biohydrogen and other bioenergy products through the process of different conversion (Wirth et al. 2018; Nagarajan et al. 2020). The biomass derived from algae is converted into biofuels via thermochemical, biochemical, transesterification and photosynthetic microbial fuel cell process. Thermochemical conversion technologies employ thermal energy and involves in the conversion of algal biomass for the synthesis of bio-oil and biochar which are further transformed into biofuels via chemical or biological routes

(Rastogi et al. 2018). In the biochemical route, enzymes are used for the hydrolysis of biomass for obtaining glucose-based carbohydrates for bioethanol production. In biochemical process, the residual biomass (deoiled cake) is subjected to anaerobic digestion for the generation of methane and biohydrogen. The extracted lipids from microalgae are converted into biodiesel via transesterification process in the presence of alcohol and catalyst; it produces more versatile glycerol as byproduct (Chozhavendhan et al. 2018). The high-value byproducts are preferred to support the main process economically.

4.5.1 Other Valuable Products from Microalgae Biorefinery

Microalgae are capable of fixing CO_2 and help to maintain the atmospheric equilibrium. They can grow in a variety of water bodies and produces numerous amounts of valuable economic compounds like pigment, lipids, protein, carbohydrates, vitamins and fine chemicals for cosmetics and pharmaceutical industries (Zhang et al. 2016). The biorefinery approaches that exploit intracellular compounds and metabolites have gained renewed interest due to their high market value (Chew et al. 2017). The multi-dimensional utilization of microalgae for the production of various products is depicted in Fig. 4.1. The photosynthetic activity of microalgae results in pigments like chlorophylls, carotenoids and phycoblins. These pigments have high nutritional and bioactive value which is used as a natural colorant in food industries. They also possess antioxidants, anti-aging anti-inflammatory properties (Begum et al. 2016). Apart from pigments, the algal biomass possesses compound like protein, vitamins and polyunsaturated fatty acids. The high concentration of protein contains all essential amino acid, and they also hold a massive amount of omega-3 fatty acids content. The presence of other intracellular compound suggests the algal biomass as a food and feed additive for human and animal. An alga in feed increases the metabolism, guts function, weight and reduces the cholesterol level. The addition of microalgae into poultry feed replaces 5–10% of conventional protein and helps to improve the quality of meat and egg without causing any negative effect (Ledda et al. 2016).

Microalgae have widely used in wastewater (agro-industrial, urban/domestic and others) treatment to remove the organic matter providing oxygen to the bacteria. The wastewater is then transformed into suitable biomass for bioenergy, bio-based product production within the economic framework (Taelman et al. 2015). The polyhydorxybutyrate (PHB) an intermediate ingredient of bioplastics falls in the category of polymer class and is produced from microalgae. The bioplastics produced from microalgae are more eco-friendly and biodegradable when compared to conventional plastics (Chozhavendhan et al. 2016a). The microalgae are used as effective biomass under an integrated biorefinery approach through techno-economic assessment and life cycle analysis. The production of low-value biofuels needs to be coupled with the production of high-value products which could make the economic sustainability of bio-based industries.

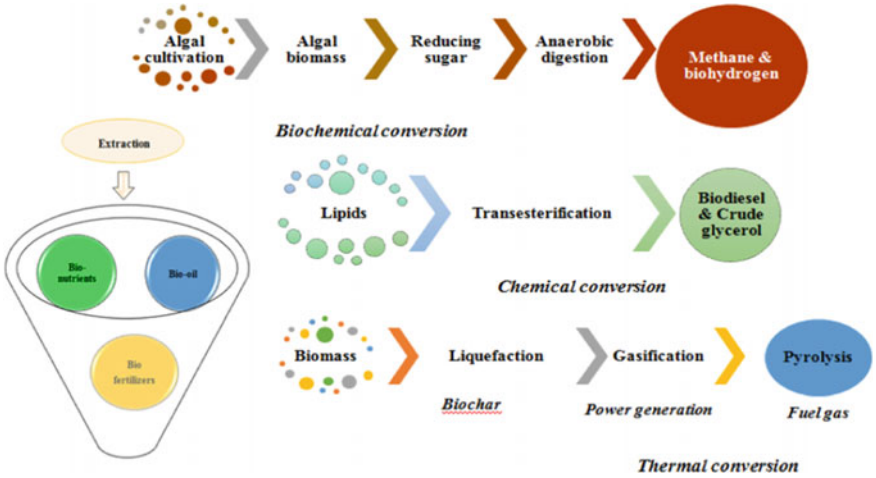


Fig. 4.1 Multi-dimensional utilization of microalgae for the production of various products

4.5.2 Utilization of Crude Glycerol for Integrated Biorefinery Concept

Transesterification of triglycerides (lipids extracted from algae) in the presence of alcohol and catalyst yields biodiesel and crude glycerol as byproduct. During the transesterification process, 10:1 ratio of biodiesel and crude glycerol are produced (Chozhavendhan et al. 2018). Crude glycerol is generally viscous, alkaline pH and consists of a copious amount of impurities like water, soap, ash and methanol. Glycerol is a versatile compound and used as a sole carbon source by many organisms for the production of high-value products like ethanol, 1,3 propanediol, succinic acid, dihydroxyacetone, acetic acid, etc. (Chozhavendhan et al. 2016b). It includes the applications such as plasticizer, lubricants in softening yarn and fabrics of textiles industries and as a major ingredient in toothpaste. Apart from this application, crude glycerol is used at low concentration for broiler and pig feed. Crude glycerol is sometimes used as an alternate for boiler fuel or thermal energy cogeneration due to its high energy content (McLea et al. 2011). Utilization of crude glycerol under integrated biorefinery concept is displayed in Fig. 4.2. The application of integrated biorefinery concepts made the biofuel industries to enjoy numerous benefits like zero liquid discharge, self-clearance, avoid the risk of contamination. The deployment of inexpensive crude glycerol from biofuel industries of microalgae provides an opportunity for the extensive production of high-value platform chemical products and thus provides a building block for biorefinery.

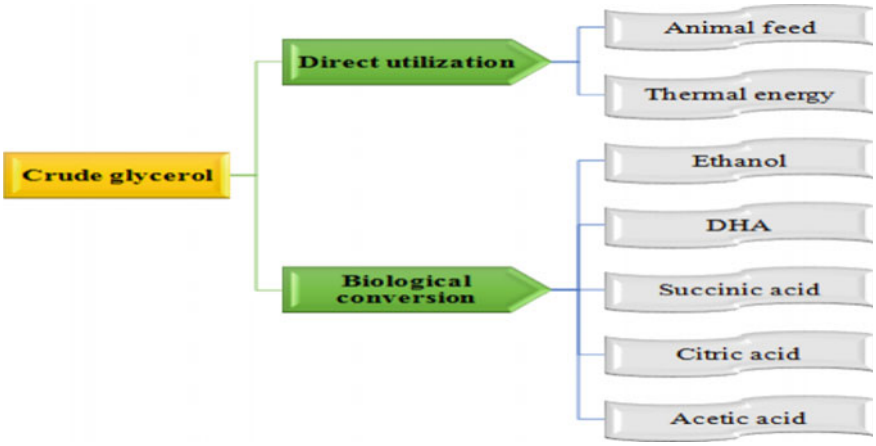


Fig. 4.2 Utilization of crude glycerol under integrated biorefinery concept

4.6 Challenges in Establishing Biofuel Industries

The main challenges involved in biofuel industries involve in the conversion of the technology from the lab level to industrial levels. Well-defined research and development set up with proper technical support shows good improvement in product separation and recovery rate (Karthiga Devi et al. 2019c). The uniformly accepted technologies across the regions of the same nation were also failed due to diverse climatic zones and produce a different quality and quantity feedstock (Mal et al. 2016). The geographic aspects of biomass also pose a vital dilemma in a regular practice of identifying the source, source collection, transport; storage of collected materials has a direct influence on effective utilization of feedstocks for the production of bioproducts. Temmes and Peck (2019) stated that still there is a colossal space between the exception and genuine recital of biofuel industries. The other major issue associated with the development of biofuel industries exacerbates the water scarcity level which put additional pressure on water demand. The demand for more lands to the non-food crops will also create a negative impact on the natural habitat, biodiversity (Nicolae et al. 2015). The increased demand for biomass and bioproducts will create a question about food security and create impacts on the prices of food materials.

The lack of proper framework and strong law enforcement on land enforcement can bring a negative impact on the environment, agriculture and forest management (Budzianowski 2017). The policy framework and incentive systems should be associated with the comprehensive scientific outcome and concerned with strong mutual relationship among stakeholders, local and national government and nongovernment agencies and private companies (Aristotle et al. 2020). The developments of techno-economic (TE) modeling enable to realize the cost-competitive for the biomass. The initiative budget planning for biofuel production and commercialization is achieved

by TE modeling through the various integrated biochemical conversion processes or catalytic conversion of biomass to bioproducts. In the end, the assessment model should try to use the real data and avoid the uncertainties or assumption data for the evaluation process of biofuel industry setup. Apart from all strong leadership, long-term consistent policies and strategies only attract investors to invest in the quite risky domain of the bioenergy sector.

4.7 Economic Development Biofuel Industries

The evolution of new ideas and innovative technologies is a great support for the market expansion of biofuel industries that lead to the satisfaction of the consumers of a growing society. Thus, the transformation of industries into more stable economically and environment is friendly (Rosales-Calderon and Arante 2019; Lourdes et al. 2021). For the economic development of biofuel industries, it is mandatory to widen the usage of renewable biomass to the core for the replacement of fossil fuels. The renewable bioresources should be cheap and available locally throughout the year to minimize the product cost. The few common feedstocks are agricultural residues and industrial waste and organic fractions of municipal waste. These effective feedstocks are converted into biofuel and other value-added platforms chemicals to enhance economic feasibility and sustainability via integrated biorefinery concepts (Zhao and Liu 2019).

According to Hilbert (2015), economic sustainable development of biofuel industries is achieved via the integrated biorefinery concept. In his study on the biomass conversion, pyramid model, bioenergy and biofuel are placed in the base of the pyramid. This indicates the bioenergies and biofuels are produced from the biomass in large volume, and hence, low-value products are placed at the base of the pyramid. Moving up to the pyramid, the human and animal feed are placed as it requires the few treatment technologies in process input to give the nutritious product (p63—Chiesa and Gnansounou 2011). Higher in the pyramid has the biomaterials especially some of the biopharmaceuticals, biocosmetics and bionutrients has high market value and relatively produced in low quantities. This product requires unique and advanced technologies and thus increases the value of the product (Shikinaka et al. 2020). Finally, the promising high-value bioproducts like phytochemicals, nutraceutics and plant and animal extracts are placed at the pyramid top because of their supply and demand in the market. Pyramid biomass conversion into energy and bio-based products are depicted in Fig. 4.3. The specific nature of biomass and the specific facilities and their performance with ample amalgamation help to develop a high-value chain including, environmental and social dimensions (Budzianowski and Postawa 2016). The high-volume biofuels and low-volume bioproducts are economically transported for longer distances with comfortable prices. Hence, integrated understanding of innovations in industrial sectors are considered right from the flow of biomass to bioproducts production processes for modern bioeconomy development aspirations (Rama Mohan 2016).

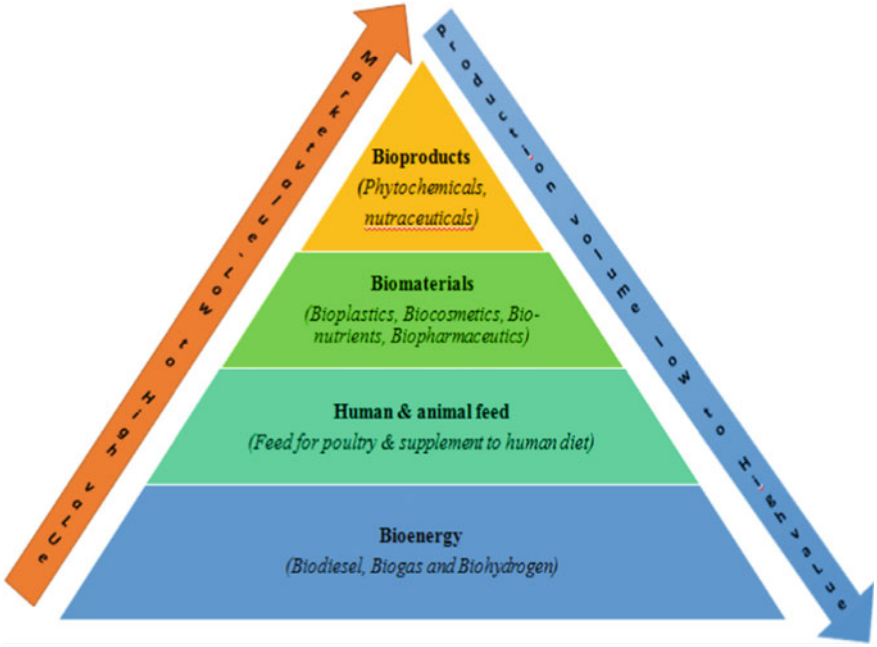


Fig. 4.3 Pyramid biomass conversion into energy and bio-based products

For the zero waste initiative and to maximize the economic status of bioenergy sector, the byproducts produced from the primary processes are processed further to produce other value-added products and finally using them as manure for the least value product (Dahiya et al. 2018). To improve the economic viability and effective utilization of resource in biofuel industries are achieved adopting various approaches as follows.

(i) Selection of renewable biomass for high-value product generation
(ii) Production of HVLV products
(iii) Business development of biorefineries
(iv) Employing integrated biorefineries concepts for the production high-value bioproducts simultaneously with biofuels.

4.8 Circular Economy, Bioeconomy and Green Economy

The integrated biorefinery has the competence to integrate a variety of biomass transformation process to produce power, fuels and chemicals. The refineries models are shaped by the following input features like feedstock, process technologies, intermediate/value-added co-product and the desired high-value products (Luguel 2011). In the past two decades, sustainability played a key role in political agendas

and has strong impacts on ecological, economical and societal developmental goals (D'Amato et al. 2017). Sustainability concepts are projected in various aspects, and among them, three concepts are mainstreamed globally such as circular economy (CE), Bioeconomy (BE) and green economy (GE) (Murray et al. 2017). The three concepts are aimed at transforming the existing conventional economy into a more sustainable one (Szekacs 2017). CE, BE and GE as input and interconnected concepts in sustainable development are discussed in Table 4.1.

The CE or Circular Economy Biorefinery is very clear and has gained evident attention of all researchers throughout the globe by the number of papers published in the journal in the last two decades. The CE professed the concept of sustainability on transforming the industrial waste discharge as a feedstock/substrate for another value-added product production. This concept can enhance the consumption of resource and recovery with the goal of zero waste discharge (Stegmann et al.

Table 4.1 CE, BE and GE input and interconnected emerging concepts in sustainable development

Sustainable concepts/ indicators	Circular economy	Bio-economy	Green economy
Definition	Circularity of economy practices to a sustainable production system	Achieving sustainable bioeconomy development by bio-based substituent as industrial input and output	Nature-based solution for green economy progress
Environmental	Recycling/ reuse, efficiency, industrial cooperation	Provides biosecurity by utilizing renewable resources	Conservation of land, water biodiversity and food security
Social	Sustainable economic development and utilization	Rural policies and application in health sciences	Sustainable development—Green investments and development in education, employment and tourism
Industrial	Production of multiple products with zero waste discharge	Production of eco-friendly products	Reduction in carbon emission, GHG and increasing green investment
Overlaps	Industrial efficiency with BE and resource efficiency with GE	Industrial efficiency with CE and territorial resilience with GE	Resource efficiency with CE and territorial resilience with BE
Divergence	Resource centered	Resource centered	Conservation and restoration of a natural process

2020). CE is predominately known for how resources are used. After analyzing, various definitions for CE Kirchherr et al. (2017) reported that CE was adequately linked with reducing, reusing and recycling actions. CE is considered to be opposite to linear economy executing zero effect to the environment and also address the social and environmental concerns (Giampietro 2019). CE, for instance, reduces the waste and utilizes the renewable resource via chemical, biological or biochemical process for the production of value-added chemicals. Besides, CE provides a remedy for improving the economic position of the bio-based industries with closed loops. The benefit of the CE includes improved usage of resource and eco-efficiency, lower GHG emissions and valorization of agro-based waste materials. Hence, CE show signs on developing sustainable and greener environment potentially (Venkata Mohan et al. 2016).

The bioeconomy (BC) has gained its attention in later 2000. BE promises to reduce climate change and creates the economic upliftment of rural people providing the employment. BE is defined as the utilization of different biological renewable sources for food, feed, biochemicals and bioenergies production. The BE biorefineries have received more attention because of its approach toward waste management. Bioprocessing waste resources and conversion of biomass to produce biomaterials and biofuels could prevent the depletion of natural resources and fossil fuels (Mishra et al. 2019). BE brings the industries close to the environment by encouraging the utilization of renewable resources and quickly reaches the limit of sustainability. Uniting the CE and BE was termed as Circular Bioeconomic (CBE). CBE adopts the closed framework of CE and applies the concept of sustainability and economic viability utilizing the raw materials for high-value products. Introducing the circular bioeconomy into biorefinery facilitates the efficient utilization of waste resources and produces multiple value-added products and biofuels. The main concept of CBE is eliminating the usage of toxic chemicals and utilization of renewable energy through proper design in all steps in the business model (Carus and Dammer 2018). CE and BE are involved in mobilizing the resources and increases yield through recycling and reducing the end uses of renewable sources. In general, BE principles will transform the chemical industries into bio-based industries with the available feedstock from agricultural biomass. The feedstocks are readily converted into biofuels and chemicals which generate chain connectivity between the biomass production site and industrial center. The innovation and market expansion in turn will create a new challenge for thrust for the researchers and offers new potential opportunities to the manufacturing industries.

Green economy includes independent development, sustainable, resilient and low carbon development and preservation of biodiversity for the next generation (Cooper et al. 2019). The concept of GE is to bring together environmental conservation and eradicate poverty with the establishment of many policy agendas linked to weak sustainability in terms of energy and pollution. The GE concepts and frameworks must coexist, overlaps, divergences, limits with other sustainable concepts like CE and BE (D'Amato et al. 2017). GE includes the idea of utilizing the renewable biomass resource efficiently and results in envision green growth investing to promote restoration, conservation and sustainable management. United National

Environmental Protection (UNEP) stated that GE outcomes in improving human comfort by appreciable plummeting the environmental risk and ecological shortage (Georgeson et al. 2017). CE and BE are resource-oriented and whereas GE refers to a range of biodiversity processes and encourages conservation and restoration of natural process at the regional level developing eco-tourism, education and enterprises. For the measurement of GE toward sustainability of biofuel industries, many indicators are required. Most prominently, the economic measurement of GE has the potential to measure the green transformation and its activities toward the environment–economy–society interactions. Loiseau et al. (2016) reported that CE and BE are allied to GE. All three concepts largely clinch the scheme of current economic improvement into a sustainable one.

4.9 Sustainability Assessment of Biorefineries

Biorefineries need to be stable, cheap source or no cost biomass residues for the production of various bioenergies and bioproducts to meet the existing demands without increasing the greenhouse gas emission, impact on biodiversity, water usage and land utilization (Van Dael et al. 2014). A lot of attempts are made to create a uniform technology that should stimulate regional and rural economic development but were failed due to various climatic zones and quantity and quality diversification in biomass feedstock materials (Richa et al. 2020). The greatest challenges in the sustainability of the biorefineries are applied for the integration of the technologies and to inflate the horizons to integrate the bioprocesses and biological systems across the waste management system. Biomass valorization helps to enrich the value of biomass wherein the utilization of biomass in biorefinery is limited by the quality and quantity of biomass and conversion technologies (Cardoen et al. 2015). Further, Liu et al. (2019) suggested high conversion yields with minimum cost for the co-product production, and separations are the fundamental requisite for the accomplishment of biomass valorization in biorefineries at the techno-economic level. Similarly, Hemalatha et al. (2019) proposed that the processing and circular cascading of valorization of biomass at all stages is achieved by self-sustainable biorefinery model. Understanding the innovation and bringing together different technologies to fit in will bring favorable economic growth and sustainable industrial development. For the sustainable development of bio-based industries and the modern drive bioeconomy objective, it is forced to understand the value of materials and waste resource management (Rama Mohan 2016).

The performance of biorefinery was earlier evaluated by economic value and now exclusively analyzed with either economic or environmental or with the combination of both. Nowadays, the sustainability of biorefineries is assessed by the triple bottom line framework consists of environmental, economic and social aspects (Tuazon et al. 2013). Many research and suggestion revealed the sustainability concern of incorporated biorefineries with their strength and weakness following the triple bottom line. The outcomes exposed that biofuel production preferentially reduced GHG emission

and has favorable impact on the rural community on by providing job. However, operational and investment cost is the major barrier along with the biomass availability (Liew et al. 2014). Hence, multi-product integrated biorefineries can adapt immediately to the market fluctuations and are more stable when compared to single product biorefineries (Cheali et al. 2015). In the biorefinery concept, the biofuel industries/bio-based industries can enjoy numerous benefits like zero liquid discharge, eliminating the risk of contamination and allowing the industries to produce a gamut of high-value platform chemicals (Chozhavendhan et al. 2019).

4.10 Verification of Sustainable Development

The development and utilization of biofuels reduce environmental pollution and significant improvement in the economic level. Bioenergy provides the energy security and economic development of the country. The National Renewable Energy Laboratory (NREL), USA, stated that the usage of biodiesel instead of fossil fuels helps to reduce 90% of the air pollution. They also stated that blending 20% of biodiesel with fossil fuel helps to reduce 20–40% of air pollution (Repo et al. 2015). Every nation in the world has its own agencies and policy decision for the sustainable development of bioenergy and bioeconomy. Renewable Energy Directive (RED) was established in 2009 with the target of contributing 20% of renewable energy to the total energy supply in the European Union with at least 10% in the transportation sector. In 2018, the revised Renewable Energy Directive (RED II) sets the target of using 32% renewable bioenergy to the total energy consumption with 14% in the transportation sector before 2030 (EU 2018). RED II proposes an effectual sustainability criterion to respond to the sustainability concerns and provides good recommendations based on the practices of policymakers, certification bodies, voluntary scheme owners and auditors involved in the sustainable development criteria of bioenergy for the long-term process (Mai-Moulin et al. 2021). The Government of India also continuously launches many programs like nationalized Policy on Biofuels, New National Biogas and Organic Manure Program (NMBOMP) to resolves future energy challenges.

Dissemination of bioenergy resources, biomass, technologies and policies connected to biofuels in government web portal are very useful to educate the stakeholders of bioenergy sector. Some indicators are used to examine various overlaps between the environmental and socioeconomic impacts for the sustainable development (Diaz-Chavez 2011). The indicators are used to evaluate local and national concert and progress in the public issue, revenue, education, health and well-being. The indicators are useful to monitor the development over time; progress is in standard level or per certification scheme, with qualitative and quantitative data, etc. The first indicator is basic information which provides backdrop information of the preferred studies and next the socioeconomic indicators provide influences raised by the bioenergy crop production and various chain processes to produce biofuel. The

final environmental indicators refer to the biodiversity impacts concerned with the socioeconomic uniqueness of the community.

The Round table on Sustainable Biomaterials expands its compass in 2013 to cover biomaterials (liquid biofuel and biomass for biogas generation) and bio-based compounds (biochemicals). The sustainability requirement should address all criteria for diverse uses of biomass which includes foodstuff, feed, chemical, biofuels, bioenergy and biomaterials (RSB 2014). The sustainability standard is achieved through enforcement of strong sustainability criteria, strict requirements in structure and mode of operation in certification systems and verification practices (Nicolae and Jean-Francois 2011).

4.11 Socioeconomic Framework Analysis

The socioeconomic analysis (SEA) is liable and more complicated for observing and measuring as it requires more survey, intensive studies, exclusive and time-consuming process. The socioeconomic analysis is examined to investigate a meticulous social phenomenon of the entire society. The SEA studies exploit to assess the local, regional and national allegation in state of affairs to economic indicators like employment and pecuniary gains. Over the period of time, the development has made in the qualitative and quantitative analysis within the standard or certification scheme on the supply chain) from the feedstock production to conversion into bioproducts. Biomass utilization, biofuel technologies and their market vary considerably from country to country. This analysis clearly illustrates that the use of biofuel is significantly increased its share in the total energy supply. In nature, the socioeconomic impacts on biofuel will be diverse because of technology, confined economic structure and social profile and production processes. Hasenheit et al. (2016) also stated that the socioeconomic analysis is not only restricted to the production of biofuel but also extend the farms where the feedstocks are cultivated. The biomass production from agricultural waste provides economic autonomy and additional activity to the local farmers which help them for sustainable development both economically and energetically (Edouard and Donatien 2018).

The evaluation of socioeconomic analysis of the rural or regional biorefinery is also integrated with the life cycle assessment (LCA) of the feedstock. The LCA mainly comprises life cycle inventory, impact assessment, goal, scope and validation of outcomes. LCA method employs for determining environmental issues in the product life cycle including the assessment of feedstocks and its challenges in the analysis (Nizami et al. 2017). Thus, aims at in identifying the opportunities for the improvement of biofuel industries under the integrated biorefinery concept. The makeover of the existing industrial production process into a bio-based product with the help of biotechnological techniques and integrated biorefinery concept will widen the market of bio-based product. The growth and economic development of biofuel industries depend on the capacity how much it replaces the fossil fuels and

the competitive product cost of bioproducts with lesser GHG emissions. The potential socioeconomic benefits by the development of biofuel industries are numerous and few of them are listed as follows: (i) development of rural infrastructure, (ii) creating new employment opportunities, (iii) expansion of rural market, (iv) increase in productivity, (v) eradication of poverty and (vi) improvement in skill acquisition and literacy level.

4.12 Conclusion

The depletion of fossil fuels and the detrimental effects like increasing GHG, environmental pollution made the researchers to work on renewable and sustainable energy. Bioenergy provides the energy security and economic development of the country. Production of numerous products from cheap, renewable biomass leads to the development of a holistic biorefinery model. Implementation of waste to energy in biorefinery concept introduces zero liquid discharge, which avoids the risk of environmental pollution and legal sanctions. For the sustainable development of bioenergy in general, 5% of biomass should yield 1.5 fold increases in profitability. The integrated biorefinery model should extend the maximum utilization of biomass from any source and produces numerous products like biofuel, bioethanol, biogas and other valuable biochemical products used in various food, cosmetics and pharmaceutical industries. The development and implementation of various strategic plan help to proliferate the economic sustainable development of biofuel industries under integrated biorefinery roof. The bioeconomy development represents reducing GHD footprints and resolves the environmental problems and food security. The integration of CBE in biorefinery addresses several environmental problems and constitutes economic sustainable development with high energy restoration. For the long-term sustainable development of biofuel, biorefineries should possess a good infrastructure and adopt various technologies for source segregation, process development and production of multiple value-added products from single biomass.

References

Abdul R, Pepijn P, Arun KV, Ming Z, Rafael L (2018) A review on sustainable microalgae based biofuel and bioenergy production: recent developments. J Clean Prod 181:42–59

Aristotle TU, Charles BF, Wei-Hsin C (2020) Biorefineries in circular bioeconomy: a comprehensive review. Bioresource Technol 299:122585

Aziz NIHA, Hanafiah MM (2020) Life cycle analysis of biogas production from anaerobic digestion of palm oil mill effluent. Renew Energ 145:847–857

Begum H, Yusoff FM, Banerjee S, Khatoon H, Shariff M (2016) Availability and utilization of pigments from microalgae. Crit Rev Food Sci Nutr 56(13):2209–2222

Budzianowski WM (2017) High-value low-volume bioproducts coupled to bioenergies with potential to enhance business development of sustainable biorefineries. Renew Sust Energ Rev 70:793–804

Budzianowski WM, Postawa K (2016) Total chain integration of sustainable biorefinery systems. Appl Energ 184:1432–1446

Cardoen D, Joshi P, Diels L, Sarma PM, Pant D (2015) Agriculture biomass in India: Part 1. Estimation and characterization. Resour Conserv Recycl 102:39–48

Carus M, Dammer L (2018) The circular bioeconomy—concepts, opportunities, and 501 limitations. Ind Biotechnol 14:83–91

Chandra R, Rohit MV, Swamy YV, Venkata Mohan S (2014) Regulatory function of organic carbon supplementation on biodiesel production during growth and nutrient stress phases of mixotrophic microalgae cultivation. Bioresour Technol 165:279–287

Cheali P, Posada JA, Gernaey KV, Sin G (2015) Upgrading of lignocellulosic biorefinery to value-added chemicals: sustainability and economics of bioethanol-derivatives. Biomass Bioenerg 75:282–300

Cherubini F (2010) The biorefinery concept: using biomass instead of oil for producing energy and chemicals. Energ Convers Manage 51(7):1412–1421

Chew KW, Yap JY, Show PL, Suan NH, Jua JC, Ling TC et al (2017) Microalgae biorefinery: high value products perspectives. Bioresour Technol 229:53–62

Chiesa S, Gnansounou E (2011) Protein extraction from biomass in a bioethanol refinery—possible dietary applications: use as animal feed and potential extension to human consumption. Bioresour Technol 102:427–436

Chozhavendhan S, Praveen Kumar R, Sivagami U, Gomathi R, Vinoth Arulraj J, Jayakumar M (2015) Glycerol as a promising substrate for the microbial production of ethanol. Asian J Microbiol Biotech Env Sc 17:79–83

Chozhavendhan S, Praveen Kumar R, Kirubalini G, Jayakumar M (2016a) Bio-conversion of glycerol into commercial production of 1, 3 propanediol—a review. J Environ Biol 37:1539–1543

Chozhavendhan S, Praveen Kumar R, Bharathiraja B, Jayakumar M (2016b) Recent progress on transforming crude glycerol into high value chemicals: a critical review. Biofuels 10(3):309–314

Chozhavendhan S, Praveen Kumar R, Elavazhagan S, Barathiraja B, Jayakumar M, Sunita JV (2018) Utilization of crude glycerol from biodiesel industry for the production of value-added bioproducts, Chap. 4. In: Waste to wealth, energy, environment, and sustainability, pp 65–82

Chozhavendhan S, Karthiga Devi G, Bharathiraja B, Praveen Kumar R, Elavazhagan S (2019) Assessment of crude glycerol utilization for sustainable development of biorefineries, Chap. 9. In: Refining biomass residues for sustainable energy and bioproducts, pp 195–212

Chozhavendhan S, Rajamehala M, Karthigadevi G, Praveenkumar R, Bharathiraja B (2020) A review on feedstock, pretreatment methods, influencing factors, production and purification processes of bio-hydrogen production. Case Stud Chem Environ Eng 2:100038

Chozhavendhan S, Rajamehala M, Karthigadevi G, Praveenkumar R, Bharathiraja B, Jayakumar M (2021) Application of nanotechnology for the sustainable development of algal biofuel industries, Chap. 19. In: Nanomaterials: application in biofuels and bioenergy production systems, pp 401–410

Cooper A, Mukonza C, Fisher E, Mulugetta Y, Gebreeyesus M, Onuoha M (2019) Mapping academic literature on governing inclusive green growth in Africa: geographical biases and topical gaps. Sustainability 12:1956

Dahiya S, Kumar AN, Shanthi Sravan J, Chatterjee S, Sarkar O, Mohan SV (2018) Food waste biorefinery: sustainable strategy for circular bioeconomy. Bioresour Technol 248:2–12

D'Amato D, Droste N, Allen B, Kettunen M, Lähtinen K, Korhonen J, Leskinen P et al (2017) Green, circular, bio economy: a comparative analysis of 430 sustainability avenues. J Clean Prod 168:716–734

Demirbas A, Demirbas MF (2011) Importance of algae oil as a source of biodiesel. Energ Convers Manage 52:163–170

Devi MP, Swamy Y, Venkata Mohan S (2013) Nutritional mode influences lipid accumulation in microalgae with the function of carbon sequestration and nutrient supplementation. Bioresour Technol 142:278–286

Diaz-Chavez R (2011) Assessing biofuels: aiming for sustainable development or complying with the market? Energ Policy 39:5763–5769

EC. A. (2018) Clean planet for all: a European long-term strategic vision for a prosperous, modern, competitive and climate, November

Edouard M, Donatien N (2018) Biomass resources assessment and bioenergy generation for a clean and sustainable development in Cameroon. Biomass Bioenerg 118:16–23

European Parliament and Council (2018) Regulation (EU) 2018/of the European Parliament and of the Council of 30 May 2018 on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework, and amending Regulation (EU), pp 1–25

Faba L, Diaz E, Ordonez S (2015) Recent developments on the catalytic technologies for the transformation of biomass into biofuels: a patent survey. Renew Sustain Energ Rev 51:273–287

Foong SY, Liew RK, Yang Y, Cheng YW, Yek PNY, Mahari WAW, Lee XY, Han CS, Vo DVN, Van Le Q (2020) Valorization of biomass waste to engineered activated biochar by microwave pyrolysis: progress, challenges, and future directions. Chem Eng J 389:124401

Georgeson L, Maslin M, Poessinouw M (2017) The global green economy: a review of concepts, definitions, measurement methodologies and their interactions. Geo Geogr Environ 4:00036

Giampietro M (2019) On the circular bioeconomy and decoupling: implications for sustainable growth. Ecol Econ 162:143–156

Hasenheit M, Gerdes H, Kiresiewa Z, Beekman V (2016) Summary report on the social, economic and environmental impacts of the bioeconomy. Promoting stakeholder engagement and public awareness for a participative governance of the European bioeconomy

Hazeena SH, Salini CN, Sindhu R, Pandey A, Binod P (2019) Simultaneous saccharification and fermentation of oil palm front for the production of 2,3-butanediol. Bioresour Technol 278:145–149

Hemalatha M, Sarkar O, Venkata Mohan S (2019) Self-sustained Azolla-Biorefinery platform for valorization of various biobased products with circular-cascading design strategy. Chem Eng J 373:1042–1053

Hilbert J (2015) Socio-economic impacts on bioenergy production. INTA 2015, 2017. Available at: https://inta.gob.ar/sites/default/files/script-tmp-inta-_impactos_socioeconomicos-en-produccion-de-bioen.pdf

IEA (International Energy Agency) (2014) Bio-based chemicals. Value added products from biorefineries. IEA Bioenergy Task 42 Biorefining. IEA, Paris

Ingle K, Vitkin E, Robin A, Yakhini Z, Mishori D, Golberg A (2018) Macroalgae biorefinery from *Kappaphycus alvarezii*: conversion modeling and performance prediction for India and Philippines as examples. Bioenerg Res 11(1):22–32

Kamm B, Kamm M (2004) Principles of biorefinery. Appl Microbiol Biotechnol 64:137–145

Karthiga Devi G, Chozhavendhan S, Bharathiraja B (2019a) Thermochemical conversion: bio-oil and syngas production, Chap. 9. In: Prospects of renewable bioprocessing in future energy systems, biofuel and biorefinery technologies, pp 251–267

Karthiga Devi G, Chozhavendhan S, Jayamuthunagai J, Bharathiraja B, Praveenkumar R (2019b) Conversion of biomass to methanol and ethanol, Chap. 4. In: Horizons in bioprocess engineering, pp 61–73

Karthiga Devi G, Vignesh K, Chozhavendhan S (2019c) Effective utilization of sugarcane trash for energy production, Chap. 12. In: Refining biomass residues for sustainable energy and bioproducts, pp 259–272

Khalil M, Berawi MA, Heryanto R, Rizalie A (2019) Waste to energy technology: the potential of sustainable biogas production from animal waste in Indonesia. Renew Sust Energ Rev 105:323–331

Kirchherr J, Reike D, Hekkert M (2017) Conceptualizing the circular economy: an analysis of definitions. Resour Conserv Recycl 127:221–232
Ledda C, Andrea S, Barbara S, Mara R, Francisco G, Acien F, Fabrizio A (2016) Integration of microalgae production with anaerobic digestion of dairy cattle manure: an overall mass and energy balance of the process. J Clean Prod 112:103–112
Liew WH, Hassim MH, Ng DKS (2014) Review of evolution, technology and sustainability assessments of biofuel production. J Clean Prod 71:11–29
Liu ZH, Le RK, Kosa M, Yang B, Yuan J, Ragauskas AJ (2019) Identifying and creating pathways to improve biological lignin valorization. Renew Sust Energ Rev 105:349–362
Loiseau E, Saikku L, Antikainen R, Droste N, Hansjurgens B, Pitkanen K et al (2016) Green economy and related concepts. J Clean Prod 139:361–371
Lourdes MQE, Andrea CL, Barry G (2021) Second generation biorefining in Ecuador: circular bioeconomy, zero waste technology, environment and sustainable development: the nexus. J Bioresour Bioprod. https://doi.org/10.1016/j.jobab.2021.01.004
Luguel C (2011) Joint European Biorefinery Vision for 2030. Star-COLIBRI
Ma J, Shi S, Jia X, Xia F, Ma H, Gao J, Xu J (2019) Advances in catalytic conversion of lignocellulose to chemicals and liquid fuels. J Energ Chem 36:74–86
Mahmoud A, Shuhaimi M (2013) Systematic methodology for optimal enterprise network 459 design between bio-refinery and petroleum refinery for the production of transportation 460 fuels. Energy 59:224–232
Mai-Moulin T, Hoefnagels R, Grundmann R, Junginger R (2021) Effective sustainability criteria for bioenergy: towards the implementation of the European renewable directive II. Renew Sust Energ Rev 138:110645
Mal R, Prasad R, Vijay VK (2016) Multi-functionality clean biomass cookstove for off-grid areas. Process Saf Environ Prot 104:85–94
McLea L, Ball MEE, Kilpatrick D, Elliott C (2011) The effect of glycerol inclusion on broiler performance and nutrient digestibility. Br Poult Sci 52:368–375
Mishra S, Roy M, Mohanty K (2019) Microalgal bioenergy production under zero-waste biorefinery approach: recent advances and future perspectives. Bioresour Technol 292:122008
Murray A, Skene K, Haynes K (2017) The circular economy: an interdisciplinary exploration of the concept and application in a global context. J Bus Ethics 140(3):369–380
Nagarajan D, Chang JS, Lee DJ (2020) Pretreatment of microalgal biomass for efficient biohydrogen production—recent insights and future perspectives. Bioresour Technol 302:122871
Nicolae S, Jean-Francois D (2011) Recent developments of biofuels/bioenergy sustainability certification: a global overview. Energ Policy 39:1630–1646
Nicolae S, Jean FD, Fabio MF, Viorel N (2015) The role of biomass and bioenergy in a future bioeconomy: policies and facts. Environ Dev 15:3–34
Nizami AS, Rehan M, Waqas M, Naqvi M, Ouda OKM, Shahzad K et al (2017) Waste biorefineries: enabling circular economies in developing countries. Bioresour Technol 241:1101–1117
NREL (National Renewable Energy Laboratory (2015). What is a biorefinery? http://www.nrel.gov/biomass/biorefinery.html. Accessed 2015–12
Ozkurt I (2009) Qualifying of safflower and algae for energy. Energ Educ Sci Technol Part A 23:145–151
Pandey VC, Bajpai O, Singh N (2016) Energy crops in sustainable phytoremediation. Renew Sust Energ Rev 54:58–73
Perna A, Minutillo M, Lavadera AL, Jannelli E (2018) Combining plasma gasification and solid oxide cell technologies in advanced power plants for waste to energy and electric energy storage applications. Waste Manag 73:424–438
Rama Mohan S (2016) Strategy and design of innovation policy roadmapping for a waste biorefinery. Bioresour Technol 215:76–83
Rastogi RP, Pandey A, Larroche C, Madamwar D (2018) Algal green energy—R&D and technological perspectives for biodiesel production. Renew Sustain Energ Rev 82:2946–2969

Rathankumar AK, Ravindran S, Saikia K, Arvind V, Batista-Garcia RA, Folch-Mallol JL, Kumar VV (2020) Simultaneous pretreatment and saccharification process for fermentable sugars production from casuarina equisetifolia biomass using transgenic *Trichoderma atroviride*. J Air Waste Manag Assoc 70:1244–1251

Repo A, Ahtikoski A, Liski J (2015) Cost of turning forest residue bioenergy to carbon neutral. Forest Policy Econ 57:12–21

Richa K, Ashutosh V, Har MS, Vinayak VP, Tyagi VV, Yadav BC, Veeramuthu A, Singh DP (2020) Assessment of Indian bioenergy policy for sustainable environment and its impact for rural India: strategic implementation and challenges. Environ Technol Innov 20:101078

Rincon L, Puri M, Kojakovic A, Maltsoglou I (2019) The contribution of sustainable bioenergy to renewable electricity generation in Turkey: evidence based policy from an integrated energy and agriculture approach. Energ Policy 130:69–88

Rosales-Calderon O, Arante V (2019) A review on commercial-scale high-value products that can be produced alongside cellulosic ethanol. Biotechnol Biofuels 12:1–58

RSB (2014) Roundtable on Sustainable Biomaterials (RSB). http://rsb.org/

Sauvee L, Viaggi D (2016) Biorefineries in the bio-based economy: opportunities and challenges for economic research. Bio-Based Appl Econ 5:1–4

Shariat Panahi HK, Dehhaghi M, Aghbashlo M, Karimi K, Tabatabae M (2020) Conversion of residues from agro-food industry into bioethanol in Iran: an undervalued biofuel additive to phase out MTBE in gasoline. Renew Energ 145:699–710

Shikinaka K, Nakamura M, Navarro RR, Otsuka Y (2020) Functional materials from plant biomass obtained by simultaneous enzymatic saccharification and communication. Trends Glycosci Glycotechnol 32:63–76

Stegmann P, Londo M, Junginger M (2020) The circular bioeconomy: its elements and role in European bioeconomy clusters. Resour Conserv Recycl X 6:100029

Szekacs A (2017) Environmental and ecological aspects in the overall assessment of bioeconomy. J Agric Environ Ethics 30:153–170

Taelman SE, Meester SD, Dijk WV, Silva VD, Dewulf J (2015) Environmental sustainability analysis of a protein-rich live stock feed ingredient in The Netherlands: micro-algae production versus soy bean import. Resour Conserv Recycl 101:61–72

Taylor G (2008) Biofuels and the biorefinery concept. Energ Policy 36:4406–4409

Temmes A, Peck P (2019) Do forest biorefineries fit with working principles of a circular bioeconomy? A case of Finnish and Swedish initiatives. In: Forest policy and economics, pp 101896–101896

Tuazon D, Corder G, McLellan B (2013) Sustainable development: a review of theoretical contributions. Int J Sustain Future Human Sec 1(1):40–48

Ubando AT, Felix CB, Chen W-H (2020) Biorefineries in circular bioeconomy: A 499 comprehensive review. Bioresour Technol 299:122585

Vaez E, Zilouei H (2020) Towards the development of biofuel production from paper mill effluent. Renew Energ 146:1408–1415

Van Dael M, Márquez N, Reumerman P, Pelkmans L, Kuppens T, Van Passel S (2014) Development and techno-economic evaluation of a biorefinery based on biomass (waste) streams–case study in the Netherlands. Biofuels Bioprod Biorefin 8(5):635–644

Venkata Mohan S, Nikhil GN, Chiranjeevi P, Nagendranatha Reddy C, Rohit MV, Kumar AN, Sarkar O (2016) Waste biorefinery models towards sustainable circular bioeconomy: critical review and future perspectives. Bioresour Technol 215:2–12

Wirth R, Lakatos G, Bojti T, Maroti G, Bagi Z, Rakhely G et al (2018) Anaerobic gaseous biofuel production using microalgal biomass—a review. Anaerobe 52:1–8

Yi H, Jiang M, Huang D, Zeng G, Lai C, Qin L et al (2018) Advanced photocatalytic Fenton-like process over biomimetic hemin-Bi_2WO_6 with enhanced pH. J Taiwan Inst Chem Eng 93:184–192

Zhang TY, Hong YH, Yin HW, Lin LZ, Xue QX, Xiao XW et al (2016) Promising solutions to solve the bottle-necks in the large-scale cultivation of microalgae for biomass/bioenergy production. Renew Sustain Energ Rev 60:602–1614

Zhao XB, Liu DH (2019) Multi-products co-production improves the economic feasibility of cellulosic ethanol: a case of Formiline pretreatment-based biorefining. Appl Energ 250:229–244