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Review

Biofuel production for circular bioeconomy: Present scenario and future scope

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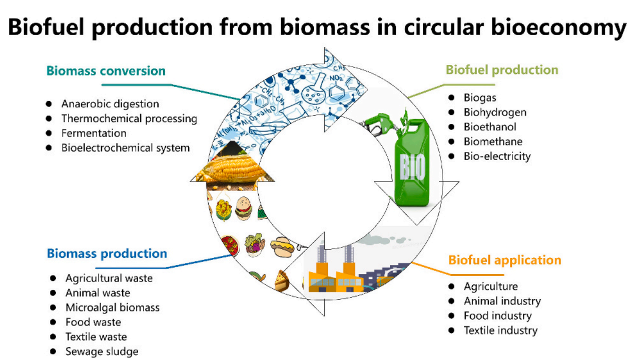
HIGHLIGHTS

- Conversion of biomass into biofuel can contribute to low-carbon lifestyle.
- Biofuel production promotes bioeconomy and enhances sustainable waste management.
- Machine learning can predict the biofuel production process for future optimization.
- Integration approaches facilitate the biofuel production towards bioeconomy.

GRAPHICAL ABSTRACT



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ABSTRACT

In recent years, biofuel production has attracted considerable attention, especially given the increasing worldwide demand for energy and emissions of greenhouse gases that threaten this planet. In this case, one possible solution is to convert biomass into green and sustainable biofuel, which can enhance the bioeconomy and contribute to sustainable economic development goals. Due to being in large quantities and containing high organic content, various biomass sources such as food waste, textile waste, microalgal waste, agricultural waste and sewage sludge have gained significant attention for biofuel production. Also, biofuel production technologies, including thermochemical processing, anaerobic digestion, fermentation and bioelectrochemical systems, have been extensively reported, which can achieve waste valorization through producing biofuels and re-utilizing wastes. Nevertheless, the commercial feasibility of biofuel production is still being determined, and it

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is unclear whether biofuel can compete equally with other existing fuels in the market. The concept of a circular economy in biofuel production can promote the environmentally friendly and sustainable valorization of biomass waste. This review comprehensively discusses the state-of-the-art production of biofuel from various biomass sources and the bioeconomy perspectives associated with it. Biofuel production is evaluated within the framework of the bioeconomy. Further perspectives on possible integration approaches to maximizing waste utilization for biofuel production are discussed, and what this could mean for the circular economy. More research related to pretreatment and machine learning of biofuel production should be conducted to optimize the biofuel production process, increase the biofuel yield and make the biofuel prices competitive.

Abbreviations

AD	anaerobic digestion
ANN	artificial neural network
ARIMA	auto-regressive integrated moving average
BES	bioelectrochemical system
BOA	bayesian optimization algorithm
DF	dark fermentation
FAO	Food and Agriculture Organization
FW	food waste
GA	genetic algorithms
GHG	greenhouse gas
GoBiGas	Gothenburg Biogas Gasification project
KNN	K-Nearest neighbors
MEC	microbial electrolysis cell
MFC	microbial fuel cell
ML	machine learning
PEM	proton exchange membrane
PF	photo fermentation
PM	particulate matter
PV/T	photovoltaic/thermal
RF	random forest
SCG	spent coffee grounds
SE	steam explosion
SVM	naive bayes, support vector machine
VFA	volatile fatty acid
VS	volatile solid
VOC	volatile organic compound
WoS	Web of Science

1. Introduction

Currently, human society's sustainable development is threatened by energy shortages, food scarcity, climate change and air pollution, in which recovery and reuse of resources is a possible solution to these challenges. Fossil fuels and their derivatives are the main source for energy production and have been for centuries, but their continued use may result in serious environmental issues including global warming, and they are finite materials that are unrenewable. It was reported that bio-materials including terrestrial plants, algae and organic substances can be converted into biofuels (Arpia et al., 2021), so they become a form of bio-energy that is environmentally friendly or 'green' energy through biochemical and thermochemical technologies (Das et al., 2020b). In this case, the issues associated with conventional energy production can be mitigated, such as emissions of greenhouse gases. According to the production sources, the biofuels could be categorized into four main categories. The first-generation biofuels are food-based sources, in which the competition with food may be a critical problem for the application of food-based biofuels. Crop residues, forest, animal wastes and wood could be used to extract the second-generation biofuels (i.e., biohydrogen, biodiesel, biobutanol and bioethanol), in which the by-products could be reused as fertilizer (Rabbani et al., 2024). Besides, algae-based biofuels that have higher productivity per unit area than the other biofuel are deemed as the third-generation biofuels while genetically modified algae is the fourth-generation biofuel, which is still under the study (Kumar et al., 2020). Ale et al. (2019) argued that the first and second generations of biofuels are mostly used whilst the other two generations are still being developed and researched.

Durable biofuels must be developed without sacrificing performance to obtain sustainable circular biofuel production and carbon neutrality. With expanding research outputs, various technologies for generating carbon-neutral biofuels have been widely developed (Stolz et al., 2022). The thermochemical method, anaerobic digestion (AD), fermentation and bioelectrochemical system (BES) have been considered one of the promising latterly proposed alternative energy conversion systems, which produce biofuel through active microorganisms or chemical transformation. A literature review was conducted to explore previous works on biofuel production from biomass using available bibliometric tools. The core collection of Clarivate's Web of Science (WoS) was investigated for all entries in the literature on the topic of "(TS=(biofuel AND production)) AND ((LA==("ENGLISH")) AND (DT==('REVIEW ARTICLE')))" during the last ten years (from 2014 to 01-01 to 2023-12-31), which was conducted on 8th April 2024 with 8363 returned and 378 related to bioeconomy. It could be seen that significant scientific progress in understanding the biofuel production process has been made from those previous investigations, in which the current development of converting biomass into biofuel has been summarized well, as well as their challenges and the future research direction in the aspects of sources and technology (Bhujbal et al., 2022; Pugazhendhi et al., 2020). Even though the techno-economic evaluation of biofuel production is studied in some papers, which is essential for policymakers and our societies to recognize the economic viability and significance of biofuel production in a circular bioeconomic model, such publications mainly focus on the biofuel production of specific biomass and pay low attention to the production technologies from the point of the circular economy. Therefore, a comprehensive review and summary of biofuel production's financial viability under a circular economy are desirable.

A literature review was conducted to explore previous works on biofuel production from biomass using available bibliometric tools. The core collection of Clarivate's Web of Science (WoS) was investigated for all entries in the literature on the topic of "(TS=(biofuel AND production)) AND ((LA==("ENGLISH")) AND (DT==('REVIEW ARTICLE')))" during the last ten years (from 2014 to 01-01 to 2023-12-31), which was conducted on 8th April 2024 with 8363 returned and 378 related to bioeconomy. It could be seen that significant scientific progress in understanding the biofuel production process has been made from those previous investigations, in which the current development of converting biomass into biofuel has been summarized well, as well as their challenges and the future research direction in the aspects of sources and technology (Bhujbal et al., 2022; Pugazhendhi et al., 2020). Even though the techno-economic evaluation of biofuel production is studied in some papers, which is essential for policymakers and our societies to

recognize the economic viability and significance of biofuel production in a circular bioeconomic model, such publications mainly focus on the biofuel production of specific biomass and pay low attention to the production technologies from the point of the circular economy. Therefore, a comprehensive review and summary of biofuel production's financial viability under a circular economy are desirable.

The current economic evaluation of various biofuel production technologies is provided in the present review. Besides, the principles of biofuel production are briefly introduced under the content that biofuel production is a part of circular bioeconomy. The technical hurdles and further direction of biofuel production are discussed to make them more economically feasible in a circular bioeconomy.

2. Types of biomass source

The bio-economy seeks to tackle social challenges such as food security, biodiversity loss, unprecedented waste generation, climate change, fossil-fuel resource dependence and natural resources scarcity through bio-based conversion technologies. It means changing natural resources into value-added products in a sustainable way (Goswami et al., 2022). Kaszycki et al. (2021) believed that the bioeconomy can promote the reuse of all so-called 'waste' materials by using sustainable clean technologies to realize 'zero waste emissions', so that waste management is put to good use. In framing the bioeconomy, waste biomass is identified as a source for high value-added products generation as depicted in Table 1.

2.1. Food waste

Food waste (FW) is derived from various sources, such as restaurants and commercial and household kitchens. FW has many sources, such as bread waste, corncob residues, kitchen waste and cheese whey (Wu et al., 2023). The bioconversion of food waste to biofuel (e.g., biodiesel and biogas) includes AD and fermentation. Due to incompetent processing and drying, poor storage facilities and inadequate infrastructure, approximately 35 % of food is wasted worldwide, according to the United Nations Food and Agriculture Organization (FAO). It was reported that the United States has an FW of about 187 kg/per capita, followed by 182 kg/ per capita in Japan and 164 kg/per capita in South Africa because of the increased population (Hafid et al., 2022). FWs can not only result in a loss of valuable nutrients but also pollute the environment, including increased greenhouse gas (GHG) emissions. The main organic fractions contained in FW include fibers, lipids, proteins and carbohydrate polymers (starch, cellulose and hemicellulose) (Sindhu et al., 2019). Besides, high calorific value and moisture content (70–80 % (*w*/w)) are also the main characteristics of FW, which has a pH range of 4–6. Therefore, employing traditional technologies such as landfills and incineration is not wise for FW's decomposition and valorization. In the present scenario, the bioconversion of FW into biofuels such as biodiesel and bioethanol is incredibly significant to achieve downstream value-added products, which also works out the energy shortage and food waste disposal (Ashine et al., 2023).

Table 1
Summary of current conversion of biomass to biofuel.

Biomass	Conversion technology	Biofuel production	Reference
Food waste	• Hydrolysis • Fermentation • Transesterification • Enzymatic saccharification	• Biohydrogen • Biodiesel • Biobutanol • Bioethanol	Qin et al. (2021); Hafid et al. (2022)
Textile waste	• Pyrolysis • Saccharification & fermentation • Anaerobic digestion	• Bio-oil • Bioethanol • Biogas	Lu et al. (2023); Petek and Marinšek Logar (2021)
Microalgal biomass	• Fermentation • Anaerobic digestion	• Biohydrogen • Biodiesel • Bioethanol • Biogas	Satpati et al. (2023); de Mendonça et al. (2022)
Animal waste	• Anaerobic digestion • Extraction • Hydrolysis/ fermentation & saccharification • Transesterification • thermo-chemical processes	• Biogas • Biodiesel • Bioethanol • Biochar • Bio-oil	Azadbakht et al. (2023); Jung et al. (2021)
Agricultural waste	• Hydrolysis • Fermentation • Anaerobic digestion	• Bioethanol • Biohydrogen • Biomethane	Ge et al. (2022); Song et al. (2020)

2.2. Textile waste

There are over 60 million tons textile waste that is annually produced in spite of 32 % being recovered (Nikolakopoulos, 2019), in which this number is increased because of 'fast fashion' culture of buy-and-throwaway at present. Textile waste includes cotton, polyester fiber and wool, in which its sustainable management is required to overcome the contamination of soil and groundwater by heavy metals, especially given over 69 % of textile waste ends up in landfill. In this scenario, the total natural fibers produced in the textile wastes contain approximately 85 % of the waste cotton textiles (Cui et al., 2018). The conversion of textile waste to bio-oil can be achieved using pyrolysis, where heavy metals in textile wastes can be used as a catalyst for the bioconversion process. Zhao et al. (2022) converted the waste cotton textiles into biochar and biocrude at 240–340 °C through hydrothermal treatment, where the maximum yield of biocrude was 23.3 %, being achieved at 320 °C for 60 min. The conversion of textile wastes to biofuel may be challenged by the highly compact and crystalline structure of cotton, in which the low bioconversion yield and rate would be obtained. For this reason, alkaline chemicals such as Na_2CO_3 and NaOH can mix with textile wastes to enhance the cotton-based waste textiles' digestibility, for which high yield of biogas or bioethanol would be obtained through further treatment (Cho et al., 2023). However, excessive use of alkaline chemicals may result in the need for neutralization and corrosion problems.

2.3. Microalgal biomass

Microalgae biomass is involved in the third generation of biofuel production and its cultivation is beneficial for progress being made in sustainable bioenergy production, especially given its easy extraction procedures, huge biomass productivity and easy extraction procedures and increased carbon-dioxide fixing capacity (Ray et al., 2022). It was reported that the microalgal biomass can serve to produce biofuels through different conversion pathways (thermochemical, chemical and biochemical methods), such as biohydrogen, biogas, biobutanol, bioethanol and biodiesel (Almomani et al., 2023). Adeniyi et al. (2018) demonstrated that microalgal biodiesel production was reported to be 2.5-times as energy-intensive as conventional diesel and such a production process is more financially and environmentally, which can be a viable alternative to conventional diesel production. Apart from this, microalgae biomass can be exploited to produce biohydrogen while the influencing factors include nitrogen oxides, carbon dioxide, sulfur dioxide, carbon-monoxide, heavy metals, water, oxygen, hydrocarbons, salinity, light and nutrients available for the microalgal growth (Bhatia et al., 2023).

For microalgae production, autotrophic and heterotrophic cultivation can be adopted. Compared to the autotrophic production of microalgae, heterotrophic production enhances the cell concentrations as well as growth performance (Ruiz et al., 2022). However, such production may need an additional carbon source and thus curtail the pigment and protein contents. Consequently, the biomass market value is reduced. For this reason, Fernández et al. (2021) believed additional carbon sources may greatly decrease the sustainability of the whole production process. In the autotrophic production of microalgae, inorganic carbon sources and necessary nutrients are needed as well as light which serves as the energy source. The microalgae production is greatly shaped by the light and nutrient input. In this scenario, it is essential to cultivate the microalgae in a system that minimizes the energy used for microalgal production and harvesting/processing and maximizes the sunlight used by the microalgae. Apart from this, the production of microalgal biomass requires a lot of phosphorous, nitrogen and carbon which can be recovered from wastewater. Consequently, the effects of microalgal production on the state of the environment can be minimized.

2.4. Animal waste

Wastes derived from various animals including pigeons, rabbits, ducks, chickens, beef, sheep and pigs can annually generate approximately 9597.4 Mm^3 of biogas through the process of AD (Khalil et al., 2019). In this scenario, livestock manures contain various chemical constituents can be converted into a variety of biofuels. Biogas production from animal waste is influenced by factors such as type of animal waste, pH, reactor configuration and temperature while the age and size of animals may also influence biogas production (Azadbakht et al., 2023). In addition to biogas, digestate is achieved during the biofuel production, which can be set aside for agriculture (Sharma et al., 2023b). In rural areas and remote sites, biofuel converted by the animal waste is a primary fuel. This is because the application of fossil-based fuels is subjected to the challenges of infrastructure installation and costs of fuel transportation (Jung et al., 2021), especially given the fact that fossil-based fuels are not readily available in such areas. It was reported recently that dried manure is utilized by over 2 billion people as their source of heat (Guo et al., 2020). From the study of Azadbakht et al. (2021), it was shown that 20,322.79 million m^3 of biogas can be generated using livestock waste in the slaughterhouse sector in Iran. Similarly, Safieddin Ardebili (2020) also demonstrated that an average of 2265.99 million m^3 of biogas can be annually produced in the poultry sector in the same country.

2.5. Agricultural residues

Agricultural residues can be categorized into process-based residues (husk) and field-based (straw) which are generally left over in huge amounts each year and up being burnt or destroyed. Reportedly, agricultural residues can be utilized to produce 5.5 billion-L bioethanol (Gnansounou et al., 2020). The selection of agricultural residue for biofuel production is guided by the production parameters, costs, availability and sources of agricultural residue. It is remiss to ignore agricultural residues for biofuel production because these materials have significant reuse potential. For example, apple waste can be utilized to produce bio-hydrogen due to its being rich in sucrose, malic acid, glucose, succinate and acetic acid (Qin et al., 2021). Bioethanol can be generated by the carrot discard through fermentation using a mixture of enzymes of Cellic CTec2 and Viscozyme L (López-Linares et al., 2023). Microbes undergo saccharification to produce bioethanol from high sugar-content residues such as molasses, potato mash and potato peels (Rajaeifar et al., 2019). Moreover, the seeds of peach and non-edible parts of pomegranate fruit are high potential sources of bioethanol production whilst grape pomace and orange residues favor high bioethanol production because they contain rich phenol and oil, respectively (El-Shamy and Farag, 2021; Jiménez-Castro et al., 2020; Kazemi Shariat Panahi et al., 2020). Apart from this, some crop residues such as barley residues and wheat residues can be employed for generating high-level bioethanol (Ambaye et al., 2021); for instance, 205 billion L-bioethanol is achieved via using 667.6 million t-rice straw sources in Asia.

2.6. Sewage sludge

As a by-product of wastewater treatment plants, sewage sludge has the potential to substitute fossil fuels as a maintainable and renewable feedstock for energy production. The quantity of sewage sludge is around 1–2 % of the volume of treated wastewater, where its main components include dead and living microorganisms (e.g., pathogens), toxic contaminants (e.g., heavy metals), organic matters (e.g., human waste) and water (98–97 %). In the past, various techniques were applied to stabilize sewage sludge to eliminate the contaminants from sludge, which mitigates the potential threat of sewage sludge to the environment and humans. In this scenario, sludge treatment may contribute to 40 % emission of GHGs derived from wastewater treatment plants (Gherghel et al., 2019) and occupy approximately 50 % of the total operation costs of the plants (Collivignarelli et al., 2015). Therefore, biofuel production from sewage sludge seems to be one of the sustainable and available methods for sewage management. Various processes and methods, including microbial fuel cells (MFCs), AD and pyrolysis, have been studied to use sewage sludge for biofuel production (Mahmoudi et al., 2024). The generation of sewage sludge has enlarged dramatically in recent years; for example, the amount of sewage sludge in China exceeded 60 million tons (based on 80 % water content) in 2022, while it was reported that the global average daily sludge production per capita is 35–85 g of dry solids (Werle and Sobek, 2019). Arelli et al. (2021) found the methane yield could reach 0.42 L CH_4/(g VS reduced) at thermophilic temperature while applying AD for sewage sludge treatment.

3. Principles of biofuel production technologies

3.1. Thermochemical processing

The thermochemical process involves cost-intensive design set-ups, and required here are energy input, high pressure and temperature (Dastyar et al., 2019) (Fig. 1).

Gasification and pyrolysis are the most common thermochemical technologies for the generation of energy products by controlling oxidation or heating (Wang et al., 2021). In the thermochemical process, the bonds between biomass are broken up to drive the conversion of biomass into biochar, bio-oil and syngas, which can be further transformed into synthetic biodiesel, biohydrogen and bio-alcohols (methanol and ethanol). Gasification can convert the biomass into syngas containing H_2 and CH_4 by partial oxidation, in which the process has the advantage of high energy utilization efficiency and low CO_2 emissions (Caldeira et al., 2020). Yu et al. (2020) note that the conversion of pruned apple branches with 1.0–2.8 mm particle size to hydrogen-rich syngas can be achieved using gasification at 0.25 g/min water flow and 850 °C reaction temperature. Some researchers believed that such hydrogen-rich syngas is a viable alternative to methane (CH_4) produced by methanogenic bacteria (Awasthi et al., 2020). Moreover, seaweed as the substrate can be employed to produce hydrogen-rich gas through gasification (Ruiz et al., 2020). However, the gasification process of biomass waste may be influenced by particle size and reaction temperature (Gnansounou et al., 2020). In the pyrolysis process, the biomass can be converted into biogas, bio-oil and biochar in the absence of oxygen, where the product yield in the pyrolysis process is highly influenced by the process parameters such as residence time and heating rate (Zhang et al., 2021). In their work, Situmorang et al. (2019) found that fast pyrolysis contributes to higher power capacity while treating apple tree stem via pyrolysis. In addition to bio-hydrogen, the pyrolysis of biomass waste can achieve other valuable metabolites such as bioenergy derived from the pyrolysis process (Ravindran et al., 2021).

3.2. Anaerobic digestion

AD can be employed to generate biogas consisting of H_2O, CH_4 and

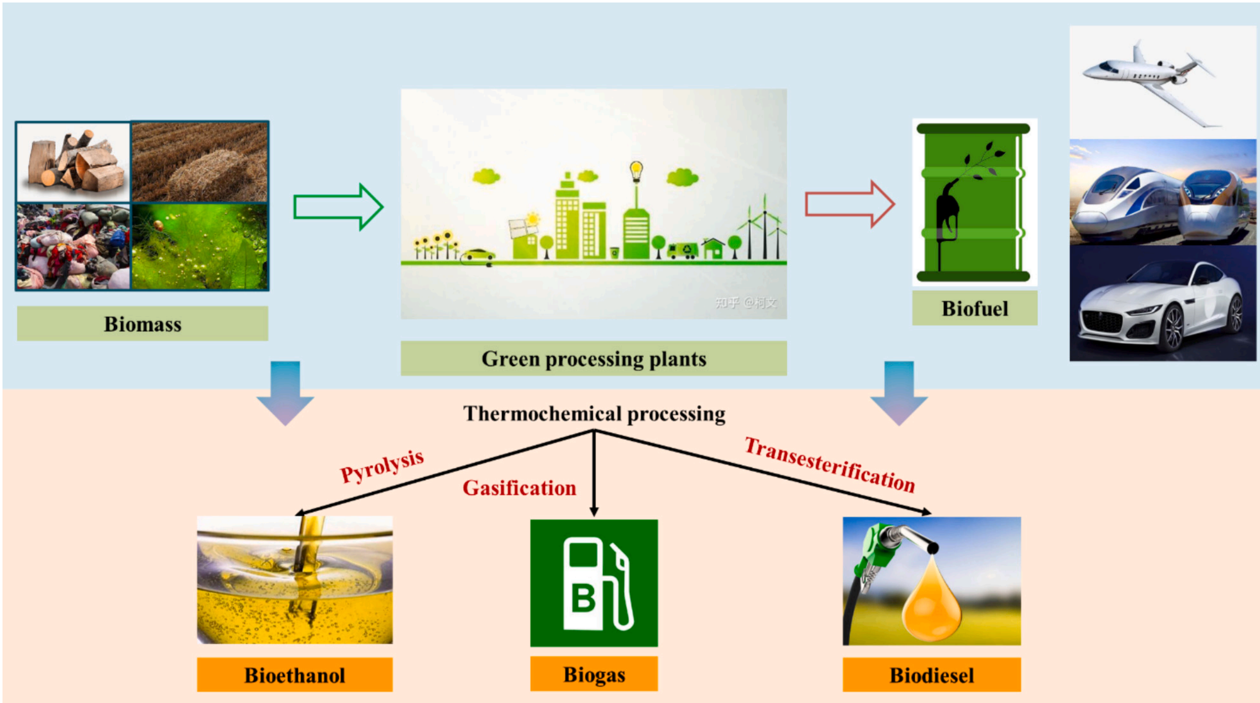

Fig. 1. Biofuel production by thermochemical processing.

CO_2, which ensures waste stabilization (Singh et al., 2023). In the AD process, organics can be anaerobically degraded into simple substances which are further transformed into biogas and other gases such as hydrogen sulfide and ammonia through microbial activity. It is well known that the AD process has four stages (Kaur et al., 2020), and the desired pH values of methanogenesis, acetogenesis and hydrolysis are in the 6.5–7.5, 6.0–7.0 and 6.0 ranges, respectively (Charalambous et al., 2020). The CO_2, alcohols and volatile fatty acids (VFA) in the AD process are firstly released by enzymatic hydrolysis products through acidogenic bacteria (*Salmonella, Bacillus, Escherichia coli, Streptococcus* and *Lactobacillus*) (Chettri et al., 2023). Subsequently, alcohols and fatty acids are transformed into CO_2, hydrogen and acetate via acetogenic bacteria (*Syntrobacter, Clostridium, Syntrophus* and *Syntrophomonas*) during the acetogenesis stage (Wu et al., 2021; Xu et al., 2019). Methanogenic Archaea (*Methanobacterium formicicum, Methanosarcina barkeri* and *Methanosarcina frisius*) employ the products of acetogenesis serving as a substrate for the methanogenesis process. The production of methane can be achieved using methanol, acetate and CO_2 and hydrogen as the substrate through methanogenic bacteria. However, methanogenesis is problematic in biomethane production since the growth rates of sensitive methanogenic bacteria are rather slow (Wang et al., 2021). Apart from this, biomass can also mix with various substances such as manures for enhanced biogas generation through the AD process. For example, different agricultural wastes can mix with human faeces in rural areas to achieve effective and promising resource recovery through the AD process. The co-digestion of peanut straw and human faeces could obtain the maximum cumulative methane yield of 688 mL/g·volatile solid (VS), higher than the sole digestion of peanut straw (531.2 mL/g·VS) and human faeces (341 mL/g·VS) (Liu et al., 2024).

3.3. Fermentation

The fermentation process can utilize the oxidation of organic waste materials (e.g., carbohydrates and proteins) via various microorganisms for energy production, which is affected by the isolated enzymes considered catalysts and applied microorganism producers (Nirmala et al., 2023). According to the microorganism features, the fermentation can be classified into dark fermentation (DF) and photo fermentation (PF). In the DF process, both [NiFe]-hydrogenases and [FeFe]-hydrogenases are responsible for producing hydrogen, which is the most common type of hydrogenase (Osman et al., 2023). Moreover, various factors such as microbial population, operational parameters (e.g., pH and temperature), reactor types and feedstock types may affect the DF performance for hydrogen output (Wang et al., 2020).

In the DF process, anaerobic enterobacteria (*Rahnella aquatilis*, *Bacillus* sp., *Clostridium butyricum* and *Escherichia coli*) can cooperate to produce carboxylic acids such as lactic and acetic acid and alcohols in the absence of light (Ortigueira et al., 2019; Park et al., 2021). Further disproportionation of formic acid can generate CO_2 and hydrogen (Viasus et al., 2019). The operation of membrane-associated or soluble enzymes hydrogenases may determine the production and metabolism of hydrogen within the bacteria, in which the reversible redox conversion of protons to hydrogen is catalyzed (Min Woon et al., 2023).

In addition, photosynthetic bacteria such as purple non-sulfur bacteria (PNSB, *Rhodopseudomonas palustris*, *Rhodobium marinum*, *Rhodobacter capsulatus* and *Rhodobacter sphaeroides*) contribute to the bio-H_2 generation in the presence of carbon sources and light in the absence of nitrogen and oxygen (Yang et al., 2023), in which organic acids including malic acid, lactic acid, propionic acid, butyric acid and acetic acid can be oxidized by PF bacteria to produce H_2. Nitrogenase, as it is called, can contribute to hydrogen output in PF, in which the process's energy conversion is highly influenced by light efficiency. In this scenario, light wavelength and intensity are significant to determine the PF performance, so the design and operation of PF reactors may be more complicated when compared to DF reactors.

3.4. Bioelectrochemical system

MFC and microbial electrolysis cells (MECs) are the most studied BESs, in which MFC can transform chemical energy stored in organic materials into bio-electrical energy through microbes (Priya et al., 2022) (Fig. 2). At the anode chamber, microorganisms anaerobically reduce the organics to produce electrons and protons. After that, the terminal electron acceptor at the cathode compartment accepts the electrons,

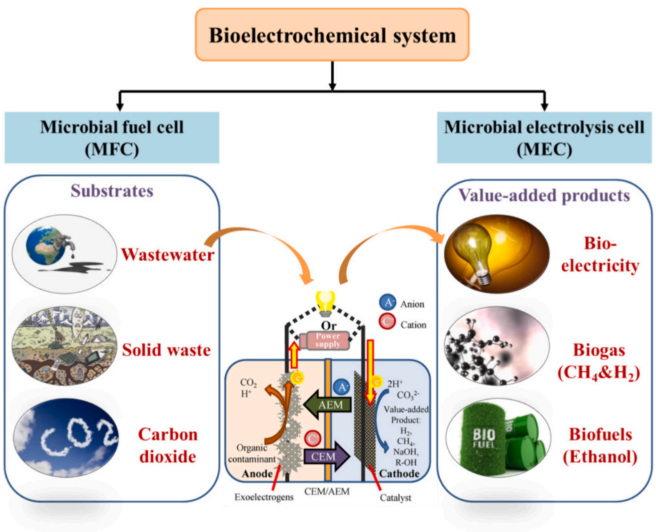

Fig. 2. Biofuel production via BESs (modified from Lu et al. (2015)).

which are transferred by the external circuit to complete the electrical circuit and thus produce electricity (Xu et al., 2023). The low voltage output and extraction of useable power may still be the biggest challenges for the commercial uptake of MFCs. For this reason, several efforts have been made to enhance the power output of MFCs, such as the connection of several MFCs in series and modifications of electrode materials (Huang et al., 2021; Olabi et al., 2020). Furthermore, energy harvesting systems can improve the performance of MFCs by ensuring a proper design to minimize the losses and number of components. Lu et al. (2019) reported that energy harvesting systems can increase the power output by up to 240 %. Another problem in commercializing MFCs is the complete utilization of substrate by bacterial species (Gebreslassie et al., 2021), in which power generation may be stopped after a specific time interval. Yaqoob et al. (2021) proposed that integrating plants with MFCs may be a significant alternative since the plants can provide a continuous and sustainable supply of root exudates and rhizodeposits as substrate at the anode region.

Besides, MEC technology could be utilized for biohydrogen production by integrating electrochemistry with bacterial metabolisms (Nirmala et al., 2023). The mechanism of MEC for hydrogen production is similar to electricity generation via MFC, in which an external power supply is provided for the proton reduction in the cathode chamber. The improvement in hydrogen generation could be obtained by modification of the anode surface, such as chemically modified three-dimensional graphite granule anode. Besides, excessive electricity losses and low proton switch may also seriously affect the MEC performance (Bora et al., 2022), which may be attributed to proton exchange membrane (PEMs) which are used to separate anode and cathode chambers in MEC technology (Shabani et al., 2020). For this reason, membrane-less MEC has been preferred in recent years to eliminate the adverse effects derived from the PEM.

3.5. *Integrated technology*

Some biomass conversion technologies have limitations and are relatively time-consuming, leading to low yield and efficiency (Qin et al., 2021). For example, new products would be produced while extracting hemicellulosic fraction from apple orchard by oligosaccharides or polysaccharides, but the full-scale applications are subject to low yield (Awasthi et al., 2019). Therefore, further efforts should be made to enhance the productivity of biomass conversion technology. Apart from this, integrating biofuel production technologies can make the entire process more economical and practical (Tao et al., 2022), as shown in Table 2. For example, MECs can be integrated with dark

Table 2
Integration approach for the biofuel production from biomass.

No.	Integrated biofuel production	Product and its yield	Reference
1	Single chamber MEC, dark fermentation	• Biohydrogen of 67.69 L·H_2/kg·$COD_{consumed}$	Varanasi and Das (2020)
2	Ultrasound-assisted deep eutectic solvent pretreatment, enzymatic hydrolysis and fermentation	• Bio-ethanol yield of 0.458 g/g·raw watermelon rind	Fakayode et al. (2021)
3	BES and AD	• methane production of 5.39 ± 0.37 L/L-reactor/d	Wang et al. (2023)
4	Microwave and pyrolysis	• Net energy output of up to 24.47 MJ/kg	Ge et al. (2020)
5	Gasification and high-temperature electrolysis	• 16,644 ton/yr of natural gas and 1412 ton/yr of biomethanol	Ghiasirad and Skorek-Osikowska (2024)
6	Electrolysis, gasification and reforming	• hydrogen production of >24,960 m^3/day.	Zhu et al. (2023)
7	DF and AD	• Methanol yield of 13.8 mmol/L in the presence of CH_4 vectors • Methanol yield of 64.6 mmol/L under the repeated batch mode	Patel et al. (2023)
8	Serial fermentation of carbohydrate/protein, and transesterification of lipid	• Bioethanol: yield of 0.48 g-ethanol/g-carbohydrate • Biodiesel: yield of 0.82–0.89 g-biodiesel/g-lipid	Ha et al. (2021)
9	Acid and base catalyzed transesterification and oil extraction	• Biodiesel: yield of 82 %	Haile (2014)
10	Transesterification and high-throughput fermentation	• Biodiesel: production rate of 1.9 g/L & yield of 0.5 g/g • Bioethanol: production rate of 10.5 g/L	El-Dalatony et al. (2019)

fermentation to produce biohydrogen (Srivastava et al., 2024), in which the MEC could utilize the VFAs present in the bioreactor effluents for extra H_2 production. Several years ago, Lenin Babu et al. (2013) employed the MEC to produce hydrogen using the acidogenic effluents of the DF process. In this scenario, the MFC achieved a high conversion efficiency of VFA to bio-hydrogen while operating MEC at 0.6 V.

3.6. *Eco-technical assessment*

For biomass gasification technique, the typical reactors include fluidized bed and fixed-bed gasifiers, in which downdraft gasifiers as the fixed-bed gasifiers are often utilized for biomass gasification because of being superior in the production of higher-quality syngas while the use of updraft gasifier is inhibited due to poor reaction capability and low syngas production (Mariyam et al., 2022; Ramos et al., 2022). The pilot-scale gasification system has been conducted for converting biomass (pine chips, pine pellets) to biofuel at the equivalence ratio of 0.21–0.36 and temperature of 785–829 °C in an 80 kWth pilot-scale bubbling fluidized bed reactor (Pio et al., 2020). In this case, 56–84.1 % of carbon conversion efficiency can be achieved, indicating a promising process for waste valorization. Besides, many other studies have reported the pilot-scale gasifier for biomass conversion (Anyaoha et al., 2020; Jiang et al., 2022; Parrillo et al., 2021). In the Gothenburg Biogas Gasification project (GoBiGas), woody biomass was transformed into synthesis gas through gasification for biomethane production at the plant scale, in which the natural gas grid accepted the generated biomethane at the end of 2018 (Thunman and Seemann, 2019). Similarly, in Finland, the Vaasa power plant, as the world's largest biomass gasification plant, used biomass feedstock such as round wood, stumps and forest residues to replace 25 %–50 % of coal by a circulating fluidized bed gasifier in which the emission of CO2 can be annually decreased by 0.23 million t (Havrysh et al., 2020).

Compared to traditional technology, biomass conversion through pyrolysis can save 15–20 % energy input, which, in terms of H2 production, conventional hydrogen production processes require 1.25–2.20 US $/kg·H2 is higher than the biomass pyrolysis 1.77–2.05 US $/kg·H2 (Nikolaidis and Poullikkas, 2017). Similarly, catalytic microalgae pyrolysis for hydrogen production can obtain the biofuel product with the price range of 1.49–1.80 $/L. Compared to slow/traditional pyrolysis, catalytic and co-pyrolysis can offer economic and environmental benefits (Chen et al., 2021), especially given the bio-oil and biochar as the co-products. However, applying such thermochemical processes in biofuel production may require more parametric studies to optimize operational parameters for enhanced performance.

The AD process for biofuel production has attracted global attention due to carbon neutrality characteristics, which means that the worldwide biogas market value may reach US$ 62.58 billion by 2030 (Subbarao et al., 2023). However, the variability of the AD process may be a big challenge for the biogas market. It was reported that converting food waste into biogas through the AD technique can achieve a profit of US$ 0.3/m3·biogas (Al-Wahaibi et al., 2020). Even so, some unexpected substances can be found in the biogas in the AD process, such as ammonia (NH3), carbon monoxide (CO), volatile organic compounds (VOCs), silicon (Si) and hydrogen sulphide (H2S) (Uddin et al., 2021). For this reason, pretreatment techniques are needed to remove the impurities and improve the quality and quantity of CH4. Still, such a process may involve much capital and energy input. Furthermore, factors including operation strategies, reactor configuration, pretreatment methods, transportation, and collection can highly influence the techno-economics of the biogas plants. It is expected to achieve a favourable trade-off between cost economics and plant capacity, in which an efficient biogas system is required.

Biohydrogen fermentation is an emerging technology, but the devices' cost, energy density, stability, and capacity may significantly affect its commercial application in infrastructural devices. For instance, looking for efficient materials with high biohydrogen storage capacity is essential because of compressed biohydrogen storage, but further efforts should be made to improve the development. Furthermore, solar photovoltaic/thermal (PV/T) technology can be introduced as a heat source, ensuring fermentation efficiency with stable temperatures under different seasonal conditions. As a result, the cost of biohydrogen production by fermentation can be significantly decreased. As a biological process, the DF performance is highly influenced by the physicochemical and operational parameters, which highly influence the DF performance, and microbial activity highly influences the DF performance. Thus, the imbalanced microbial structure may reduce the biohydrogen yield. Even though the pretreatment technique may mitigate such issues, its application is subject to technical and economic challenges (Rajesh Banu et al., 2020a).

The application of BESs for producing bioelectricity and biohydrogen has been extensively reported. However, their pilot-scale applications are still subject to a deep investigation of the systems, electrode material, and design consistency. Some studies have used pilot/plant-scale BES at wastewater treatment plants for bioelectricity generation, but few studies focus on biohydrogen production; for example, Blatter et al. (2021) designed a 1000-L MFC with electrolytes shared in 12 m long half-cells, which achieved 5.8–12.1 % of energy efficiency with electricity output of 0.015 to 0.060 kWh/m3; 720 L of on-site sanitary wastewater was treated by a field-scale stacked MFC consisting of six individual 120 L-MFCs (Das et al., 2020a), where a maximum power of 61 mW was generated. Due to the availability of organic content for microbial activity, it is recommended that MFC be implemented after primary sedimentation (Hiegemann et al., 2016). Sharma et al. (2023a) believed that additional biomass could offer more carbon sources and thus improve the efficiency of bio-electricity generation via MFCs. Apart from this, there may be competition between microbial communities for electrogene in terms of the generation of bioelectricity and biohydrogen (Sharma et al., 2023a), so pretreatments including physicochemical and biological techniques are recommended to enhance bioelectricity or biohydrogen generation. As a biological technology, biocatalytic activity should be significantly considered on a large scale, especially given that it is affected by operating conditions, electrode materials, feedstock compositions, and inoculum sources. The different biofuel production technologies are summarized in Table 3.

4. A new strategy for biofuel production: Circular bioeconomy

The imprudent use of fossil fuels is producing large and dangerous emissions of GHGs including CO_2 and N_2O, and to deal with the threat of pollution and destruction of the ozone layer, there are now widespread demands for using renewable energy (Li et al., 2020). The bioeconomy is a strategy to utilize biological processes and/or products to produce renewable multiple substances such as chemicals, materials and energy (Platform, 2018), where bio-waste is deemed as a possible feedstock for building up bioeconomy. Bioeconomy can effectively and economically manage the (waste) biomass for biofuel production to reduce the reliance upon fossil-based petroleum fuels, sustainably manage different waste biomasses and decrease the emissions of GHGs, in which various biofuels can be produced to supplement the current energy demand. The scalability of biofuel production is subjected to logistical issues, facilities and storage space because the suitable collection systems and technologies can sustainably valorize the biomass (Rajesh Banu et al., 2020b). The high value-added production of biofuel should also take into account the important economic, environmental and social factors (Okolie et al., 2022). At the present scenario, some companies have conducted the plant-scale conversion of waste biomass into biofuel (Dhiman and Mukherjee, 2021), which deem biofuels would be the main driver for the improvement and nourishment of national economy in the coming years ahead. Circular bioeconomy decreases strain on natural resources and wastes to realize environmental sustainability, in which the framework implements a zero-discharge idea, eliminating the hazardous chemicals, using renewable energy and reclaiming natural resources to establish the end-of-life period (Ferraz and Pyka, 2023). In this scenario, resource conservation can be promoted while biomaterials as feedstocks can be recycled, both of which contribute to a sustainable economy. Biomaterials such as biomass and wastewater are among the valuable materials with more comprehensive applications such as biofuels and bioelectricity. It is necessary to enact the circular bioeconomy under environmental, economic and social domains given the sustainability and characteristics of biomaterials.

5. Bioeconomy assessment of biofuel production

Increased fuel demand is due to longer lifespans, improved quality of life, and rapid urbanization, where circular bioeconomy can mitigate environmental footprint by substituting biomass-based commodities for depletable resources. Biomaterials can be converted into clean energy products in various forms, vital in promoting the circular economy and securing sustainability across environmental and energy sectors. Biofuel production via circular bioeconomy is a promising strategy for GHG reduction, green energy generation and waste/wastewater management. The transition from a fossil fuel-based economy to a circular bioeconomy requires sustainable resources and materials production, so biofuel outputs via biomaterials are the core idea of a circular economy.

Various types of biofuel production processes have been estimated using bioeconomy analysis. In the study of Chen et al. (2022), they utilized enzymatic hydrolysis and fermentation to achieve bioethanol using FW as a feedstock, where the minimum selling price of ethanol obtained was $ 548.48/t while the fuel ethanol price was $1082/t in

Table 3
Summary of different biofuel production technologies.

Technology	Production conditions	Biofuel	Advantages	Disadvantages
Thermochemical processing	◆ 350–1800 °C	◆ H_2 ◆ CH_4 ◆ Bio-oil	◆ Compact ◆ Low cost ◆ High efficiency (40%–50%)	◆ High emissions of NO_x, CO_2 and ash ◆ Complexity
Anaerobic digestion	◆ 35–55 °C ◆ anaerobic	◆ CH_4	◆ Commercially proven ◆ Applicable to biomass with high moisture content	◆ Bad odors ◆ Low substrate levels inside the reactor ◆ Long reaction process
Fermentation	◆ 30–50 °C ◆ pH 4.5–6.0	◆ Bioethanol	◆ Large-scale application	◆ Complexity ◆ High cost (especially with lignocellulosic biomass)
Bioelectrochemical system	◆ 20–30 °C	◆ Bio-electricity ◆ Biohydrogen	◆ Various value-added products ◆ High conversion of degradation-resistant organic biomass	◆ Additional pretreatment ◆ Growth of the undesirable microbial community

2022. In one study, Gubicza et al. (2016) received the minimum ethanol selling price in a range of 50.38–62.72 cents/L for ethanol production using a liquefaction plus simultaneous saccharification and co-fermentation process of sugarcane bagasse. As mentioned above, a difference in feedstocks may result in variation in biofuel yields, which may be attributed to processes involving pretreatment bioconversions and energy input. Integrating fermentation with BES can increase economic benefits from multiple products (e.g., biofuel and bioelectricity), in which the BES can exploit the residue derived from the fermentation process to generate electricity. Apart from this, fermentation of global municipal solid waste for ethanol production could contribute to $465.7 billion, with its annual production yield at 2.01 billion tons (Kumar et al., 2023).

As a typical biomass, microalgae can be used for biodiesel production and generate a higher oil yield when compared to plant biomass due to its better solar energy use. In this scenario, the costs for microalgal hydrogen production ranged from $2.82–30.97/kg, which is affected by the design parameters, scale and reactor types (Khetkorn et al., 2017). It was also reported that the minimum sale price of jet biofuels made from microalgae was $5.89/L, 4 times more expensive than fossil-based jet fuel ($0.43/L) (Ewurum, 2019). For this reason, a significant reduction in the cost of microalgae-based biofuel production is essential; for instance, wastewater and CO_2 in flue gas were used to decrease cultivation inputs (Venkata Subhash et al., 2022). The tubular reactor is a classical option for pilot-scale microalgae cultivation (Sathinathan et al., 2023), while the flat-plate reactor for microalgae cultivation is relatively inexpensive despite its high maintenance cost. Microalgae cultivation currently integrates with waste valorization to reduce the costs involved in microalgal outputs; for example, microalgae employs the volatile fatty acids derived from FW fermentation for its growth, which could increase microalgal lipid yield and decrease the costs of biodiesel production to $2.3/gal (Fei et al., 2015). Thus, microalgae cultivation via wastewater is a promising path to promote the sustainability of microalgae-based zero-waste industries because of simultaneous microalgae harvesting for biofuel production and nutrient recovery from wastewater for resource security.

6. Machine learning for biofuel production

Due to the 4th industrial revolution, biofuel production can be integrated with machine learning (ML)-based optimization approaches to increase its competitiveness with traditional fossil-based fuels (Sharma et al., 2023c). Unlike physical modelling, ML-based techniques involve data-driven modelling, making it more effective and realistic because of its features such as risk tolerance, high learning capacity and robustness (Forootan et al., 2022). More specifically, in contrast to the conventional investigations in the quantitative relationship between quality and quantity of biofuels, operational factors and biomass feedstock characteristics (Velidandi et al., 2023), the ML does not explore the relationship between inputs and outcomes and aims to predict the results and optimize the system parameters using the historical data (Culaba et al., 2022). Velidandi et al. (2023) reported that ML algorithms have been applied in the biofuel production process, such as prediction in biofuel yield, production process and biomass characteristics, where the ML technologies mainly include deep learning, Genetic Algorithms (GAs), K-Nearest Neighbors (KNNs), sparse dictionary learning, metric learning, random forests (RFs), decision trees, naive bayes, support vector machines (SVMs), logistic regression, neural networks and linear regression. Besides, data-driven decision-making, safety, process reliability, cost-effectiveness and efficiency are highly affected by the algorithms involved in the ML, such as Bayesian optimization, computational methods and artificial neural networks (ANNs) (Culaba et al., 2022). also believed that understanding the inputs for biofuel yield and production rate can be improved through ML algorithms (Bosu et al., 2022). For example, the conversion of microalgae biomass to biodiesel was modelled using the integration of ML (i.e., SVR and ANN) with the Bayesian optimization algorithm (BOA), in which the efficiency of the hybrid model (i.e., BOA-ANN and BOA-SVR) was increased by 36.03 % in terms of hyperparameters optimization (Sultana et al., 2022). Moreover, the nonlinear and complex interactions for DF can be described using some ML tools such as ANN and SVM; for instance, Mahata et al. (2020) used SVM and ANN models to study the experimental data for H2 production derived from organic biomass through DF, where the prediction ability of SVM presents better than that of ANN because of higher values of R2 (0.988) and RMSE (0.0103). Compared to the traditional optimization, using SNM-based models can increase the bio-hydrogen yield by 2.1 times. To maximize the biohydrogen production, the AD process parameters were evaluated using fuzzy-logic model and ANN, in which the parameters for BioH2 production could be better predicted using fuzzy-logic model (R2 > 0.8485) instead of ANN (R2 > 0.7866) (Moreno Cárdenas et al., 2020).

Apart from this, biofuel production and its application are highly dependent on architecture and optimization of supply chain architecture at the plant scale (Momenitabar et al., 2022). Zerafati et al. (2022) utilized a two-stage deterministic model to design a supply chain network for microalgae-based biofuel, in which the transportation means, applied technology, and property and quantity of microalgae can be identified as well as the suitable sites for microalgal cultivation. The appropriate biomass or biofuel demand level in the supply chain network can be calculated through auto-regressive integrated moving averages (ARIMA) and ANN algorithms (Akbarian-Saravi et al., 2020; Safaei et al., 2022).

Recently, ML applications have minimized the unfavourable environmental effects of waste-to-fuel conversion. However, ML-integrated biofuel production is still in its infancy, so a larger dataset is required to avoid incorrect model predictions. Comprehensive datasets covering a wide range of feedstocks and operating conditions are necessary, in which standardization of operating conditions and biomass characteristics should be conducted, as well as ultimate and proximate analysis for biomass composition.

7. Challenges and future perspectives

Within the bioeconomy framework, biofuel production should find a way to maximize the reuse of so-called waste. Developing new technologies is needed to diminish the contamination and consumption of water and energy during the entire biofuel production process. As well as the waste biomass itself, its side-streams should be also included into marketable value chains to create commercially successful products. Moreover, the market penetration of biofuel derived from waste biomass should be increased, in which such biofuels can serve as a green alternative to current fuels.

The research on biofuel production has attracted considerable attention due to its ability to produce alternatively green and sustainable fuels. However, full-scale studies of the process are few and far between. The kinds of products derived from biomass should be expanded whilst the purity and value of such end-product should be increased. Simultaneously, the effects of biofuel production on the environment should be minimized as well as the costs of downstream and upstream unit operations. Moreover, biofuel production needs a large amount of biomass, so its availability is a key factor affecting the biofuel yield. In this scenario, a robust collection and transportation system is needed for the biomass. If biofuel production is located close to the collection of raw waste biomass, the effect of waste on the environment during transportation would be reduced and transportation costs and time minimized (Suárez et al., 2020). Biofuel production technologies should be compatible with sustainable development goals and adhere to the principles of engineering and green chemistry. More efforts should be made to produce biofuel that combines maximum profits but minimal or no damage done to the environment. The commercial possibilities of biofuels should be encouraged with viable production programs put in place. Moreover, biofuel production is preferred to be undertaken using an integrated approach in a closed-loop, in which the reactor effluent from one process will act as a potential feedstock in the following process to enable maximum resource recovery from biomass. In general, the raw materials may only account for a small amount of the overall costs, so the production process and product transportation may be the main factors determining biofuel production's economic sustainability from water biomass (Cristóbal et al., 2018).

Application of the aforementioned biomass conversion techniques can increase the possibility of biofuel production derived from waste biomass. The yield of biofuels gives substantial commercialization despite some biomass conversion processes are only in progress (Godvin Sharmila et al., 2021).

Apart from this, waste biomass's utility rate and conversion technologies also determine biofuel production's economic feasibility. It was reported that different technologies could convert apple orchard wastes into pectin and inorganic materials, valuable extracts (antioxidants and nutraceuticals), and biofuels (Qin et al., 2021). In this scenario, producing such multiple products can lead to 1) a comprehensive increase in value, 2) a substantial decrease in production costs, and 3) an efficient and comprehensive use of waste biomass. However, the biofuel production process may result in pollution; for example, even if the anaerobic digestion of spent coffee ground (SCG) results in methane production, CO_2 emissions are observed, and global warming worsens (Rajesh Banu et al., 2020b). For this reason, the environment, economy and energy should be analysed before biofuel production is implemented.

In addition, commercial enzymes can be used as the pretreatment to enhance the kinetics of biochemical reactions in bioprocess operations and subsequently improve the efficiency of biofuel production. However, further development of enzymes is needed to reduce the technological discrepancy between laboratory synthesis and commercial production of these enzymes. Recently, Igbokwe et al. (2022) reported that synthetic biology techniques can be used to develop enzymes with high economic feasibility, efficiency and operational stability to improve the application prospects of biofuel generated from waste biomass in bioeconomy as well as metabolomics, meta-transcriptomics, meta-proteomics and meta-genomics. It is noted that biohydrogen production is complicated by the low substrate conversion efficiency, which is attributed to the substrate's complexity (Ferraren-De Cagalitan and Abundo, 2021). In this scenario, the complex substrate may not be hydrolyzed due to the lack of a specific microbial population.

Moreover, acid metabolites such as butyric acid, propionic acid, and formic acid may accumulate in the biohydrogen production process, resulting in acidic conditions that affect the reactor. As a result, the microbial activity of hydrogen-producing microbes is seriously compromised (Tang et al., 2022). Similarly, steam explosion (SE) has been widely studied to pretreat lignocellulosic biomass, in which the structure of the plant cell walls can be broken, and the cellulosic accessibility and surface area can be thereby increased (Cantero et al., 2019; Sarker et al., 2021). Moreover, SE-based pretreatment could be applied to various biomasses, and its energy input is much less than that involved in mechanical pretreatments (Yu et al., 2022). However, creating the steam may require high temperatures and high-cost reactor manufacturing materials, making the process slightly expensive compared to other methods. Thus, further efforts should be made to optimize the SE, having both advantages and disadvantages regarding social, economic, and environmental sustainability. Biofuel production can positively contribute to energy security, greenhouse effect mitigation and sustainable waste management. Still, the production of biofuel feedstock may result in indirect/direct land-use change (e.g., increased emissions of greenhouse gases) and adverse effects on ecosystems, degradation of water resources, forests and land (Khan and Rehman, 2023).

Furthermore, using first-generation biofuel feedstocks (i.e., food crop-related biomass) may increase the concerns about the rapid demand for agricultural products. In this scenario, the farmland may transfer itself towards biofuel production. In contrast, more land and forests with high biodiversity value may be exploited to enhance biofuel feedstock production, which simultaneously increases the use of pesticides, fertilizers and freshwater. Consequently, the environment may be seriously influenced. Algae-based biofuels can be cultivated in wastewater and on nonarable land. They may have insignificant impacts on land use, but the economic sustainability and high energy input challenge their commercial application.

The use and production of biofuel may result in the emission of various pollutants such as VOCs, hydrocarbons, NOx, CO and particulate matter (PM), which may increase the morbidity and mortality of malignancies, respiratory disorders and cardiovascular. Although biofuels have higher emissions of NOx when compared to fossil diesel, they may release low content of VOCs, hydrocarbons, CO and PM. Larcombe et al. (2015) reported that more ultrafine particles (< 100 nm diameter) were found during the emission of biodiesel than in the diesel exhaust. As a result, the biodiesel exhaust may be more severe to human health since it is easier for the tiny particles to inhale and penetrate the lungs. Therefore, the effect of biofuel on human health is significant, but more information and evidence are required to explore the vulnerabilities that need to be addressed.

8. Conclusion

Biomass offers much potential for sustainable resource recovery with bioeconomy goals, primarily since biofuels can act as an alternative to fossil fuels. Various technologies for biofuel production have been reported in this review, which positively contribute to zero waste generation. Although biofuel production may negatively impact the environment, such adverse effects can be mitigated while producing biofuel under the framework of circular bioeconomy. Improvement in the efficiency of biofuel production can be obtained through pretreatment of biomass (e.g., enzyme treatment). Besides, ML opens a new opportunity in predicting biofuel systems and can optimize the production process via modelling and prediction. Further research should focus on the applicable multidisciplinary methodology to make biofuel production more economically feasible and environmentally friendly. More effort should be made to devise integrated approaches to maximize waste reuse efficiency to produce bio in the output.

CRediT authorship contribution statement

Yuanyao Ye: Writing – original draft, Resources, Methodology, Formal analysis. **Wenshan Guo:** Writing – review & editing, Supervision. **Huu Hao Ngo:** Writing – review & editing, Supervision, Project administration, Formal analysis. **Wei Wei:** Writing – review & editing, Resources, Data curation. **Dongle Cheng:** Resources, Formal analysis, Data curation. **Xuan Thanh Bui:** Resources, Formal analysis, Data curation. **Ngoc Bich Hoang:** Validation, Resources, Data curation. **Huiying Zhang:** Writing – review & editing, Project administration, Formal analysis, Data curation.

Declaration of competing interest

All the authors have read the manuscript and agreed to submit to this journal. We confirm the work has not been published before and is not being submitted to any other journal for publication. The authors declare that they have no conflict of interest.

Data availability

Data will be made available on request.

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