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Overview of biomass-based waste to renewable energy technology, socio-economic, and environmental impact

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Abstract

The increasing energy demand has impacted global economic development. The increase in energy and the growing economy have strained the supply chain of energy sources. The higher energy demand can still be covered by the availability of fossil energy, making it one of the sources of environmental pollution. Therefore, finding safe, renewable, and sustainable alternatives has become urgent. Energy from waste is one of the alternative sources to fossil fuels as it is sustainable for economic, social, and environmental growth. A significant contributor to the development of renewable energy, the economy, and the environment is municipal solid waste (MSW). Waste disposal and scarcity of renewable energy sources have become challenging problems, especially in developing countries. This has caused problems both economically, socially, and environmentally. Based on these problems, researchers' interest in converting and developing alternative energy from solid waste has attracted worldwide attention. Reliable waste-to-energy technologies have been developed under various scenarios such as plasma, thermal conversion (pyrolysis, incineration, torrefaction, and gasification), biochemical, and mechanical technologies. In addition, automated biological treatment technologies (MBT), bio-electrochemical, and photo-biological processes aim to remedy developing countries' energy scarcity. The framework for evaluating solid waste-to-energy technologies was reviewed in depth to facilitate the work of researchers in carrying out their duties in the field. Furthermore, this review is to conclude that renewable energy sources from solid waste have the potential to meet energy needs. Thus, MSW management can address environmental pollution efficiently.

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1. Introduction

Economic growth and progress in a country are highly dependent on the availability of energy sources and have become a concern for governments worldwide (Pirlogea and Cicea 2012; Sáez-Martínez et al. 2016; Deprá et al. 2022). The exponential increase in energy for industrial needs has reduced interest in using non-renewable energy sources as they still depend on fossil fuels. Dependence on fossil fuels has increased global pollution (Guruswamy 2015; Schneider

2016). Industrial and economic growth in a country is closely related to the generation of municipal solid waste (MSW). MSW increases as society grows, especially in developing countries (Fazeli et al. 2016; Shah et al. 2021). Urban expansion, population growth, and technology also contribute to the increase of MSW (Tozlu et al. 2016; Rajaeifar et al. 2017; Erdiwansyah et al. 2021). Increasing waste generation and unreliable energy sources have caused environmental problems, especially greenhouse gas emissions and air pollution (Aja and Al-Kayiem 2014; Tsai et al. 2020; Hoang et al. 2022). Global MSW production has already reached two billion tons; by 2050, it is expected to reach 9.5 billion annually (Chen 2016; Sodari 2017). MSW will also increase significantly, especially in developing countries (Zuberi and Ali 2015; Rena et al. 2020; Chew et al. 2022). Industrial, domestic, commercial, and institutional waste constitute municipal solid waste (Pavlas and Touš 2009; Zhang et al. 2022). Plastic, textiles, wood, paper, glass, hazardous household garbage, leather, recyclables, and food waste account for 25–70% of the MSW that the IPCC is given (Albores et al. 2016; Baniasadi et al. 2016; Beyene et al. 2018; Dong et al. 2019). Clean and environmentally friendly energy is renewable and can contribute to power generation globally (Herva and Roca 2013; Antonopoulos et al. 2014).

The energy development from biomass conversion in recent years has attracted worldwide attention. This is due to less environmental impact, climate change, and lower energy costs (Apergis and Payne 2011; Radmehr et al. 2021; Sharma et al. 2021). Non-renewable energy sources have increased in price, so converting solid waste into energy has become a significant focus for researchers worldwide (Arafat et al. 2015; Ali et al. 2020; Ríos and Picazo-Tadeo 2021). Reliable waste-to-energy technology has been so well recognised that it has become challenging. However, toxic emissions are the most difficult challenge to solid waste-to-energy (Zhao et al. 2016; Cudjoe and Wang 2022). Lack of funding to develop energy from solid waste is also one of the challenges (Zhang et al. 2010; Khan et al. 2022; Sajid et al. 2022). Developed countries have now started to implement and utilise power from solid waste. The new reliable waste energy technologies that have emerged with MSW feedstock for renewable energy production are exhaustively discussed in this work. The main focus of this review is the current and future trends of conversion technologies. Renewable energy production through MSW conversion is the best, most profitable, and environmentally friendly suggestion. Attempts to present renewable technologies from solid waste to energy have been discussed, and especially those that are not widely known are also discussed in this paper. Energy production from solid waste, environmental, water, and soil pollution can also be well-controlled and profitable.

2. The requirements to produce solid waste into energy

By the end of this century, global energy demand is predicted to have multiplied six times from what it is now (Kothari et al. 2010; Jaiswal et al. 2022; Zhou and Li 2022). The need for energy supply in some developed countries is lower than the collection required. The primary source of electricity generation today around the world still relies on fossil fuels. Fossil fuels are needed to meet 84% of electricity demand (Ouda et al. 2016, 2017). The depletion of fossil fuel reserves has required scientists to find solutions to find alternative sources to reduce future energy crises. These renewable energy sources include solid waste that can be produced into energy (Charters 2001; Radpour et al. 2021). As has been done in some developed countries, massive urban waste generation can be relied upon as a sustainable energy source (Aljerf 2016). Environmental pollution is very high, one of which is caused by MSW. Solar energy sources can help fulfil energy needs because they are sustainable. Strict government regulations, such as incentives, industrial development, and pollution control systems, can help develop solid waste-to-energy technology as a clean energy alternative, especially in developing countries.

Alternative energy sources can be provided through reliable waste-to-energy technology. In addition, this technology can reduce the damage caused by unused materials. Electricity production using one ton of MSW can reduce CO_2 emissions by 1.3 tons (Scarlat et al. 2015; Adeboye et al. 2022; Misganaw and Teffera 2022). This is similar to that obtained from fossil fuel power plants (Elmnifi et al. 2019; Farouk et al. 2022). However, this power plant is different from fossil fuel power plants. These power plants only deal with burning waste to solve the energy crisis. In addition, fewer pollutants and carbon are associated with residual fuel power plants (Patumsawad and Cliffe 2002; Suksankraisorn et al. 2003, 2010). Falsifying waste data for some landfill sites has increased the public's response to environmental impacts, forcing the government to develop designs such as operational facilities and landfills (Sikarwar et al. 2016; Lopez et al. 2018). The development of solid waste-to-energy technology is still very little compared to landfills, so the amount of existing waste has not been handled optimally (Jamasb and Nepal 2010; Haraguchi et al. 2019). The existence of plants for energy production from solid waste only reaches 30 years. Only about 1 million tons of garbage can be disposed of each year. Approximately 100,000 m2 of plant space is required, and 300,000 m^2 is needed to dispose of 30 million tons of MSW (Arena 2012; Munir et al. 2019; Hameed et al. 2021; Sajid et al. 2022).

3. Solid waste options for energy

The primary goals of waste management systems are energy and material recovery and the disposal of residues. On the other hand, the optimal selection of waste management technologies is related not only to resource recovery, economic desires, or the ability to destroy waste but also to the search for such a regulations configuration on environmental preservation in the concerned area. As a result, choosing the best waste management technology that meets all of the necessary criteria for efficient operation is critical (Ali et al. 2013). Numerous waste transformation techniques use the three most commonly available technologies (Kalyani and Pandey 2014). These techniques include gas recovery from landfills, biological conversion, and thermal conversion. The performance standards and MSW treatment methods are shown in **Fig. 1.**

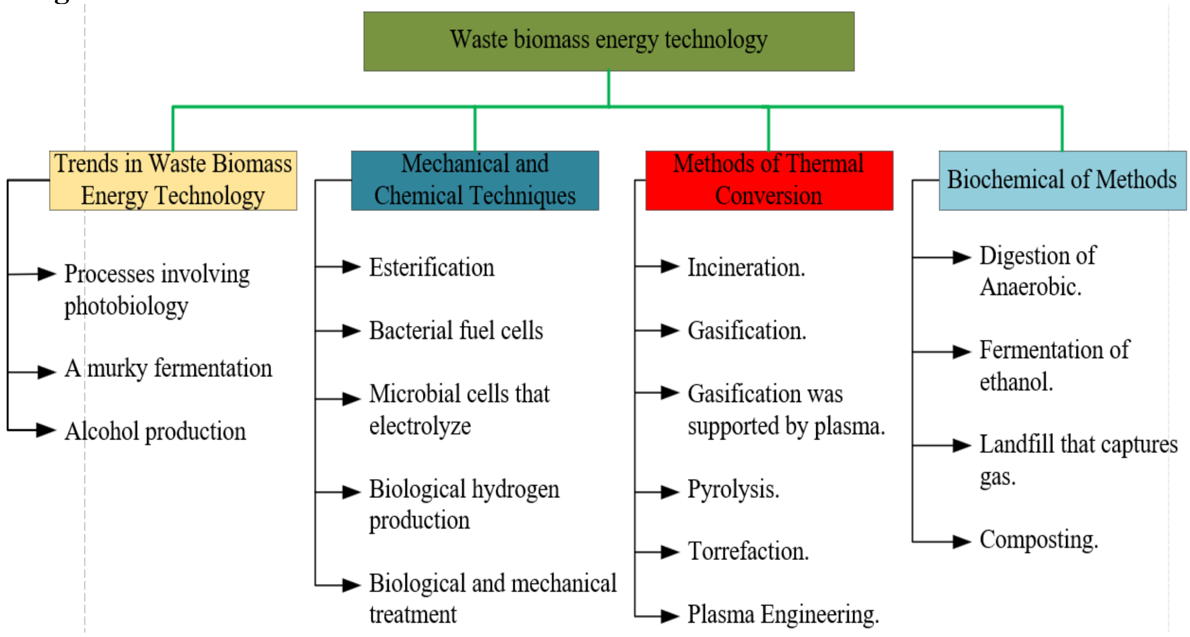

Fig. 1. Several waste-to-energy procedures convert municipal solid waste (MSW) into valuable products.

4. Methodology of solid waste technology: Combustion

Incinerators were primarily used to reduce volume rather than recover energy and protect the environment and public health from hazardous waste (Brunner and Rechberger 2015). Incineration is now purposefully viewed as an appealing method for waste treatment, especially in developing countries, due to advancements in environmental technologies and methodologies for controlling air pollution (Psomopoulos et al. 2009; Sadef et al. 2016). Due to stringent regulations against landfilling waste, Scarlet and colleagues found that incineration is the most widely used technique for waste disposal in most developed nations like Japan, Europe, and the United States (Scarlat et al. 2015). In 2003, the US Agency for Environmental Protection declared that burning waste is a cleaner and more environmentally friendly energy source (Leme et al. 2014). It is the most commonly used waste treatment method in which the capacity and excess mass can be reduced to 90% and 70%, singly, by producing electricity and heat simultaneously (Cheng and Hu 2010; Singh et al. 2011; Chand Malav et al. 2020; Ding et al. 2021). In nations with shallow temperatures, incinerators provide heat for local heating and occasionally to factories like the paper industry, while electricity is produced in all other circumstances (Brunner and Rechberger 2015). The schematic representation of the procedure is shown in **Fig. 2**.

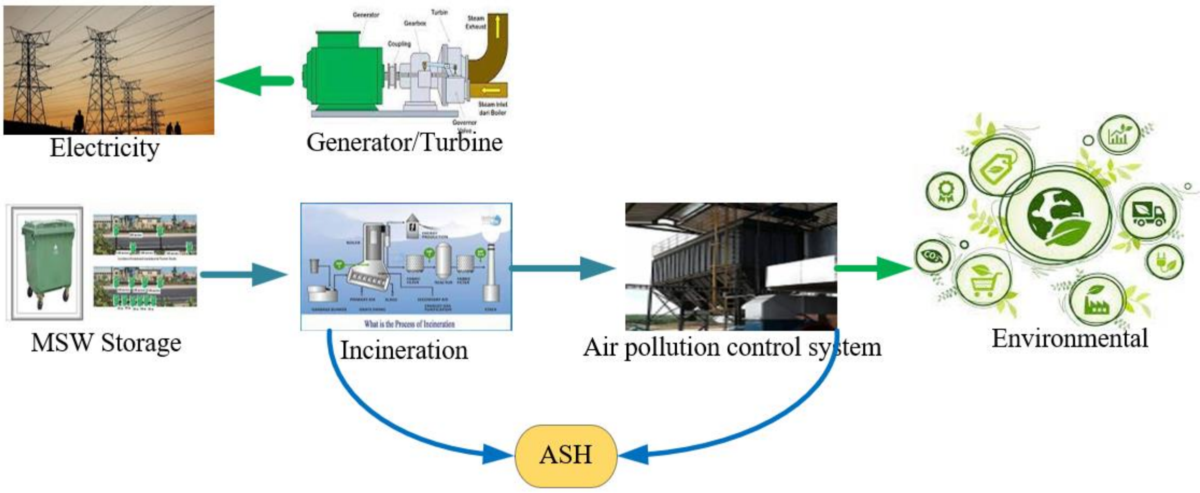

Fig. 2. The process of incineration is schematically illustrated.

In addition to electricity generation and volume reduction, the researchers have documented other benefits in other reports. These benefits may include using waste and byproducts (fly ash) from burning plants in adhesive manufacturing and road construction and retrieving non-ferrous and ferrous residents (Allegrini et al. 2014; Gomes et al. 2020; Bakalár et al. 2021). As a result, further technological advancements in metal recovery from incineration plant dry bottom ash will increase recognition of waste-to-energy accessibility (Morf et al. 2013). In developing countries, on the other hand, incineration is regarded as the most cost-effective and dependable method of burning waste without the need for waste pretreatment to generate electricity. The approach's main advantage is the conversion of organic substances, minerals, and living organisms into innocuous end products (Brunner and Rechberger 2015). Because MSW's physical characteristics and arrangement are incredibly mixed, they must be evaluated previously in the waste-to-energy technology structure (Turconi et al. 2011). Tan and colleagues discovered that combustion is relevant for undelaying and flammable MSW with less moisture (Tan et al. 2014; Chand Malav et al. 2020; Varjani et al. 2022). The most notable feature to be discussed here is that using these fuels with MSW is not required when MSW's latent vaporised heat (LHV) is surrounded by 1000 kcal/kg and 1700 kcal/kg above. Secondary

fuels occasionally incinerate MSW (Chen and Christensen 2010; Komilis et al. 2014). According to the World Bank, once the calorific value of MSW reaches 1700 kcal/kg, the incineration process's effectiveness and energy recovery are advantageous (Kumar and Samadder 2017). However, the International Energy Agency believes these values should exceed 1900 kcal/kg (Melikoglu 2013; Hameed et al. 2021; Huang and Fooladi 2021). Additionally, it is well known that the presence of passive waste and moist contents significantly affect combustion due to the reduction in calorific values, which has a noticeable impact on incinerator performance (Aljerf 2016). This disadvantage can be reduced by chemically, biologically, thermally, or mechanically pretreating MSW to eliminate wetness, toxic essentials, inert waste, such as chlorine and mercury, or both (Lombardi et al. 2015).
Modern MSW incineration facilities in developed nations effectively increase energy production (Psomopoulos et al. 2009). Reduced operative and yearly principal costs, skilled labour, and increased daily production (Psomopoulos et al. 2009). Compared to other waste-to-energy technologies, incineration is unquestionably more striking for developing countries' cities due to the increased calorific value of waste (Bosmans et al. 2013). Japan is the leading Asian nation for waste-burning technology due to its strict regulations and constrained disposal options. Similarly, 35% and 80% of MSW is burned on a larger scale in some European countries (Reddy 2011). Only incineration is used to recover energy from the North-eastern US's total solid waste production—more than 40%. Incineration is not a practical method for various emerging nations, except for those with rapidly expanding economies (like Malaysia, China, etc.). This is due to several factors, including (a) high conservation and working investment prices, (b) the ease with which cheap land can be acquired for waste disposal, (c) a lack of technical experts, and (d) the hazardous configuration and physical characteristics of waste.

Nevertheless, China has recently made enormous strides in the incineration of MSW, and by the end of 2020, this volume is anticipated to reach 500,000 tons/day (Lu et al. 2017; Fu et al. 2022; Wei et al. 2022b). According to Li and colleagues, China had 166 coal combustion facilities producing electricity from MSW at a rate of 166,000 tons of coal per day by 2013 (Li et al. 2015; Song et al. 2017; Wei et al. 2022a). The team noted that incomplete combustion, poor waste feedstock quality, and increased air pollution are all issues China has when incinerating MSW (Lombardi et al. 2015). Variable composition, increased moisture, and low energy content are other significant issues with burning MSW in developing nations (Minghua et al. 2009; Chen et al. 2010; Reddy 2011).

a. Pyrolysis

Another cutting-edge method constructed on the thermal action of MSW is pyrolysis. It operates at temperatures between 400 and 800ºC without air or oxygen (Czajczyńska et al. 2017b, a; Tayibi et al. 2021). How much char, oil, and pyrolysis gas are produced throughout the process varies on several factors, including heating rate, residence time, temperature test, waste particle size, and composition (Kalyani and Pandey 2014; Lombardi et al. 2015). Wax, tar, and pyrolysis oil are the byproducts of the pyrolysis response at temperatures below 500–550°C. In contrast, the main byproduct of the reaction at temperatures above 700°C is the smoke formed by pyrolysis (Kern et al. 2012; Gholizadeh et al. 2020). The following types of feedstocks, such as wood waste, plastic, electronic waste, electrical waste, tyres, etc., can be used to produce high-quality products. Reports on the specific waste type for pyrolysis have been published, and the findings of numerous investigations have been presented. These studies are focused more on the pyrolysis process than the potentially lucrative commercial applications of the pyrolysis products. Pyrolysis has recently drawn attention, especially for reprocessing fight tyres to recover oil, gas, wire, and carbon black (Lombardi et al. 2015; Ni et al. 2022; Peltola et al. 2023). Additionally, using MSW, pyrolysis has been used commercially on a large scale for energy recovery. Since 1987, a plant in Germany (Burgau) that processes 110 tons of MSW per day has successfully used pyrolysis to generate electricity (Lombardi et al. 2015; Ni et al. 2022; Peltola et al. 2023).

It is heated using a microwave or traditional methods without shredding the feedstock. The pyrolysis process can be used for large-scale commercialisation due to the production's flexibility and low cost, as it is affordable and straightforward to use in the commercial sphere (Sipra et al. 2018; Lu et al. 2020a; Gao et al. 2022). The physical separation of glass and metal (an incombustible material) before pyrolysis prevents its adverse effects. Some synthetic or natural catalysts' chemical and biological properties are reduced due to structural restrictions and high costs. For instance, impurities and contaminants in the mixed type of MSW can prevent the catalysts in the feedstock from carrying out their catalytic function. Unlike natural stimuli, synthetic catalysts like ruthenium and nickel deactivate quickly (Sipra et al. 2018; Lu et al. 2020a; Gao et al. 2022). The temperature is typically kept on the higher side to activate the motivation and at an appropriate particle size (Lappas et al. 2016; Kabakcı and Hacıbektaşoğlu 2017; Zhang et al. 2018). The heavy metals and organic pollutants pyrolysis easily contaminate the char.

b. Gasification

The organic compounds are converted into syngas under precise oxygen and temperature conditions (Arafat and Jijakli 2013). The primary outcome of the gasification process is the gas, which is also used to fuel the combustion process for energy generation. Chemical feedstock and liquid fuels are additional process byproducts (Yap and Nixon 2015). The process is depicted schematically in **Fig. 3**. Most documented reports show that Specific types of MSW and homogenised solid fuel flows, like coal, wood, etc., are the areas of concern. Although gasification is regarded as an essential potential option for energy recovery from MSW, it is most commonly used in the coal industry (Arafat and Jijakli 2013; Chanthakett et al. 2021; Rahman et al. 2022). When Panepinto and colleagues looked into how many plants used the gasification technique, they discovered that 100 plants used it worldwide to treat MSW (Panepinto et al. 2015). Eighty-five gasification plants operated in Japan in 2007 (Sikarwar et al. 2016). At the same time, other nations like Germany, the United States, Norway, the United Kingdom, Iceland, and Italy use gasification to treat MSW (Panepinto et al. 2015). When dealing with the same amount of MSW, gasification technology produces significantly less CO_2 than incineration (Murphy et al. 2004). Modern gasification plants have inclusions that effectively reduce the likelihood of soil and water groundwater pollution (Kumar and Samadder 2017). Asia is now considered the region most favourable for gasification technology after Africa, Europe, and the United States due to the recent massive increase in this technology there (Ouda et al. 2016; Almulhim 2022; Melaibari et al. 2023). The best methods for treating MSW are gasification and pyrolysis regarding energy recovery and environmental impact (Zaman 2010). Compared to incineration, gasification and pyrolysis technologies can reduce waste volume by 95% and require less extensive flue gas cleaning (Nixon et al. 2013; Yap and Nixon 2015; Malinauskaite et al. 2017). Compared to other waste-to-energy techniques, both strategies are less polluting and more efficient at recovering energy. Due to insufficient gas cleaning techniques, gasifier efficiency, particle size, heterogeneity in high moisture content, and MSW composition, they must be developed globally on a large scale, particularly in developing countries (Leme et al. 2014; Luz et al. 2015; Liu et al. 2022).

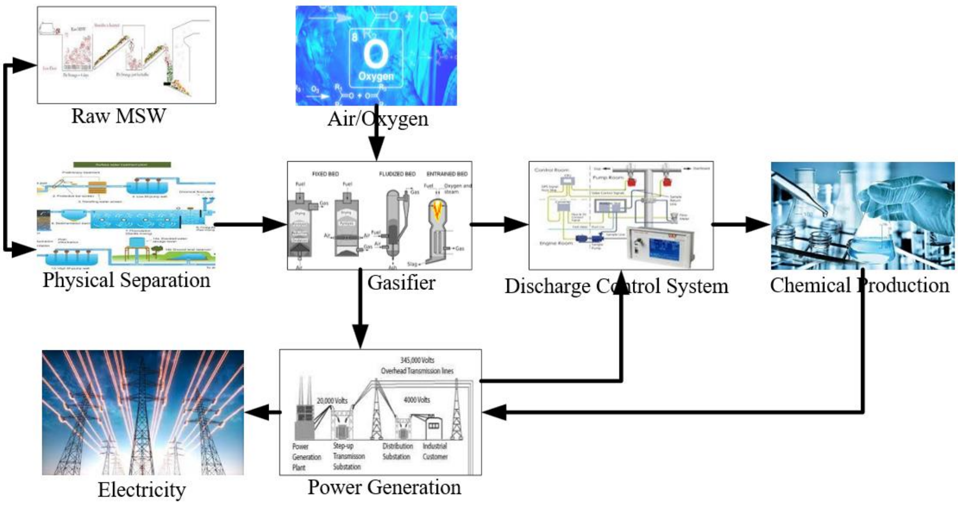

Fig. 3. The gasification process is depicted schematically.

The treatment of MSW using plasma-supported gasification is becoming increasingly popular in the United States (Rajasekhar et al. 2015; Ramos et al. 2020; Hameed et al. 2021). Tyres, hazardous waste, and MSW are just a few wastes used by plasma gasification (Sikarwar et al. 2016; Dai and Whitty 2022; Nirmala et al. 2022). The solid waste component is pyrolysed into syngas using an AC or DC plasma torch as a heat source (Anyaegbunam 2013). The heat energy is produced by a plasma torch, allowing an electric current to pass through oxygen or air (gas) to be used for oxidation (Campos et al. 2015; Pandey et al. 2016). Fluidised bed plasma gasification, which can improve gasification performance in solid waste, is a promising new technology (Du et al. 2018). Plasma-supported gasification has several benefits and drawbacks compared to other waste-to-energy technologies. The following is a list of some of them.

Advantages. Waste-to-energy technology is more effective and cleaner. When compared to conventional gasifiers, plasma stimulates a more significant amount of syngas. The operating temperature is typically in the range of 5000^{o}C, which is exceptionally high. In this method, the components of the inorganic waste are impassive as inert vitrified slag, with minimal solubility of toxic compounds (Rajasekhar et al. 2015; Ramos et al. 2020; Hameed et al. 2021). Compared to traditional gasification and incineration methods, syngas contain fewer poisonous elements. Additionally, plasma gasification exhibits significantly lower slag leachate harmful effects than incinerator ash in garbage dumps (Mountouris et al. 2003).

Disadvantages. (a) This method's use in solid waste is relatively new despite being recognised in nearly biological and metal manufacturing (Sanlisoy and Carpinlioglu 2017; Cudjoe and Wang 2022; Lee 2022). (b) This technology is not widely used for MSW commercial action in the US. (c) Most of these methods are still in the investigational justification or demo step for industrial and pilot-scale use (Fabry et al. 2013; Pang et al. 2018; Ramos and Rouboa 2018). As a result, US military installations are considering using available waste-to-energy techniques for waste management at their facilities (Bing et al. 2016; Mesjasz-Lech 2019; Santos and Ogunseitan 2022). A small number of businesses, such as Gas Energy Technologies, InEnTec Biological LLC, Green Energy Processes LLC, and Geo-plasma Inc., are in the stage of development (Jones et al. 2013; Danthurebandara et al. 2015; Laner et al. 2019).

c. Plasma of Technology

Plasma technology works at the time of energy change from solid to liquid and further to the gas mixture to become heat and energy. Thus, the gas content can be organised by applying more power, known as plasma, because it is rich in energy (Burm 2012; Frank-Kamenetskii 2012; Keidar et al. 2019). This technology uses energy from thermal or electric currents and electromagnetic radiation. The presence of gas species makes it more reactive with different behaviour from other materials. The advantage of plasma technology is that there is energy content, so biomass energy is more minor and unsuitable for gasification technology power plant feedstock (Gumisiriza et al. 2017). High temperatures in plasma technology can help integrate organic materials into their constituents. Ultimately, each can develop a synthetic gas with high energy. In addition, hydrogen and carbon monoxide contents serve as the main constituents. However, plasma-based methods can be used for more interesting future waste management. Furthermore, inorganic parts such as glass, silicates, and metals, when melted, turn into solid, inert, unverified slugs that can be harmful when disposed of in the environment.

d. Torrefaction

Homogeneous products can be improved through thermal biomass compacted by palletisation to produce reliable energy. They are torrefied pellets or briquettes with the same properties as coal (Batidzirai et al. 2013; Kota et al. 2022). This energy is beneficial for the conversion process of more thermocyclers (Yan et al. 2010; Mamvura and Danha 2020). This torrefaction technology is known as the trivial pyrolysis method. The recommended temperature range for thermochemical technology is between 200-300°C for low heating and in an inert atmosphere (Medic et al. 2010; Thengane et al. 2022). To enable more efficient drying and screening of impurities from chipping biomass so that drying rates of up to 20% can be achieved (Batidzirai et al. 2013; Chen et al. 2022a). Torrefied biomass from briquettes can retain up to 96% of its chemical energy and withstand hydrophobicity and biodegradation in nature (Chen and Kuo 2010; Safar et al. 2019). Thus, it can replace coal fuel for heating, power generation, cooking, gasification, and co-firing (Prins et al. 2006; Phanphanich and Mani 2011; Kong et al. 2022).

e. Convection Thermal

This technique thermally treats the organic MSW matrix to produce gas, heat energy, or fuel oil (Abdel-Shafy and Mansour 2018; Ezeudu et al. 2021; Tejaswini et al. 2022). Low moisture content (dry waste) and more undelaying organic matter should undergo thermal treatment. Thermal treatment technology is frequently used on combustible materials with a higher heat value (RDF) (Azam et al. 2019). By palletising and grating the remaining waste, fireproof and recyclable components are separated from MSW to create the RDF (Rezaei et al. 2020). Incineration is the most frequently used thermal treatment technology. Controlled combustion raises the temperature of the waste residues.

Additionally, techniques for thermal conversion like pyrolysis and gasification are still in their infancy. Due to inadequate facility design, preliminary MSW data and characterisation, and poor feedstock quality, they are unsuitable for large-scale commercial production (Appels et al. 2011; Tsapekos et al. 2022; Song et al. 2023). A few plants based on gasification are in operation worldwide to treat MSW. These plants treat MSW and other types of waste, such as biomass, biomedical, and industrial waste (Ionescu et al. 2013; Awasthi et al. 2022; Saif et al. 2022). The main differences between these three thermal treatment methods are the operating temperature and environmental factors. Both parameters are in charge of the reaction's product quality and useful intermediated products. Similarly, the design of the process and the feedstock material significantly impact the operational temperature of the process. MSW supplementation is not well set for incineration in developing nations, so raw MSW has been used effectively as raw material (Nie 2008).

f. Bio-Chemistry

It is known that thermal or thermochemical technologies have limitations for high moisture content, such as banana waste. Thus, biochemical technology is the right choice compared to the above mentioned technologies. In addition, biochemical technology is also very friendly to the environment. The conversion of waste into energy is due to enzymes from microorganisms. Anaerobic digestion technology has been very well developed, especially for converting energy from waste. Some developing countries have also used this technology as it has a standardized cost. This is because destruction is highly associated with organic matter. The decomposition of airless waste can be done with the help of microbes so that moisture is maintained and biogas can be extracted (Ahn et al. 2009). Carbon dioxide, methane, and elements produced from biogas can be further purified to remove various impurities and carbon dioxide. Thermophilic 50-60^{o}C and mesophilic 30-37^{o}C can be grouped as far as digester classification is concerned, but depending on the temperature range of the digester itself (Van et al. 2020; Cazaudehore et al. 2022). Each type has attributes such as ease of maintenance and operation with slight deactivation of pathogens. At the same time, the latter is a bit more challenging to operate but still doable with a longer time to process the effluent (Zaks et al. 2011; Fekete et al. 2021).

Two-phase anaerobic digestion has also been reported to offer better methane production rates than single-phase anaerobic digestion. Two-phase anaerobic digestion in renewable and renewable energy technology has enormous potential. Biohythane can be disposed of from organic waste while solving energy scarcity and overcoming waste disposal. Two-phase anaerobic technology can also provide an optimized process, increased energy efficiency, and maintained control. On the other hand, the benefits of total AD solids and Wet AD obtained from the three-stage anaerobic digester were more significant. In addition, significantly increased methane production was possible in the three-stage anaerobic system compared to the conventional one. Increased treatment capacity and reduced solids rate with smaller reactor volume are advantages of the three-stage anaerobic digester. This three-stage digester is ideal, especially for the anaerobic digestion of food-based and other waste materials. However, there are several methods in anaerobic digestion, but it can be done for the primary process, pre, and post-process. This technology must be controlled continuously by making the control automatic (Nguyen et al. 2015; Wu et al. 2021; Vu et al. 2022). Anaerobic digestion systems also have disadvantages and advantages, like other technologies, as presented in **Table 1**.

Table 1. Anaerobic digestion's benefits and drawbacks (Chand Malav et al. 2020; Mukherjee et al. 2020; Hanson et al. 2022).

Benefits	Drawbacks
Applications for digestive agents in agriculture.	Expensive biogas removal Digester sensitivity to weather; Blender malfunction; Unexpected digester shutdowns; Solids accumulating
Biogas has a variety of uses (e.g. heating, cooking, generating electricity)	Decreased biodegradability

The process of converting ethanol from fructose and glucose found in fruits and sugar cane can be done through fermentation so that it can be used as an alternative engine fuel. The process is directly carried out with alcohol fermentation microorganisms. Saccharolytic and ethanologenic fermentation processes through co-metabolism are carried out with microorganisms to produce ethanol (Fernández-Sandoval et al. 2019). This technique has tremendous potential, but several issues must be addressed, such as the danger of producing by-products in the distillation process. In addition, the challenges of ethanol's hygroscopicity to power generation and spark generation in machinery (Atabani et al. 2013; Deshmukh et al. 2019; Harish et al. 2021). Ethanol fermentation has the advantage of contributing to reducing CO_2 emissions. At the same time, the limitation of solid waste that is rich in cellulose or must make the activity of ethanol fermentation.

Landfilling is better and more economical than directly burning waste in incinerators. Landfilling is done by burying waste in pits and allowing it to decompose naturally over time. The process of operating waste in landfills has specific requirements to minimise seepage, odours and greenhouse gases. The use of this technology also has advantages and disadvantages, as presented in **Table 2**. Some of the current technologies that have been used and have been running well include:

- Persulfate and oxidation applications that serve as leachate treatment (Usman et al. 2020).
- Irradiation using microwaves so that the carbon in the waste can be activated.
- Hydrogen proxied oxidation with adsorption for leachate removal (Adeniran et al. 2017; Eljaiek-Urzola et al. 2018; Ugwu et al. 2020).

Table 2. Benefits and Drawbacks of Gas Capture Landfill (Mukherjee et al. 2020).

Benefits	Drawbacks
It is more cost-effective than the incineration of waste.	Methane is created, a more potent greenhouse gas than other greenhouse gases (such as CO_2, CO, and NOx). Leachate contamination of underground water.
Methane produced in this way can be utilized to generate energy and heat.	Significant, isolated lands are needed for it.

Composting is a stable waste production process that converts biodegradable waste to heat, compost, water, and carbon dioxide under normal conditions. Further use of compost can improve the properties of the soil, which is easier to maintain (Irvine et al. 2010; Chand Malav et al. 2020). Generally, three types of microorganisms are involved in composting: actinomycetes, bacteria, and fungi. However, the degradation process is initially directly through mesophilic microorganisms through heat generation from metabolic activities. Subsequently, thermophiles can increase the temperature to 60-65°C (Ugwuanyi et al. 2004, 2008). In addition, bacteria and fungi can recolonize so that the process can be completed. Composting is specially organized through static compost piles with thinning and stored in an isolated space. The use of fans dissipates the heat generated from the metabolic process of microorganisms. The level of effectiveness of this technique is a success against thermal energy, which is rarely reported in its use. In addition, the composting process through waste mixing causes heavy metals to enter the food chain.

g. Torrefaction

Torrefied pellets (TOPs), a denser energy product with properties similar to coal, are produced by thermally upgrading biomass into a more homogeneous product that is then densified over palletization (Batidzirai et al. 2013). This energy can facilitate more thermochemical conversions (Yan et al. 2010). The term "trivial pyrolysis method" is another name for this technology (torrefaction). This thermochemical method operates in the 200–300oC temperature range with minimal heating and an inert atmosphere (Medical.,2010). The process entails chipping biomass to enable impurity screening and effective drying before sizing and drying to a moisture content level of 20% **Fig. 4** (Schorr et al. 2012). The briquettes produced by torrefying biomass are hydrophobic and retain up to 96% of their chemical energy (Chen and Christensen 2010; Hoekman et al. 2014). As a result, it can replace charcoal or coal in domestic heating, co-firing, gasification, and power generation systems (Phanphanich and Mani 2011; Chen et al. 2022a).

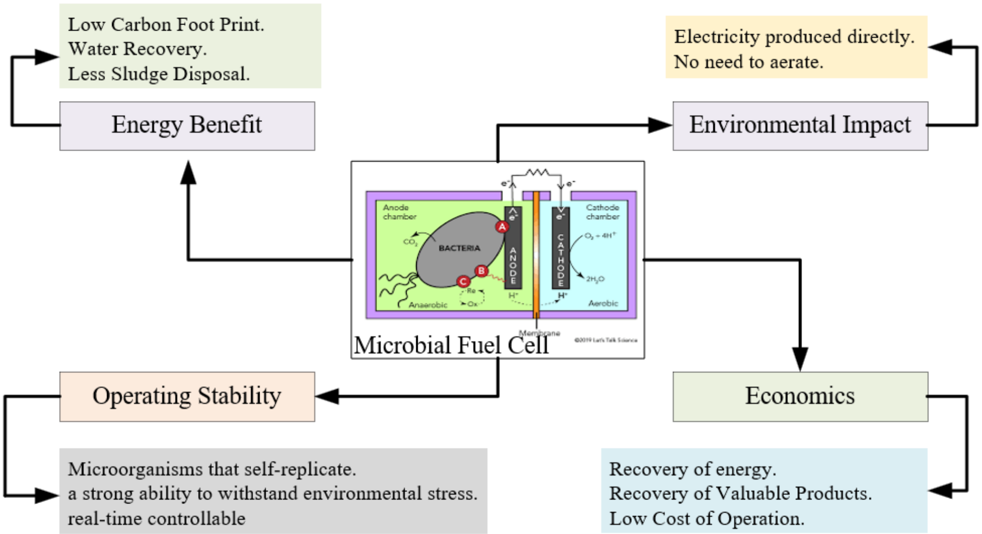

Fig. 4. Microbial Fuel Cell Scheme for direct electricity generation. It is reproduced from reference with permission (Beyene et al. 2018).

5. Mechanical and Chemical Methodologies

Biodiesel is created through the esterification of used vegetable oil (Aljerf 2016). The three primary techniques for producing biodiesel from used cooking oil are as follows ((a). transesterification with a base catalyst; (b). transesterification catalyzed by an acid; (c). oil is converted first into fatty acids, then into biodiesel). The first of the methods mentioned above is most frequently used because it is the most cost-effective. The maximum yield of 98% involves low-temperature and low-pressure processing. Transesterification is completed when the reaction produces distinct layers of glycerol and esters. The resulting biodiesel is less toxic than petroleum diesel and more likely to degrade, so it is frequently used in conjunction with it (Wang et al. 2009; Chou et al. 2014; Ren et al. 2022).

a. Microbial Fuel Cells

These are devices that use a variety of substrates and bio-electrogenic microorganisms to produce energy. With the aid of bacteria, which serves as a catalyst, biohydrogen is made using aerobic and anaerobic processes. A wide range of animal, sludge, and household waste can be used as feedstock. It is cutting-edge technology that can attempt to meet the needs for hydrogen and electricity. It operates on electron distribution, which occurs within bacteria through a redox reaction. A metabolic pathway allows a bacterium to take in and transfer the electrons current in proteins, fats, and further fragments due to absorption (Rabaey and Verstraete 2005).

The Kerb cycle comes next, and an organic process occurs within the membrane as the final step (Logroño et al. 2015). The following is a list of the benefits this technology offers: (a) direct generation of electricity; b) a smaller carbon footprint; c) water recovery; d) colony self-renewal in microorganisms; e) low sludge production; and f) low operating costs).

MFCs are bio-electrochemical devices that use bio-electrogenic microorganisms on various substrates to produce organic reactions that release energy. These devices generate electricity using electrochemically active microorganisms (EAM) (Logroño et al. 2015). MFC uses bacteria as a catalyst in both anaerobic and aerobic conditions. It's a promising method for producing bio-hydrogen. Various organic substrates can be used as feedstock, including sludge, animal, and household waste. The MFC promotes an eco-friendly way to meet rising energy demands by converting MSW into electricity and hydrogen gas. MFC will produce electricity by utilising the microbe's options for relocation because of the electron passage cable to the electrode surface and the creation of a nucleon engine (Li et al. 2014**).** Most metabolic processes with high microbe inhabitants use fruit waste for organic reactions (Nitisoravut and Regmi 2017; Narayana Prasad and Kalla 2021; Wang et al. 2021) **Fig. 4** and **5**. Monosaccharides, disaccharides, and polysaccharides are present in fruit waste. Waste from vegetables contains polysaccharides. Polysaccharides require more energy to break down and participate in the metabolic pathway (Logroño et al. 2014, 2015; Tremouli et al. 2019). MFC is a great way to apply the concept of electron allocation. Redox reactions occur in bacteria when they consume food (MSW).

The absence of oxygen in the environment typically limits the bacterium's growth. The bacterium is moved along the metabolic pathway of the microorganism by taking electrons from sugars or other waste molecules. A straightforward method by which cells use electrons as energy **Fig. 5** (Logroño et al. 2014, 2015; Tremouli et al. 2019). Pyruvate is converted to CO_2 and Acetyl-CoA in the mitochondrial cells of the second section by distraction. Oxaloacetate is produced from Acetyl-CoA and enters the Krebs cycle after that. NADH and its byproduct store high-energy electrons and CO_2. The Krebs cycle is unaffected by NAD+ regeneration because it uses molecular oxygen. NADH enables high-energy electrons to interact with O_2 and produce water in the membrane-bound electron transport chain. Aldohexose is finally converted to an organic step bound to an energy membrane in the third section (Xavier et al. 2016). The electron transport chain is used by mitochondria and cellular membranes in eukaryotic and prokaryotic cells (Gunawardena et al. 2008). When protons cross the membrane again, ADP is phosphorylated to create ATP. NADH, FADH, and QH2 coenzymes function as electron carriers by reducing oxygen. Nanowires or other membrane-associated electron mediators directly transfer electrons from the anode to the cathode (Xavier et al. 2016).

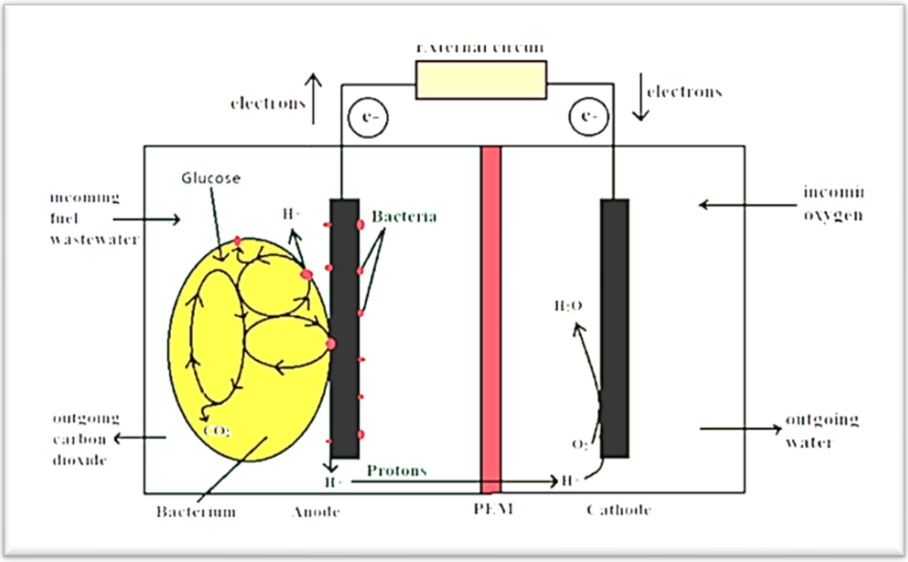

Fig. 5. The microbial fuel cell's schematic. It is reproduced from reference with permission (Rabaey and Verstraete 2005).

b. Microbial cells that electrolyze.

It is a futuristic, intelligent, green technology to address climate change and rising energy demands. It can generate a variety of chemicals, including hydrogen, methane, formic acid, acetate, ethanol, and hydrogen peroxide. Except for the cathode not being exposed to air, it is constructed similarly to a microbial fuel cell. When the reduction process occurs, and the electrons reach the cathode, hydrogen is created. When combined with fermentation, this technology can boost the yield even more. The main advantages include a higher hydrogen recovery rate (roughly 90%, as opposed to dark fermentation's value of just 33%), availability of a wide range of substrates compared to MFC and fermentation, and a climate that is both carbon-neutral and energy-positive (Beyene et al. 2018). It transforms MSW into H_2 and chemicals such as acetate, formic acid, ethanol, hydrogen peroxide, and CH_4 (Kadier et al. 2015). Although MECs and MFCs techniques are similar, the MECs cathode is not open air (Kadier et al. 2016). MEC has gained attention recently for its capacity to produce affordable, clean energy from waste (Xavier et al. 2016; Yin et al. 2017).

MEC is substrate-diverse and shows high hydrogen recovery compared to MFC, photo, and dark fermentation (Rahimnejad et al. 2015; Erdiwansyah et al. 2021; Thulasinathan et al. 2022). **Fig. 6** explains how MECs can produce H_2, biofuels, and other valuable materials from every biodegradable waste. However, applying it to various substrates or environments can significantly alter the system's value. Since this electrolysis is endothermic, it needs external hydrogen pressure to proceed spontaneously to have H_2 from photons flow electrons to the cathode (Khan et al. 2017; Katuri et al. 2019; Desmarais and Kraljić 2021). This process produces hydrogen by overcoming an endothermic barrier induced by microbial fermentation products. The potential required to overcome this barrier is minimal for water electrolysis. By applying an external voltage, electrochemically active bacteria grow selectively and are easily susceptible to electron sinking (Zhao et al. 2017; Wang and Jiang 2019; Shi et al. 2021). In MEC, 90% of the hydrogen is recovered compared to 33% in dark fermentation. MEC demonstrated immediate wastewater treatment and converting organic materials to CH_4 and H_2 (Karampinis et al. 2015).

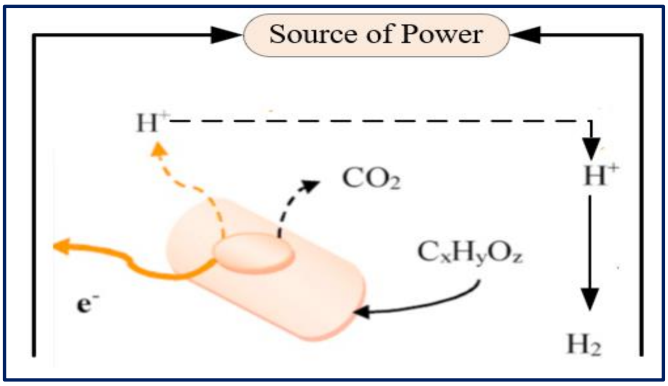

Fig. 6. Microbial electrolysis cell with a single chamber. It is reproduced from reference with permission (Beyene et al. 2018).

As demonstrated by MEC, the use of waste biorefineries in the future has a high potential. By converting biodegradable waste into bioproducts and value-added energy carriers, MECs enable carbon-neutral and energy-positive systems. Integrating MEC increases fermentation speed and yield. By utilizing new materials and altering reactor configuration, prices are decreased while system efficiency is improved. Investigations lead to a deeper comprehension of syntrophic competition and interactions among various microorganism groups, including Proteus vulgaris, Erwinia dissolvens, Shewanella putrefacient, Rhodoferax ferry reducers, Pseudomonas aeruginosa, Escherichia coli, Rhodoferax ferry reducers, Geobacter sulfur reducers, etc. Methods are frequently developed to reduce energy and increase syntrophic connections for system application and proportion (Beyene et al. 2018).

c. Hydrogen Production Via Biological Means

Hydrogen, the most common element in the universe, is usually found in the necessary arrangement. It can be produced by electrolyzing water, reforming fossil fuels, being a significant source of hydrogen, or being a byproduct of an industrial process. According to predictions, traditional fossil fuels will soon be replaced by hydrogen. Additionally, waste has been discovered to be a sustainable and renewable source of hydrogen production (Dehhaghi et al. 2019). In essence, microorganisms are responsible for converting trash into hydrogen. The element hydrogen is unusually prevalent on the planet but does not exist in its elemental form. Fossils are the primary source for the industrial mass production of H_2 gas through water splitting, natural gas steam reforming, and as a byproduct of some industrial systems (Beyene et al. 2018). Hydrogen is currently produced by several sources, including water electrolysis (4%), coal (18%), oil (30%), and natural gas (48%) above one billion m/day globally (Kian 2020; Liguori et al. 2020). Researchers think hydrogen is the "fuel of the future" and will eventually replace non-renewable fuels globally (El Bouraie and El Din 2016; Lin et al. 2018; Srinivasan and Sadasivam 2021; Wang et al. 2023). Demand for biologically produced hydrogen from waste is rising due to its natural sustainability and replenishment ability. MSW is converted into bio hydrogen energy by the action of microorganisms with various flexible digestive mechanisms (Kourkoumpas et al. 2015). Biologically produced hydrogen is preferable due to its low energy requirement, cost-effectiveness, high yield (142kjg^{-1}, 2.75 times that of any other hydrocarbon fuel), high calorific value, and GHG-free nature (Kumar and Samadder 2017; Bello et al. 2022; Luís Padilha and Luiz Amarante Mesquita 2022). In addition, hydrogen is an essential feedstock for chemical plants (Fountoulakis and Manios 2009; Zahedi et al. 2016). Biological and physical-chemical processes, such as thermal conversion, dark fermentation, photo fermentation, and photo-biological operation, are the two main ways to produce hydrogen. The two main categories of photo-biological fermentation are light-dependent. The former is exhausting and contributes to global warming.

In contrast, the latter is environmentally friendly, lessens energy depletion, provides inexpensive substrate, has a high calorific value, and yields superior energy. Light-dependent or light-independent anaerobic fermentation also controls biological production techniques (Beyene et al. 2018). Although greenhouse gases are produced using energy-intensive physical-chemical processes that contribute to global warming, natural methods are more environmentally friendly, use less energy, and require less expensive substrate (Zhang and Angelidaki 2014; Kadier et al. 2016; Bora et al. 2022).

Hydrogen production is influenced by many factors, including the bioreactor used, pH, temperature, microbial strains, light intensity, hydraulic retention time, nutrients, and hydrogen partial pressure. Two different types of bioreactors are used to produce biological hydrogen. One is an open system comprised of lacks and open ponds (raceway ponds), and the other is a closed system composed of flat plates, tubular fermenters, pyramidal fermenters, conical fermenters, etc. Biohydrogens are a growing field of study, and researchers are interested (Zahedi et al. 2016; Bernat et al. 2021; Mahesh et al. 2021). **Fig. 7** provides a schematic representation of biomass change into several forms of bioenergy consuming various wastes.

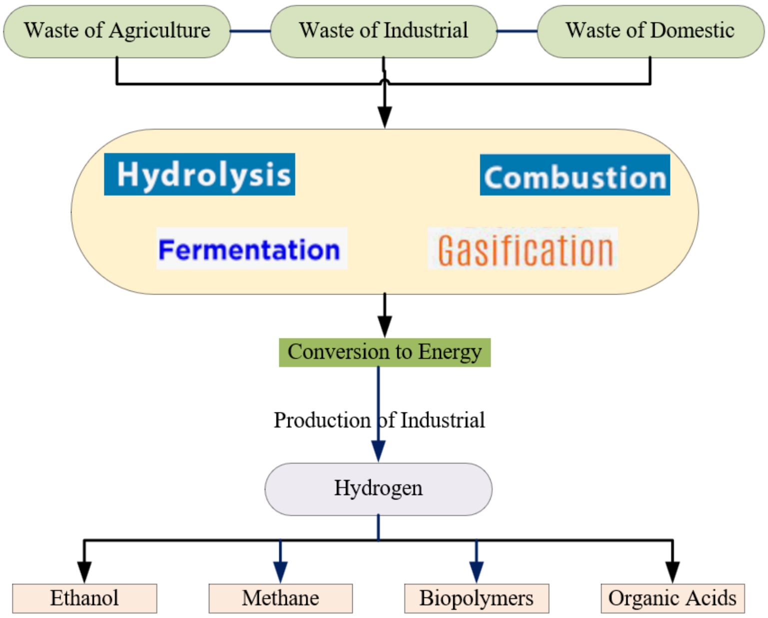

Fig. 7. Utilization of various wastes to convert biomass into bioenergy. It is reproduced from reference with permission (Dehhaghi et al. 2019).

Analysis of the techno-economic viability of producing biohydrogen. According to the current trend, energy needs are expected to increase by 60%, with India and China accounting for 35% of global demand (Khatib 2011). A multifaceted approach should be used to reduce ecological footprints, focusing on renewable energy sources, particularly biohydrogen (Sudhakar et al. 2011). Increased CO_2 emissions from their burning accompany the depletion of conventional fuels (Srivastava and Prasad 2000). In this case, hydrogen gas may be viable in meeting the energy requirements because it is a carbon-free fuel with a high energy density per unit of mass and is regenerative. Biohydrogen production has several advantages compared to other hydrogen generation methods (Dutta et al. 2005). The estimated capital costs of USD 40 million and operating costs of USD 10 million go along with the estimated annual output of N1.0 million GJ from photo-bioreactors (14 h) and open pond-based (140 h) systems, which include bio-photolysis. The estimated cost of producing hydrogen is USD 10/GJ, representing about 90% of the total price with a 25% annual charge (Akkerman et al. 2002; Sakurai et al. 2013; Poudyal et al. 2015). It's challenging and technologically advanced to produce hydrogen using algae. Because it is believed to be the safest, cleanest, and most environmentally friendly fuel, hydrogen has increased in demand in recent years (Sathyaprakasan and Kannan 2015). It is the best fuel for generating electricity using fuel cells because it does not produce carbon dioxide or hydrogen sulfide when used (Macaskie et al. 2005). It is necessary to form a group of committed engineers and scientists who can research biohydrogen and fuel cells and supply an uninterrupted supply of hydrogen using bioreactors. The bioreactor's design and the chosen production method will affect how much biohydrogen costs.

For this reason, it is strongly advised to use cost-effective and R&D-based technologies for hydrogen production. Because hydrogen can be directly supplied to the fuel cell at room temperature, one feature that sets it apart from other fuels, developed nations plan to build hydrogen highways to encourage using hydrogen fuel cells (Demirbas 2009). The following estimate the reactors' construction costs: Blue trap $0.46, PVC $5.56, glass $51.61, and Plexiglas $15.47 (Sathyaprakasan and Kannan 2015). According to the literature, a closed plant would require labour costs of about $15,000 per hour and maintenance costs of 10% per hour for a total price of $100,000. An estimated $50 billion will be spent on labour for the larger bioreactors (2 million ha) (Sathyaprakasan and Kannan 2015).

d. Biological and Mechanical Treatment

Anabaena variabilis 32 W/m2 7.73 l/kg/h 1.32 and mechanical treatment (MT) are two pretreatment stages for waste production known as MBT. Mechanical treatment in the first stage determines a larger MSW size, and in the BT stage, MT residue is used to create organic fertilizer and biogas. Material capital is recycled using the MBT method. This restricts the emission of greenhouse gases. MBT increases resource recovery, reduces landfill waste volume, and produces renewable MSW fuels. The MBT application manages and transports waste feed in various streams for material recycling, disposal, and energy recovery (2009; Khatib 2011, 2012). Mechanical separation involves using multiple tools, including magnets, ballistic separators, and near-infrared (NIR) separators, and manually removing bulky, heavy materials. Waste materials like plastic and glass are typically broken into a few hundred millimetres of fragments to facilitate separation (Kourkoumpas et al. 2015).

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6. New Technologies and Trends

a. Processes Involving Photobiology

Rhodopseudomonas palustris, Rhodopseudomonas capsulate, Rhodobacter sphaeroides, and Rhodospirillum rubrum are light-dependent examples of phototropic bacteria that are used in these processes, along with organic carbon as a substrate. In contrast to hydrogenase and nitrogenase, bacteria use other enzymes to break down substrate into bio-hydrogen, carbon monoxide, and organic acid. Additionally, bacteria lose photosystem II, which aids in removing oxygen from the system and permits a fully anaerobic condition during application (Sudhakar et al. 2011). **Table 3** lists the rates at which bacteria and algae produce hydrogen.

Table 3. Rate of hydrogen synthesis by different cyanobacteria and green algae strains. They are taken from a reference (Mona et al. 2020; Karishma et al. 2022; Kumar Sharma et al. 2022).

Microorganism	PCC7: Anabaena 120	Anabaena diverse	Anabaena of variabilis	Alpicola Gloeocapsa	Synechococcus sp.	Phyllostachys reinhardtii
Light Illumination (μE/m²/s)	456	32 W/m²	353	165	25 W/m²	100
Rate mL/h	14.9	7.73 l/ kg/h	20	25	-	2.8–2.9
The efficiency of Light Conversion (%)	0.042	1.32	1	-	2.6	-

b. Fermentation of ethanol

It is a biochemical reaction that involves the hydrolysis of sucrose and the fermentation of sugars. First, sugar hydrolysis by the enzyme produces glucose and fructose. Then, ethanol is delivered through an enzyme reaction from glucose and fructose. Up until the enzyme is inactivated, fermentation continues to hydrolyze enzymes. Then, water is removed during distillation to produce anhydrous bioethanol (Boukelia et al. 2015, 2016, 2017). Various food waste, including cafeteria food waste, banana peel waste, potato peel waste, grape waste, and household food waste, can be converted into bio-ethanol (Zaman 2009; Kobayashi et al. 2012; Sarkar et al. 2016; Baldi et al. 2019). Waste is pretreated using enzymatic, thermal, alkali, and acid processes to increase cellulose solubility (Dong et al. 2009; Allegue et al. 2020; Jojoa-Unigarro and González-Martínez 2023). Enzymatic hydrolysis is the most popular pretreatment method for producing ethanol from food waste (Alibardi and Cossu 2015; Paillet et al. 2021; Zhou et al. 2021). To produce ethanol from food waste, ethanol fermentation is an alluring technology and viable strategy that reduces carbon footprint and food waste. Research is still required to determine the process's price and viability to increase the economics of producing ethanol from food (Tawfik and El-Qelish 2014; Yong et al. 2021; Zamri et al. 2021). **Fig. 8** shows a general schematic illustration of the procedure.

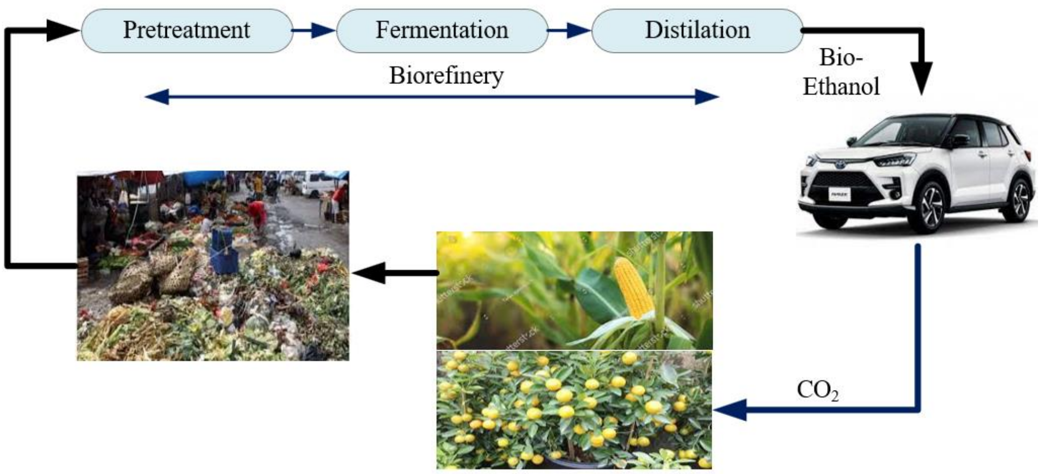

Fig. 8. Diagram of the organic matter used in ethanol fermentation and reproduced from reference with permission (Beyene et al. 2018).

7. Impacts on the Environment and Health

Air pollution occurs due to the release of COx, NOx, SOx, furans, and dioxin from the incineration of MSW. Thanks to efforts to improve pollution control mechanisms and incineration energy recovery systems, the MSWM option has become more appealing (Raheem et al. 2016). Compared to conventional coal-related power plants, Incineration plants' climate-friendly controls focus on capturing furans, dioxin, nitrogen oxides, and fine particles (Kim et al. 2011). Numerous studies have found that incineration plants potentially risk human health. The public is against incineration plants because they are expected to pose a health risk, even in developed nations like the UK. However, incinerations produce a variety of pollutants, and incomplete combustion results in the production of polychlorinated biphenyls, polychlorinated dibenzofuran, and polychlorinated dibenzo-p-dioxin, which is the leading cause for concern (Khan and Faisal 2008; Nixon et al. 2013; Yap and Nixon 2015). Dioxins are highly carcinogenic to animals, according to laboratory research by the International Agency for Cancer Research, which also examined a group of residents of industrial (Oberoi et al. 2011a, b; Mishra et al. 2020). Additionally, numerous studies found conflicting and improbable effects of incineration on public health (Arapoglou et al. 2010; Lu et al. 2020b; Soltaninejad et al. 2022).

8. Effect of Climate Change

Most of the evidence presented in reports on the impact of waste-to-energy technologies and additional MSWM options on environmental change comes from developing nations (Rodríguez et al. 2010). Because environment modification is a global problem, collective efforts are required to reverse it. Technologies that reduce greenhouse gas emissions and improve climate change brought on by producing and using energy derived from conformist methods are necessary (Matsakas et al. 2014). MSW is the third-largest source of anthropogenetic methane gas, accounting for 3-4% of global GHG and 18% of global methane production (Matsakas et al. 2014; Liu et al. 2020; Chen et al. 2022b). Since there is currently no thoroughly recommended method, the methane emission from landfills is estimated using theoretical models with numerous assumptions (Mohanty et al. 2009; Rodríguez et al. 2010; Mazaheri et al. 2012). Because methane is 21 times more potent than carbon dioxide and has a high energy content, methane capture requires a mechanism of sense to protect the environment from its potential GHG. According to research, recycling and waste minimization effectively reduce global GHG emissions (Ali et al. 2013; Baniya et al. 2021a, b). Biofuels from MSW (non-recyclable) will positively impact climate change (Damgaard et al. 2010; Siddiqi et al. 2020). The present ability of waste-to-energy technologies to combat global warming and estimate that using integrated SWM and the 3Rs principle can reduce global GHG emissions by up to 15-20% (Reduce, Reuse, and Recycle) (Bruno et al. 2021; Abbasi et al. 2022; Dan et al. 2023).

9. Conclusion

Finally, various waste-to-energy technologies used for energy recovery have been examined. Municipal solid waste (MSW) is one of the renewable energy sources that could be used by implementing waste-to-energy technologies. To meet the growing energy demand and reduce the MSWM problem, it is determined that adopting waste-to-energy technologies will reduce reliance on stereotypical energy conversion sources. The most practical technologies are landfilling for inert wastes, anaerobic digestion, pyrolysis, incineration for mixed MSW, and gasification for electronic tools, wood, plastic, electric wastes, tyres, etc. Additionally, choosing a suitable waste-to-energy technique depends critically on the makeup and characteristics of MSW. While waste-to-energy technologies are meticulously used in developing nations to manage MSW, most facilities lack proper infrastructure, maintenance, and pollution control. Investigations show that, in contrast to developing countries, the waste-to-energy sectors are given priority and are well-established and equipped with advanced technology. Although on a smaller scale, some developed nations have already installed waste-to-energy plants. On the other hand, waste-to-energy technologies in developing countries can be strengthened by enhancing governmental policies, regulations, and financial support. This modest effort will undoubtedly assist researchers and policymakers in classifying the best waste-to-energy technologies for developed countries.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Abbasi G, Khoshalhan F, Javad Hosseininezhad S (2022) Municipal solid waste management and energy production: A multi-objective optimization approach to incineration and biogas waste-to-energy supply chain. Sustain Energy Technol Assessments 54:102809. https://doi.org/https://doi.org/10.1016/j.seta.2022.102809

Abdel-Shafy HI, Mansour MSM (2018) Solid waste issue: Sources, composition, disposal, recycling, and valorization. Egypt J Pet 27:1275–1290. https://doi.org/https://doi.org/10.1016/j.ejpe.2018.07.003

Adeboye BS, Idris MO, Adedeji WO, et al. (2022) Characterization and energy potential of municipal solid waste in Osogbo metropolis. Clean Waste Syst 2:100020. https://doi.org/https://doi.org/10.1016/j.clwas.2022.100020

Adeniran AE, Nubi AT, Adelopo AO (2017) Solid waste generation and characterization in the University of Lagos for a sustainable waste management. Waste Manag 67:3–10. https://doi.org/https://doi.org/10.1016/j.wasman.2017.05.002

Ahn HK, Sauer TJ, Richard TL, Glanville TD (2009) Determination of thermal properties of composting bulking materials. Bioresour Technol 100:3974–3981. https://doi.org/https://doi.org/10.1016/j.biortech.2008.11.056

Aja OC, Al-Kayiem HH (2014) Review of municipal solid waste management options in Malaysia, with an emphasis on sustainable waste-to-energy options. J Mater cycles waste Manag 16:693–710

Akkerman I, Janssen M, Rocha J, Wijffels RH (2002) Photobiological hydrogen production: photochemical efficiency and bioreactor design. Int J Hydrogen Energy 27:1195–1208. https://doi.org/https://doi.org/10.1016/S0360-3199(02)00071-X

Albores P, Petridis K, Dey PK (2016) Analysing Efficiency of Waste to Energy Systems: Using Data Envelopment Analysis in Municipal Solid Waste Management. Procedia Environ Sci 35:265–278. https://doi.org/https://doi.org/10.1016/j.proenv.2016.07.007

Ali G, Abbas S, Mueen Qamer F (2013) How effectively low carbon society development models contribute to climate change mitigation and adaptation action plans in Asia. Renew Sustain Energy Rev 26:632–638. https://doi.org/https://doi.org/10.1016/j.rser.2013.05.042

Ali J, Rasheed T, Afreen M, et al. (2020) Modalities for conversion of waste to energy — Challenges and perspectives. Sci Total Environ 727:138610. https://doi.org/https://doi.org/10.1016/j.scitotenv.2020.138610

Alibardi L, Cossu R (2015) Composition variability of the organic fraction of municipal solid waste and effects on hydrogen and methane production potentials. Waste Manag 36:147–155. https://doi.org/https://doi.org/10.1016/j.wasman.2014.11.019

Aljerf L (2016) Reduction of gas emission resulting from thermal ceramic manufacturing processes through development of industrial conditions. Sci J King Faisal Univ 17:1–10

Allegrini E, Maresca A, Olsson ME, et al. (2014) Quantification of the resource recovery potential of municipal solid waste incineration bottom ashes. Waste Manag 34:1627–1636.

https://doi.org/https://doi.org/10.1016/j.wasman.2014.05.003
Allegue LD, Puyol D, Melero JA (2020) Novel approach for the treatment of the organic fraction of municipal solid waste: Coupling thermal hydrolysis with anaerobic digestion and photo-fermentation. Sci Total Environ 714:136845. https://doi.org/https://doi.org/10.1016/j.scitotenv.2020.136845
Almulhim AI (2022) Household's awareness and participation in sustainable electronic waste management practices in Saudi Arabia. Ain Shams Eng J 13:101729. https://doi.org/https://doi.org/10.1016/j.asej.2022.101729
Antonopoulos I-S, Perkoulidis G, Logothetis D, Karkanias C (2014) Ranking municipal solid waste treatment alternatives considering sustainability criteria using the analytical hierarchical process tool. Resour Conserv Recycl 86:149–159. https://doi.org/https://doi.org/10.1016/j.resconrec.2014.03.002
Anyaegbunam F (2013) Plasma Gasification for waste management and sustainable renewable clean energy generation. Proc Natl Acad Sci 6:33–50
Apergis N, Payne JE (2011) The renewable energy consumption–growth nexus in Central America. Appl Energy 88:343–347. https://doi.org/https://doi.org/10.1016/j.apenergy.2010.07.013
Appels L, Lauwers J, Degrève J, et al. (2011) Anaerobic digestion in global bio-energy production: Potential and research challenges. Renew Sustain Energy Rev 15:4295–4301. https://doi.org/https://doi.org/10.1016/j.rser.2011.07.121
Arafat HA, Jijakli K (2013) Modeling and comparative assessment of municipal solid waste gasification for energy production. Waste Manag 33:1704–1713. https://doi.org/https://doi.org/10.1016/j.wasman.2013.04.008
Arafat HA, Jijakli K, Ahsan A (2015) Environmental performance and energy recovery potential of five processes for municipal solid waste treatment. J Clean Prod 105:233–240. https://doi.org/https://doi.org/10.1016/j.jclepro.2013.11.071
Arapoglou D, Varzakas T, Vlyssides A, Israilides C (2010) Ethanol production from potato peel waste (PPW). Waste Manag 30:1898–1902. https://doi.org/https://doi.org/10.1016/j.wasman.2010.04.017
Arena U (2012) Process and technological aspects of municipal solid waste gasification. A review. Waste Manag 32:625–639. https://doi.org/https://doi.org/10.1016/j.wasman.2011.09.025
Atabani AE, Silitonga AS, Ong HC, et al. (2013) Non-edible vegetable oils: A critical evaluation of oil extraction, fatty acid compositions, biodiesel production, characteristics, engine performance and emissions production. Renew Sustain Energy Rev 18:211–245. https://doi.org/https://doi.org/10.1016/j.rser.2012.10.013
Awasthi SK, Sarsaiya S, Kumar V, et al (2022) Processing of municipal solid waste resources for a circular economy in China: An overview. Fuel 317:123478. https://doi.org/https://doi.org/10.1016/j.fuel.2022.123478
Azam M, Jahromy SS, Raza W, et al. (2019) Comparison of the combustion characteristics and kinetic study of coal, municipal solid waste, and refuse-derived fuel: Model-fitting methods. Energy Sci Eng 7:2646–2657
Bakalár T, Pavolová H, Hajduová Z, et al. (2021) Metal recovery from municipal solid waste incineration fly ash as a tool of circular economy. J Clean Prod 302:126977. https://doi.org/https://doi.org/10.1016/j.jclepro.2021.126977
Baldi F, Iannelli R, Pecorini I, et al. (2019) Influence of the pH control strategy and reactor volume on batch fermentative hydrogen production from the organic fraction of municipal solid waste. Waste Manag Res 37:478–485
Baniasadi M, Tugnoli A, Conti R, et al. (2016) Waste to energy valorization of poultry litter by slow pyrolysis. Renew Energy 90:458–468. https://doi.org/https://doi.org/10.1016/j.renene.2016.01.018
Baniya B, Giurco D, Kelly S (2021a) Changing policy paradigms: How are the climate change mitigation-oriented policies evolving in Nepal and Bangladesh? Environ Sci Policy 124:423–432. https://doi.org/https://doi.org/10.1016/j.envsci.2021.06.025
Baniya B, Giurco D, Kelly S, Aryal PP (2021b) Mainstreaming climate change mitigation actions in Nepal: Influencing factors and processes. Environ Sci Policy 124:206–216. https://doi.org/https://doi.org/10.1016/j.envsci.2021.06.018

Batidzirai B, Mignot APR, Schakel WB, et al (2013) Biomass torrefaction technology: Techno-economic status and future prospects. Energy 62:196–214. https://doi.org/https://doi.org/10.1016/j.energy.2013.09.035

Bello AS, Al-Ghouti MA, Abu-Dieyeh MH (2022) Sustainable and long-term management of municipal solid waste: A review. Bioresour Technol Reports 18:101067. https://doi.org/https://doi.org/10.1016/j.biteb.2022.101067

Bernat K, Zaborowska M, Wojnowska-Baryła I, Piotrowicz B (2021) Leachate after aerobic stabilization of municipal solid waste supplemented by waste glycerine from saponification to improve biogas production during co-digestion. Biomass and Bioenergy 144:105908. https://doi.org/https://doi.org/10.1016/j.biombioe.2020.105908

Beyene HD, Werkneh AA, Ambaye TG (2018) Current updates on waste to energy (WtE) technologies: a review. Renew Energy Focus 24:1–11. https://doi.org/https://doi.org/10.1016/j.ref.2017.11.001

Bing X, Bloemhof JM, Ramos TRP, et al. (2016) Research challenges in municipal solid waste logistics management. Waste Manag 48:584–592. https://doi.org/https://doi.org/10.1016/j.wasman.2015.11.025

Bora A, Mohanrasu K, Angelin Swetha T, et al. (2022) Microbial electrolysis cell (MEC): Reactor configurations, recent advances and strategies in biohydrogen production. Fuel 328:125269. https://doi.org/https://doi.org/10.1016/j.fuel.2022.125269

Bosmans A, Vanderreydt I, Geysen D, Helsen L (2013) The crucial role of Waste-to-Energy technologies in enhanced landfill mining: a technology review. J Clean Prod 55:10–23. https://doi.org/https://doi.org/10.1016/j.jclepro.2012.05.032

Boukelia TE, Arslan O, Mecibah MS (2017) Potential assessment of a parabolic trough solar thermal power plant considering hourly analysis: ANN-based approach. Renew Energy 105:324–333. https://doi.org/https://doi.org/10.1016/j.renene.2016.12.081

Boukelia TE, Arslan O, Mecibah MS (2016) ANN-based optimization of a parabolic trough solar thermal power plant. Appl Therm Eng 107:1210–1218. https://doi.org/https://doi.org/10.1016/j.applthermaleng.2016.07.084

Boukelia TE, Mecibah MS, Kumar BN, Reddy KS (2015) Investigation of solar parabolic trough power plants with and without integrated TES (thermal energy storage) and FBS (fuel backup system) using thermic oil and solar salt. Energy 88:292–303. https://doi.org/https://doi.org/10.1016/j.energy.2015.05.038

Brunner PH, Rechberger H (2015) Waste to energy–key element for sustainable waste management. Waste Manag 37:3–12

Bruno M, Abis M, Kuchta K, et al (2021) Material flow, economic and environmental assessment of municipal solid waste incineration bottom ash recycling potential in Europe. J Clean Prod 317:128511. https://doi.org/https://doi.org/10.1016/j.jclepro.2021.128511

Burm K (2012) Plasma: The fourth state of matter. Plasma Chem Plasma Process 32:401–407

Campos U, Zamenian H, Koo DD, Goodman DW (2015) Waste-to-Energy (WTE) technology applications for Municipal Solid Waste (MSW) treatment in the urban environment. Int J Emerg Technol Adv Eng 5:504–508

Cazaudehore G, Guyoneaud R, Evon P, et al. (2022) Can anaerobic digestion be a suitable end-of-life scenario for biodegradable plastics? A critical review of the current situation, hurdles, and challenges. Biotechnol Adv 56:107916. https://doi.org/https://doi.org/10.1016/j.biotechadv.2022.107916

Chand Malav L, Yadav KK, Gupta N, et al. (2020) A review on municipal solid waste as a renewable source for waste-to-energy project in India: Current practices, challenges, and future opportunities. J Clean Prod 277:123227. https://doi.org/https://doi.org/10.1016/j.jclepro.2020.123227

Chanthakett A, Arif MT, Khan MMK, Oo AMT (2021) Performance assessment of gasification reactors for sustainable management of municipal solid waste. J Environ Manage 291:112661. https://doi.org/https://doi.org/10.1016/j.jenvman.2021.112661

Charters WWS (2001) Developing markets for renewable energy technologies. Renew Energy 22:217–222. https://doi.org/https://doi.org/10.1016/S0960-1481(00)00018-5

Chen D, Cen K, Gan Z, et al. (2022a) Comparative study of electric-heating torrefaction and solar-driven torrefaction of biomass: Characterization of property variation and energy usage with

torrefaction severity. Appl Energy Combust Sci 9:100051. https://doi.org/https://doi.org/10.1016/j.jaecs.2021.100051
Chen D, Christensen TH (2010) Life-cycle assessment (EASEWASTE) of two municipal solid waste incineration technologies in China. Waste Manag Res 28:508–519
Chen W-H, Kuo P-C (2010) A study on torrefaction of various biomass materials and its impact on lignocellulosic structure simulated by a thermogravimetry. Energy 35:2580–2586. https://doi.org/https://doi.org/10.1016/j.energy.2010.02.054
Chen X, Geng Y, Fujita T (2010) An overview of municipal solid waste management in China. Waste Manag 30:716–724
Chen X, Zheng X, Pei Y, et al. (2022b) Process design and techno-economic analysis of fuel ethanol production from food waste by enzymatic hydrolysis and fermentation. Bioresour Technol 363:127882. https://doi.org/https://doi.org/10.1016/j.biortech.2022.127882
Chen Y-C (2016) Potential for energy recovery and greenhouse gas mitigation from municipal solid waste using a waste-to-material approach. Waste Manag 58:408–414. https://doi.org/https://doi.org/10.1016/j.wasman.2016.09.007
Cheng H, Hu Y (2010) Municipal solid waste (MSW) as a renewable source of energy: Current and future practices in China. Bioresour Technol 101:3816–3824. https://doi.org/https://doi.org/10.1016/j.biortech.2010.01.040
Chew ZT, Hoy ZX, Woon KS, Liew PY (2022) Integrating greenhouse gas reduction and waste policy targets to identify optimal waste treatment configurations via Carbon Emission Pinch Analysis. Process Saf Environ Prot 160:661–675. https://doi.org/https://doi.org/10.1016/j.psep.2022.02.060
Chou T-Y, Whiteley CG, Lee D-J (2014) Anodic potential on dual-chambered microbial fuel cell with sulphate reducing bacteria biofilm. Int J Hydrogen Energy 39:19225–19231. https://doi.org/https://doi.org/10.1016/j.ijhydene.2014.03.236
Cudjoe D, Wang H (2022) Plasma gasification versus incineration of plastic waste: Energy, economic and environmental analysis. Fuel Process Technol 237:107470. https://doi.org/https://doi.org/10.1016/j.fuproc.2022.107470
Czajczyńska D, Anguilano L, Ghazal H, et al (2017a) Potential of pyrolysis processes in the waste management sector. Therm Sci Eng Prog 3:171–197. https://doi.org/https://doi.org/10.1016/j.tsep.2017.06.003
Czajczyńska D, Nannou T, Anguilano L, et al (2017b) Potentials of pyrolysis processes in the waste management sector. Energy Procedia 123:387–394. https://doi.org/https://doi.org/10.1016/j.egypro.2017.07.275
Dai J, Whitty KJ (2022) Chemical looping gasification and sorption enhanced gasification of biomass: A perspective. Chem Eng Process - Process Intensif 174:108902. https://doi.org/https://doi.org/10.1016/j.cep.2022.108902
Damgaard A, Riber C, Fruergaard T, et al. (2010) Life-cycle-assessment of the historical development of air pollution control and energy recovery in waste incineration. Waste Manag 30:1244–1250. https://doi.org/https://doi.org/10.1016/j.wasman.2010.03.025
Dan Z, Che Y, Wang X, et al. (2023) Environmental, economic, and energy analysis of municipal solid waste incineration under anoxic environment in Tibet Plateau. Environ Res 216:114681. https://doi.org/https://doi.org/10.1016/j.envres.2022.114681
Danthurebandara M, Van Passel S, Vanderreydt I, Van Acker K (2015) Assessment of environmental and economic feasibility of Enhanced Landfill Mining. Waste Manag 45:434–447. https://doi.org/https://doi.org/10.1016/j.wasman.2015.01.041
Dehhaghi M, Tabatabaei M, Aghbashlo M, et al. (2019) A state-of-the-art review on the application of nanomaterials for enhancing biogas production. J Environ Manage 251:109597. https://doi.org/https://doi.org/10.1016/j.jenvman.2019.109597
Demirbas A (2009) Production of combustible gas from triglycerides via pyrolysis. Energy Sources, Part A 31:870–875
Deprá MC, Dias RR, Zepka LQ, Jacob-Lopes E (2022) Building cleaner production: How to anchor sustainability in the food production chain? Environ Adv 9:100295. https://doi.org/https://doi.org/10.1016/j.envadv.2022.100295
Deshmukh S, Kumar R, Bala K (2019) Microalgae biodiesel: A review on oil extraction, fatty acid composition, properties and effect on engine performance and emissions. Fuel Process Technol

191:232–247. https://doi.org/https://doi.org/10.1016/j.fuproc.2019.03.013

Desmarais M, Kraljić D (2021) Chapter 19 - Clean biological hydrogen production in microbial electrolysis cell. In: Bhaskar T, Varjani S, Pandey A, Rene ERBT-WB (eds). Elsevier, pp 491–505

Ding Y, Zhao J, Liu J-W, et al. (2021) A review of China's municipal solid waste (MSW) and comparison with international regions: Management and technologies in treatment and resource utilization. J Clean Prod 293:126144. https://doi.org/https://doi.org/10.1016/j.jclepro.2021.126144

Dong J, Tang Y, Nzihou A, Chi Y (2019) Key factors influencing the environmental performance of pyrolysis, gasification and incineration Waste-to-Energy technologies. Energy Convers Manag 196:497–512. https://doi.org/https://doi.org/10.1016/j.enconman.2019.06.016

Dong L, Zhenhong Y, Yongming S, et al. (2009) Hydrogen production characteristics of the organic fraction of municipal solid wastes by anaerobic mixed culture fermentation. Int J Hydrogen Energy 34:812–820. https://doi.org/https://doi.org/10.1016/j.ijhydene.2008.11.031

Du C, Qiu R, Ruan J (2018) Scientific and industrial application of plasma fluidized bed. In: Plasma Fluidized Bed. Springer, pp 81–121

Dutta D, De D, Chaudhuri S, Bhattacharya SK (2005) Hydrogen production by cyanobacteria. Microb Cell Fact 4:1–11

El Bouraie M, El Din WS (2016) Biodegradation of Reactive Black 5 by Aeromonas hydrophila strain isolated from dye-contaminated textile wastewater. Sustain Environ Res 26:209–216. https://doi.org/https://doi.org/10.1016/j.serj.2016.04.014

Eljaiek-Urzola M, Guardiola-Meza L, Ghafoori S, Mehrvar M (2018) Treatment of mature landfill leachate using hybrid processes of hydrogen peroxide and adsorption in an activated carbon fixed bed column. J Environ Sci Heal Part A 53:238–243

Elmnifi M, Alshilmany M, Abdraba M (2019) Potential of municipal solid waste in Libya for energy utilization. globe 11:13

Erdiwansyah, Mahidin, Husin H, et al. (2021) A critical review of the integration of renewable energy sources with various technologies. Prot Control Mod Power Syst 6:3. https://doi.org/10.1186/s41601-021-00181-3

Ezeudu OB, Ezeudu TS, Ugochukwu UC, et al. (2021) Enablers and barriers to implementation of circular economy in solid waste valorization: The case of urban markets in Anambra, Southeast Nigeria. Environ Sustain Indic 12:100150. https://doi.org/https://doi.org/10.1016/j.indic.2021.100150

Fabry F, Rehmet C, Rohani V, Fulcheri L (2013) Waste gasification by thermal plasma: a review. Waste and Biomass Valorization 4:421–439

Farouk H, Lang A, Tahir F, Al-Ghamdi SG (2022) Municipal solid waste: A potential source of clean energy for Khartoum State in Sudan. Energy Reports 8:342–349. https://doi.org/https://doi.org/10.1016/j.egyr.2022.05.145

Fazeli A, Bakhtvar F, Jahanshaloo L, et al. (2016) Malaysia's stand on municipal solid waste conversion to energy: A review. Renew Sustain Energy Rev 58:1007–1016. https://doi.org/https://doi.org/10.1016/j.rser.2015.12.270

Fekete H, Kuramochi T, Roelfsema M, et al (2021) A review of successful climate change mitigation policies in major emitting economies and the potential of global replication. Renew Sustain Energy Rev 137:110602. https://doi.org/https://doi.org/10.1016/j.rser.2020.110602

Fernández-Sandoval MT, Galíndez-Mayer J, Bolívar F, et al. (2019) Xylose–glucose co-fermentation to ethanol by Escherichia coli strain MS04 using single-and two-stage continuous cultures under micro-aerated conditions. Microb Cell Fact 18:1–11

Fountoulakis MS, Manios T (2009) Enhanced methane and hydrogen production from municipal solid waste and agro-industrial by-products co-digested with crude glycerol. Bioresour Technol 100:3043–3047. https://doi.org/https://doi.org/10.1016/j.biortech.2009.01.016

Frank-Kamenetskii D (2012) Plasma: the fourth state of matter. Springer Science & Business Media

Fu Z, Lin S, Tian H, et al. (2022) A comprehensive emission inventory of hazardous air pollutants from municipal solid waste incineration in China. Sci Total Environ 826:154212. https://doi.org/https://doi.org/10.1016/j.scitotenv.2022.154212

Gao N, Humphrey Milandile M, Tariq Sipra A, et al (2022) Co-pyrolysis of municipal solid waste

(MSW) and biomass with Co/sludge fly ash catalyst. Fuel 322:124127. https://doi.org/https://doi.org/10.1016/j.fuel.2022.124127
Gholizadeh M, Li C, Zhang S, et al. (2020) Progress of the development of reactors for pyrolysis of municipal waste. Sustain Energy Fuels 4:5885–5915
Gomes HI, Funari V, Dinelli E, Soavi F (2020) Enhanced electrodialytic bioleaching of fly ashes of municipal solid waste incineration for metal recovery. Electrochim Acta 345:136188. https://doi.org/https://doi.org/10.1016/j.electacta.2020.136188
Gumisiriza R, Hawumba JF, Okure M, Hensel O (2017) Biomass waste-to-energy valorisation technologies: a review case for banana processing in Uganda. Biotechnol Biofuels 10:1–29
Gunawardena A, Fernando S, To F (2008) Performance of a yeast-mediated biological fuel cell. Int J Mol Sci 9:1893–1907
Guruswamy L (2015) International Energy and Poverty
Hameed Z, Aslam M, Khan Z, et al (2021) Gasification of municipal solid waste blends with biomass for energy production and resources recovery: Current status, hybrid technologies and innovative prospects. Renew Sustain Energy Rev 136:110375. https://doi.org/https://doi.org/10.1016/j.rser.2020.110375
Hanson JL, Onnen MT, Yeşiller N, Kopp KB (2022) Heat energy potential of municipal solid waste landfills: Review of heat generation and assessment of vertical extraction systems. Renew Sustain Energy Rev 167:112835. https://doi.org/https://doi.org/10.1016/j.rser.2022.112835
Haraguchi M, Siddiqi A, Narayanamurti V (2019) Stochastic cost-benefit analysis of urban waste-to-energy systems. J Clean Prod 224:751–765. https://doi.org/https://doi.org/10.1016/j.jclepro.2019.03.099
Harish H, Rajanna S, Prakash GS, Muzzamil Ahamed S (2021) Extraction of biodiesel from tung seed oil and evaluating the performance and emission studies on 4-stroke CI engine. Mater Today Proc 46:4869–4877. https://doi.org/https://doi.org/10.1016/j.matpr.2020.10.328
Herva M, Roca E (2013) Ranking municipal solid waste treatment alternatives based on ecological footprint and multi-criteria analysis. Ecol Indic 25:77–84. https://doi.org/https://doi.org/10.1016/j.ecolind.2012.09.005
Hoang AT, Varbanov PS, Nižetić S, et al (2022) Perspective review on Municipal Solid Waste-to-energy route: Characteristics, management strategy, and role in circular economy. J Clean Prod 359:131897. https://doi.org/https://doi.org/10.1016/j.jclepro.2022.131897
Hoekman SK, Broch A, Warren A, et al (2014) Laboratory pelletization of hydrochar from woody biomass. Biofuels 5:651–666
Huang W, Fooladi H (2021) Economic and environmental estimated assessment of power production from municipal solid waste using anaerobic digestion and landfill gas technologies. Energy Reports 7:4460–4469. https://doi.org/https://doi.org/10.1016/j.egyr.2021.07.036
Ionescu G, Rada EC, Ragazzi M, et al. (2013) Integrated municipal solid waste scenario model using advanced pretreatment and waste to energy processes. Energy Convers Manag 76:1083–1092. https://doi.org/https://doi.org/10.1016/j.enconman.2013.08.049
Irvine G, Lamont ER, Antizar-Ladislao B (2010) Energy from waste: reuse of compost heat as a source of renewable energy. Int J Chem Eng 2010:
Jaiswal KK, Chowdhury CR, Yadav D, et al. (2022) Renewable and sustainable clean energy development and impact on social, economic, and environmental health. Energy Nexus 7:100118. https://doi.org/https://doi.org/10.1016/j.nexus.2022.100118
Jamasb T, Nepal R (2010) Issues and options in waste management: A social cost–benefit analysis of waste-to-energy in the UK. Resour Conserv Recycl 54:1341–1352. https://doi.org/https://doi.org/10.1016/j.resconrec.2010.05.004
Jojoa-Unigarro GD, González-Martínez S (2023) Methane production from ethanolic and acid fermentations of the organic fraction of municipal solid waste under different pH and reaction times. Biochem Eng J 190:108743. https://doi.org/https://doi.org/10.1016/j.bej.2022.108743
Jones PT, Geysen D, Tielemans Y, et al. (2013) Enhanced Landfill Mining in view of multiple resource recovery: a critical review. J Clean Prod 55:45–55. https://doi.org/https://doi.org/10.1016/j.jclepro.2012.05.021
Kabakcı SB, Hacıbektaşoğlu Ş (2017) Catalytic pyrolysis of biomass. Pyrolysis 7:167–196
Kadier A, Abdeshahian P, Simayi Y, et al. (2015) Grey relational analysis for comparative assessment

of different cathode materials in microbial electrolysis cells. Energy 90:1556–1562. https://doi.org/https://doi.org/10.1016/j.energy.2015.06.108

Kadier A, Kalil MS, Abdeshahian P, et al. (2016) Recent advances and emerging challenges in microbial electrolysis cells (MECs) for microbial production of hydrogen and value-added chemicals. Renew Sustain Energy Rev 61:501–525. https://doi.org/https://doi.org/10.1016/j.rser.2016.04.017

Kalyani KA, Pandey KK (2014) Waste to energy status in India: A short review. Renew Sustain Energy Rev 31:113–120. https://doi.org/https://doi.org/10.1016/j.rser.2013.11.020

Karampinis E, Kourkoumpas D, Grammelis P, Kakaras E (2015) New power production options for biomass and cogeneration. Wiley Interdiscip Rev Energy Environ 4:471–485

Karishma S, Saravanan A, Senthil Kumar P, Rangasamy G (2022) Sustainable production of biohydrogen from algae biomass: Critical review on pretreatment methods, mechanism and challenges. Bioresour Technol 366:128187. https://doi.org/https://doi.org/10.1016/j.biortech.2022.128187

Katuri KP, Ali M, Saikaly PE (2019) The role of microbial electrolysis cell in urban wastewater treatment: integration options, challenges, and prospects. Curr Opin Biotechnol 57:101–110. https://doi.org/https://doi.org/10.1016/j.copbio.2019.03.007

Keidar M, Yan D, Sherman JH (2019) Plasma as a fourth state of matter. This content has been downloaded from IOPscience Please scroll down to see full text

Kern S, Halwachs M, Kampichler G, et al. (2012) Rotary kiln pyrolysis of straw and fermentation residues in a 3MW pilot plant – Influence of pyrolysis temperature on pyrolysis product performance. J Anal Appl Pyrolysis 97:1–10. https://doi.org/https://doi.org/10.1016/j.jaap.2012.05.006

Khan MZ, Nizami AS, Rehan M, et al. (2017) Microbial electrolysis cells for hydrogen production and urban wastewater treatment: A case study of Saudi Arabia. Appl Energy 185:410–420. https://doi.org/https://doi.org/10.1016/j.apenergy.2016.11.005

Khan S, Anjum R, Raza ST, et al. (2022) Technologies for municipal solid waste management: Current status, challenges, and future perspectives. Chemosphere 288:132403. https://doi.org/https://doi.org/10.1016/j.chemosphere.2021.132403

Khan S, Faisal MN (2008) An analytic network process model for municipal solid waste disposal options. Waste Manag 28:1500–1508. https://doi.org/https://doi.org/10.1016/j.wasman.2007.06.015

Khatib H (2011) IEA World Energy Outlook 2010—A comment. Energy Policy 39:2507–2511. https://doi.org/https://doi.org/10.1016/j.enpol.2011.02.017

Khatib H (2012) IEA World Energy Outlook 2011—A comment. Energy Policy 48:737–743. https://doi.org/https://doi.org/10.1016/j.enpol.2012.06.007

Kian K (2020) Opportunities and Challenges of Low-Carbon Hydrogen via Metallic Membrane Reactors. Chem Eng

Kim JH, Lee JC, Pak D (2011) Feasibility of producing ethanol from food waste. Waste Manag 31:2121–2125. https://doi.org/https://doi.org/10.1016/j.wasman.2011.04.011

Kobayashi T, Xu K-Q, Li Y-Y, Inamori Y (2012) Evaluation of hydrogen and methane production from municipal solid wastes with different compositions of fat, protein, cellulosic materials and the other carbohydrates. Int J Hydrogen Energy 37:15711–15718. https://doi.org/https://doi.org/10.1016/j.ijhydene.2012.05.044

Komilis D, Kissas K, Symeonidis A (2014) Effect of organic matter and moisture on the calorific value of solid wastes: An update of the Tanner diagram. Waste Manag 34:249–255. https://doi.org/https://doi.org/10.1016/j.wasman.2013.09.023

Kong G, Wang K, Zhang X, et al. (2022) Torrefaction/carbonization-enhanced gasification-steam reforming of biomass for promoting hydrogen-enriched syngas production and tar elimination over gasification biochars. Bioresour Technol 363:127960. https://doi.org/https://doi.org/10.1016/j.biortech.2022.127960

Kota KB, Shenbagaraj S, Sharma PK, et al. (2022) Biomass torrefaction: An overview of process and technology assessment based on global readiness level. Fuel 324:124663. https://doi.org/https://doi.org/10.1016/j.fuel.2022.124663

Kothari R, Tyagi V V, Pathak A (2010) Waste-to-energy: A way from renewable energy sources to

sustainable development. Renew Sustain Energy Rev 14:3164–3170. https://doi.org/https://doi.org/10.1016/j.rser.2010.05.005
Kourkoumpas D-S, Karellas S, Kouloumoundras S, et al. (2015) Comparison of waste-to-energy processes by means of life cycle analysis principles regarding the global warming potential impact: applied case studies in Greece, France and Germany. Waste and biomass valorization 6:605–621
Kumar A, Samadder SR (2017) A review on technological options of waste to energy for effective management of municipal solid waste. Waste Manag 69:407–422. https://doi.org/https://doi.org/10.1016/j.wasman.2017.08.046
Kumar Sharma A, Kumar Ghodke P, Goyal N, et al. (2022) Machine learning technology in biohydrogen production from agriculture waste: Recent advances and future perspectives. Bioresour Technol 364:128076. https://doi.org/https://doi.org/10.1016/j.biortech.2022.128076
Laner D, Esguerra JL, Krook J, et al. (2019) Systematic assessment of critical factors for the economic performance of landfill mining in Europe: What drives the economy of landfill mining? Waste Manag 95:674–686. https://doi.org/https://doi.org/10.1016/j.wasman.2019.07.007
Lappas AA, Kalogiannis KG, Iliopoulou EF, et al. (2016) Catalytic pyrolysis of biomass for transportation fuels. Adv Bioenergy Sustain Chall 45–56
Lee D-J (2022) Gasification of municipal solid waste (MSW) as a cleaner final disposal route: A mini-review. Bioresour Technol 344:126217. https://doi.org/https://doi.org/10.1016/j.biortech.2021.126217
Leme MMV, Rocha MH, Lora EES, et al. (2014) Techno-economic analysis and environmental impact assessment of energy recovery from Municipal Solid Waste (MSW) in Brazil. Resour Conserv Recycl 87:8–20. https://doi.org/https://doi.org/10.1016/j.resconrec.2014.03.003
Li W-W, Yu H-Q, He Z (2014) Towards sustainable wastewater treatment by using microbial fuel cells-centered technologies. Energy Environ Sci 7:911–924
Li Y, Zhao X, Li Y, Li X (2015) Waste incineration industry and development policies in China. Waste Manag 46:234–241. https://doi.org/https://doi.org/10.1016/j.wasman.2015.08.008
Liguori S, Kian K, Buggy N, et al. (2020) Opportunities and challenges of low-carbon hydrogen via metallic membranes. Prog Energy Combust Sci 80:100851
Lin C-Y, Nguyen TM-L, Chu C-Y, et al. (2018) Fermentative biohydrogen production and its byproducts: A mini review of current technology developments. Renew Sustain Energy Rev 82:4215–4220. https://doi.org/https://doi.org/10.1016/j.rser.2017.11.001
Liu Y, Han W, Xu X, et al. (2020) Ethanol production from waste pizza by enzymatic hydrolysis and fermentation. Biochem Eng J 156:107528. https://doi.org/https://doi.org/10.1016/j.bej.2020.107528
Liu Y, Liao C, Tang Y, et al. (2022) Techno-environmental-economic evaluation of the small-scale municipal solid waste (MSW) gasification-based and incineration-based power generation plants. J Taiwan Inst Chem Eng 141:104594. https://doi.org/https://doi.org/10.1016/j.jtice.2022.104594
Logroño W, Ramírez G, Recalde C, et al (2015) Bioelectricity Generation from Vegetables and Fruits Wastes by Using Single Chamber Microbial Fuel Cells with High Andean Soils. Energy Procedia 75:2009–2014. https://doi.org/https://doi.org/10.1016/j.egypro.2015.07.259
Logroño W, Recalde C, Echeverria M (2014) Influence of cell size on performance of microbial fuel cells of single chamber using organic solid waste with Amazonian and High Andeans soils from Ecuador. N Biotechnol 31:S213. https://doi.org/https://doi.org/10.1016/j.nbt.2014.05.997
Lombardi L, Carnevale E, Corti A (2015) A review of technologies and performances of thermal treatment systems for energy recovery from waste. Waste Manag 37:26–44. https://doi.org/https://doi.org/10.1016/j.wasman.2014.11.010
Lopez G, Artetxe M, Amutio M, et al (2018) Recent advances in the gasification of waste plastics. A critical overview. Renew Sustain Energy Rev 82:576–596. https://doi.org/https://doi.org/10.1016/j.rser.2017.09.032
Lu J-S, Chang Y, Poon C-S, Lee D-J (2020a) Slow pyrolysis of municipal solid waste (MSW): A review. Bioresour Technol 312:123615. https://doi.org/https://doi.org/10.1016/j.biortech.2020.123615
Lu J-W, Zhang S, Hai J, Lei M (2017) Status and perspectives of municipal solid waste incineration in China: A comparison with developed regions. Waste Manag 69:170–186.

https://doi.org/https://doi.org/10.1016/j.wasman.2017.04.014
Lu Y, Zhang Q, Wang X, et al. (2020b) Effect of pH on volatile fatty acid production from anaerobic digestion of potato peel waste. Bioresour Technol 316:123851. https://doi.org/https://doi.org/10.1016/j.biortech.2020.123851
Luís Padilha J, Luiz Amarante Mesquita A (2022) Waste-to-energy effect in municipal solid waste treatment for small cities in Brazil. Energy Convers Manag 265:115743. https://doi.org/https://doi.org/10.1016/j.enconman.2022.115743
Luz FC, Rocha MH, Lora EES, et al (2015) Techno-economic analysis of municipal solid waste gasification for electricity generation in Brazil. Energy Convers Manag 103:321–337. https://doi.org/https://doi.org/10.1016/j.enconman.2015.06.074
Macaskie LE, Baxter-Plant VS, Creamer NJ, et al. (2005) Applications of bacterial hydrogenases in waste decontamination, manufacture of novel bionanocatalysts and in sustainable energy
Mahesh D, Ahmad S, Kumar R, et al. (2021) Hydrothermal liquefaction of municipal solid wastes for high quality bio-crude production using glycerol as co-solvent. Bioresour Technol 339:125537. https://doi.org/https://doi.org/10.1016/j.biortech.2021.125537
Malinauskaite J, Jouhara H, Czajczyńska D, et al. (2017) Municipal solid waste management and waste-to-energy in the context of a circular economy and energy recycling in Europe. Energy 141:2013–2044. https://doi.org/https://doi.org/10.1016/j.energy.2017.11.128
Mamvura TA, Danha G (2020) Biomass torrefaction as an emerging technology to aid in energy production. Heliyon 6:e03531. https://doi.org/https://doi.org/10.1016/j.heliyon.2020.e03531
Matsakas L, Kekos D, Loizidou M, Christakopoulos P (2014) Utilization of household food waste for the production of ethanol at high dry material content. Biotechnol Biofuels 7:1–9
Mazaheri D, Shojaosadati SA, Mousavi SM, et al. (2012) Bioethanol production from carob pods by solid-state fermentation with Zymomonas mobilis. Appl Energy 99:372–378. https://doi.org/https://doi.org/10.1016/j.apenergy.2012.05.045
Medic D, Darr M, Potter B, Shah A (2010) Effect of torrefaction process parameters on biomass feedstock upgrading. In: 2010 Pittsburgh, Pennsylvania, June 20-June 23, 2010. American Society of Agricultural and Biological Engineers, p 1
Melaibari AA, Alamoudi AS, Mostafa ME, Abu-Hamdeh NH (2023) Utilization of various waste sources in Saudi Arabia as a new clean and renewable energy source: Adsorption of phenol pollutants and removal from petroleum industrial wastes via molecular dynamics simulation. Eng Anal Bound Elem 147:164–170. https://doi.org/https://doi.org/10.1016/j.enganabound.2022.12.010
Melikoglu M (2013) Vision 2023: Assessing the feasibility of electricity and biogas production from municipal solid waste in Turkey. Renew Sustain Energy Rev 19:52–63. https://doi.org/https://doi.org/10.1016/j.rser.2012.11.017
Mesjasz-Lech A (2019) Reverse logistics of municipal solid waste – towards zero waste cities. Transp Res Procedia 39:320–332. https://doi.org/https://doi.org/10.1016/j.trpro.2019.06.034
Minghua Z, Xiumin F, Rovetta A, et al. (2009) Municipal solid waste management in Pudong new area, China. Waste Manag 29:1227–1233
Misganaw A, Teffera B (2022) An assessment of the waste-to-energy potential of municipal solid wastes in Ethiopia. Bioresour Technol Reports 19:101180. https://doi.org/https://doi.org/10.1016/j.biteb.2022.101180
Mishra RR, Samantaray B, Chandra Behera B, et al. (2020) Process optimization for conversion of Waste Banana peels to biobutanol by A yeast Co-Culture fermentation system. Renew Energy 162:478–488. https://doi.org/https://doi.org/10.1016/j.renene.2020.08.045
Mohanty SK, Behera S, Swain MR, Ray RC (2009) Bioethanol production from mahula (Madhuca latifolia L.) flowers by solid-state fermentation. Appl Energy 86:640–644. https://doi.org/https://doi.org/10.1016/j.apenergy.2008.08.022
Mona S, Kumar SS, Kumar V, et al. (2020) Green technology for sustainable biohydrogen production (waste to energy): A review. Sci Total Environ 728:138481. https://doi.org/https://doi.org/10.1016/j.scitotenv.2020.138481
Morf LS, Gloor R, Haag O, et al. (2013) Precious metals and rare earth elements in municipal solid waste–sources and fate in a Swiss incineration plant. Waste Manag 33:634–644
Mountouris A, Voutsas E, Magoulas K, et al. (2003) Plasma waste treatment: Process design and energy

optimization. In: Proc. 8th Int. Conf. Environ. Sci. Technol. pp 588–595
Mukherjee C, Denney J, Mbonimpa EG, et al. (2020) A review on municipal solid waste-to-energy trends in the USA. Renew Sustain Energy Rev 119:109512. https://doi.org/https://doi.org/10.1016/j.rser.2019.109512
Munir MT, Mardon I, Al-Zuhair S, et al. (2019) Plasma gasification of municipal solid waste for waste-to-value processing. Renew Sustain Energy Rev 116:109461. https://doi.org/https://doi.org/10.1016/j.rser.2019.109461
Murphy JD, McKeogh E, Kiely G (2004) Technical/economic/environmental analysis of biogas utilisation. Appl Energy 77:407–427. https://doi.org/https://doi.org/10.1016/j.apenergy.2003.07.005
Narayana Prasad P, Kalla S (2021) Plant-microbial fuel cells - A bibliometric analysis. Process Biochem 111:250–260. https://doi.org/https://doi.org/10.1016/j.procbio.2021.10.001
Nguyen D, Gadhamshetty V, Nitayavardhana S, Khanal SK (2015) Automatic process control in anaerobic digestion technology: A critical review. Bioresour Technol 193:513–522. https://doi.org/https://doi.org/10.1016/j.biortech.2015.06.080
Ni T, Si J, Lu F, et al. (2022) Performance analysis and optimization of cascade waste heat recovery system based on transcritical CO2 cycle for waste heat recovery in waste-to-energy plant. J Clean Prod 331:129949. https://doi.org/https://doi.org/10.1016/j.jclepro.2021.129949
Nie Y (2008) Development and prospects of municipal solid waste (MSW) incineration in China. Front Environ Sci Eng China 2:1–7
Nirmala N, Subathra M, Shyam S, et al (2022) 11 - Hydrothermal gasification of biomass for hydrogen production: Advances, challenges, and prospects. In: Nanda S, Vo D-VBT-I in TT for BP (eds). Elsevier, pp 259–273
Nitisoravut R, Regmi R (2017) Plant microbial fuel cells: A promising biosystems engineering. Renew Sustain Energy Rev 76:81–89. https://doi.org/https://doi.org/10.1016/j.rser.2017.03.064
Nixon JD, Dey PK, Ghosh SK, Davies PA (2013) Evaluation of options for energy recovery from municipal solid waste in India using the hierarchical analytical network process. Energy 59:215–223. https://doi.org/https://doi.org/10.1016/j.energy.2013.06.052
Oberoi HS, Vadlani P V, Nanjundaswamy A, et al. (2011a) Enhanced ethanol production from Kinnow mandarin (Citrus reticulata) waste via a statistically optimized simultaneous saccharification and fermentation process. Bioresour Technol 102:1593–1601. https://doi.org/https://doi.org/10.1016/j.biortech.2010.08.111
Oberoi HS, Vadlani P V, Saida L, et al. (2011b) Ethanol production from banana peels using statistically optimized simultaneous saccharification and fermentation process. Waste Manag 31:1576–1584. https://doi.org/https://doi.org/10.1016/j.wasman.2011.02.007
Ouda OKM, Raza SA, Al-Waked R, et al. (2017) Waste-to-energy potential in the Western Province of Saudi Arabia. J King Saud Univ - Eng Sci 29:212–220. https://doi.org/https://doi.org/10.1016/j.jksues.2015.02.002
Ouda OKM, Raza SA, Nizami AS, et al. (2016) Waste to energy potential: A case study of Saudi Arabia. Renew Sustain Energy Rev 61:328–340. https://doi.org/https://doi.org/10.1016/j.rser.2016.04.005
Paillet F, Barrau C, Escudié R, et al. (2021) Robust operation through effluent recycling for hydrogen production from the organic fraction of municipal solid waste. Bioresour Technol 319:124196. https://doi.org/https://doi.org/10.1016/j.biortech.2020.124196
Pandey BK, Vyas S, Pandey M, Gaur A (2016) Municipal solid waste to energy conversion methodology as physical, thermal, and biological methods. Curr Sci Perspect 2:39–44
Panepinto D, Tedesco V, Brizio E, Genon G (2015) Environmental performances and energy efficiency for MSW gasification treatment. Waste and Biomass Valorization 6:123–135
Pang Y, Bahr L, Fendt P, et al (2018) Plasma-assisted biomass gasification with focus on carbon conversion and reaction kinetics compared to thermal gasification. Energies 11:1302
Patumsawad S, Cliffe KR (2002) Experimental study on fluidised bed combustion of high moisture municipal solid waste. Energy Convers Manag 43:2329–2340. https://doi.org/https://doi.org/10.1016/S0196-8904(01)00179-0
Pavlas M, Touš M (2009) Efficient waste-to-energy system as a contribution to clean technologies. Clean Technol Environ Policy 11:19–29
Peltola P, Ruottu L, Larkimo M, et al. (2023) A novel dual circulating fluidized bed technology for

thermal treatment of municipal sewage sludge with recovery of nutrients and energy. Waste Manag 155:329–337. https://doi.org/https://doi.org/10.1016/j.wasman.2022.11.017
Phanphanich M, Mani S (2011) Impact of torrefaction on the grindability and fuel characteristics of forest biomass. Bioresour Technol 102:1246–1253. https://doi.org/https://doi.org/10.1016/j.biortech.2010.08.028
Pirlogea C, Cicea C (2012) Econometric perspective of the energy consumption and economic growth relation in European Union. Renew Sustain Energy Rev 16:5718–5726. https://doi.org/https://doi.org/10.1016/j.rser.2012.06.010
Poudyal RS, Tiwari I, Koirala AR, et al. (2015) 10 - Hydrogen production using photobiological methods. In: Subramani V, Basile A, Veziroğlu TNBT-C of HE (eds) Woodhead Publishing Series in Energy. Woodhead Publishing, Oxford, pp 289–317
Prins MJ, Ptasinski KJ, Janssen FJJG (2006) More efficient biomass gasification via torrefaction. Energy 31:3458–3470. https://doi.org/https://doi.org/10.1016/j.energy.2006.03.008
Psomopoulos CS, Bourka A, Themelis NJ (2009) Waste-to-energy: A review of the status and benefits in USA. Waste Manag 29:1718–1724. https://doi.org/https://doi.org/10.1016/j.wasman.2008.11.020
Rabaey K, Verstraete W (2005) Microbial fuel cells: novel biotechnology for energy generation. Trends Biotechnol 23:291–298. https://doi.org/https://doi.org/10.1016/j.tibtech.2005.04.008
Radmehr R, Henneberry SR, Shayanmehr S (2021) Renewable Energy Consumption, CO2 Emissions, and Economic Growth Nexus: A Simultaneity Spatial Modeling Analysis of EU Countries. Struct Chang Econ Dyn 57:13–27. https://doi.org/https://doi.org/10.1016/j.strueco.2021.01.006
Radpour S, Gemechu E, Ahiduzzaman M, Kumar A (2021) Developing a framework to assess the long-term adoption of renewable energy technologies in the electric power sector: The effects of carbon price and economic incentives. Renew Sustain Energy Rev 152:111663. https://doi.org/https://doi.org/10.1016/j.rser.2021.111663
Raheem A, Hassan MY, Shakoor R (2016) Bioenergy from anaerobic digestion in Pakistan: Potential, development and prospects. Renew Sustain Energy Rev 59:264–275. https://doi.org/https://doi.org/10.1016/j.rser.2016.01.010
Rahimnejad M, Adhami A, Darvari S, et al. (2015) Microbial fuel cell as new technology for bioelectricity generation: A review. Alexandria Eng J 54:745–756. https://doi.org/https://doi.org/10.1016/j.aej.2015.03.031
Rahman W-U, Patel M, Kurian V, Kumar A (2022) A comparative techno-economic assessment of fast pyrolysis, hydrothermal liquefaction, and intermediate pyrolysis of municipal solid waste for liquid transportation fuels production. Energy Convers Manag 267:115877. https://doi.org/https://doi.org/10.1016/j.enconman.2022.115877
Rajaeifar MA, Ghanavati H, Dashti BB, et al. (2017) Electricity generation and GHG emission reduction potentials through different municipal solid waste management technologies: A comparative review. Renew Sustain Energy Rev 79:414–439. https://doi.org/https://doi.org/10.1016/j.rser.2017.04.109
Rajasekhar M, Rao NV, Rao GC, et al (2015) Energy Generation from Municipal Solid Waste by Innovative Technologies – Plasma Gasification. Procedia Mater Sci 10:513–518. https://doi.org/https://doi.org/10.1016/j.mspro.2015.06.094
Ramos A, Berzosa J, Espí J, et al (2020) Life cycle costing for plasma gasification of municipal solid waste: A socio-economic approach. Energy Convers Manag 209:112508. https://doi.org/https://doi.org/10.1016/j.enconman.2020.112508
Ramos A, Rouboa A (2018) A techno-economic approach to plasma gasification. In: AIP Conference Proceedings. AIP Publishing LLC, p 30038
Reddy PJ (2011) Municipal solid waste management. Netherlands CRC Press Retrieved Oct 9:2012
Ren Z, Ji G, Liu H, et al. (2022) Accelerated start-up and improved performance of wastewater microbial fuel cells in four circuit modes: Role of anodic potential. J Power Sources 535:231403. https://doi.org/https://doi.org/10.1016/j.jpowsour.2022.231403
Rena, Arya S, Chavan D, et al (2020) Reducing Greenhouse Gas Emission From Waste Landfill. In: Hashmi S, Choudhury IABT-E of R and SM (eds). Elsevier, Oxford, pp 685–701
Rezaei H, Panah FY, Lim J, Sokhansanj S (2020) Pelletization of Refuse-Derived Fuel with varying compositions of plastic, paper, organic and wood. Sustainability 12: 4645. DOI

org/103390/su12114645
Ríos A-M, Picazo-Tadeo AJ (2021) Measuring environmental performance in the treatment of municipal solid waste: The case of the European Union-28. Ecol Indic 123:107328. https://doi.org/https://doi.org/10.1016/j.ecolind.2020.107328
Rodríguez LA, Toro ME, Vazquez F, et al (2010) Bioethanol production from grape and sugar beet pomaces by solid-state fermentation. Int J Hydrogen Energy 35:5914–5917. https://doi.org/https://doi.org/10.1016/j.ijhydene.2009.12.112
Sadef Y, Nizami AS, Batool SA, et al. (2016) Waste-to-energy and recycling value for developing integrated solid waste management plan in Lahore. Energy Sources, Part B Econ Planning, Policy 11:569–579
Sáez-Martínez FJ, Lefebvre G, Hernández JJ, Clark JH (2016) Drivers of sustainable cleaner production and sustainable energy options. J Clean Prod 138:1–7. https://doi.org/https://doi.org/10.1016/j.jclepro.2016.08.094
Safar M, Lin B-J, Chen W-H, et al. (2019) Effects of impregnated potassium on biomass torrefaction. Energy Procedia 158:55–60. https://doi.org/https://doi.org/10.1016/j.egypro.2019.01.035
Saif Y, Griffiths S, Almansoori A (2022) Municipal solid waste supply chain management under an integrated optimization of sustainability targets. Comput Chem Eng 160:107725. https://doi.org/https://doi.org/10.1016/j.compchemeng.2022.107725
Sajid M, Raheem A, Ullah N, et al. (2022) Gasification of municipal solid waste: Progress, challenges, and prospects. Renew Sustain Energy Rev 168:112815. https://doi.org/https://doi.org/10.1016/j.rser.2022.112815
Sakurai H, Masukawa H, Kitashima M, Inoue K (2013) Photobiological hydrogen production: Bioenergetics and challenges for its practical application. J Photochem Photobiol C Photochem Rev 17:1–25. https://doi.org/https://doi.org/10.1016/j.jphotochemrev.2013.05.001
Sanlisoy A, Carpinlioglu MO (2017) A review on plasma gasification for solid waste disposal. Int J Hydrogen Energy 42:1361–1365. https://doi.org/https://doi.org/10.1016/j.ijhydene.2016.06.008
Santos SM, Ogunseitan OA (2022) E-waste management in Brazil: Challenges and opportunities of a reverse logistics model. Environ Technol Innov 28:102671. https://doi.org/https://doi.org/10.1016/j.eti.2022.102671
Sarkar O, Kumar AN, Dahiya S, et al. (2016) Regulation of acidogenic metabolism towards enhanced short chain fatty acid biosynthesis from waste: metagenomic profiling. RSC Adv 6:18641–18653
Sathyaprakasan P, Kannan G (2015) Economics of bio-hydrogen production. Int J Environ Sci Dev 6:352
Scarlat N, Motola V, Dallemand JF, et al. (2015) Evaluation of energy potential of Municipal Solid Waste from African urban areas. Renew Sustain Energy Rev 50:1269–1286. https://doi.org/https://doi.org/10.1016/j.rser.2015.05.067
Schneider JD (2016) International energy and poverty: The emerging contours
Schorr C, Muinonen M, Nurminen F (2012) Torrefaction of biomass. Mikkeli Miktech Ltd/Centre Expert 55
Shah A V, Srivastava VK, Mohanty SS, Varjani S (2021) Municipal solid waste as a sustainable resource for energy production: State-of-the-art review. J Environ Chem Eng 9:105717. https://doi.org/https://doi.org/10.1016/j.jece.2021.105717
Sharma GD, Tiwari AK, Erkut B, Mundi HS (2021) Exploring the nexus between non-renewable and renewable energy consumptions and economic development: Evidence from panel estimations. Renew Sustain Energy Rev 146:111152. https://doi.org/https://doi.org/10.1016/j.rser.2021.111152
Shi Z, Luo H, Li Z, et al (2021) Small boreholes embedded in the sediment layers make big difference in performance of sediment microbial fuel cells: Bioelectricity generation and microbial community. Int J Hydrogen Energy 46:30124–30134. https://doi.org/https://doi.org/10.1016/j.ijhydene.2021.06.155
Siddiqi A, Haraguchi M, Narayanamurti V (2020) Urban waste to energy recovery assessment simulations for developing countries. World Dev 131:104949. https://doi.org/https://doi.org/10.1016/j.worlddev.2020.104949
Sikarwar VS, Zhao M, Clough P, et al. (2016) An overview of advances in biomass gasification. Energy Environ Sci 9:2939–2977

Singh RP, Tyagi V V, Allen T, et al (2011) An overview for exploring the possibilities of energy generation from municipal solid waste (MSW) in Indian scenario. Renew Sustain Energy Rev 15:4797–4808. https://doi.org/https://doi.org/10.1016/j.rser.2011.07.071

Sipra AT, Gao N, Sarwar H (2018) Municipal solid waste (MSW) pyrolysis for bio-fuel production: A review of effects of MSW components and catalysts. Fuel Process Technol 175:131–147. https://doi.org/https://doi.org/10.1016/j.fuproc.2018.02.012

Sodari KB (2017) Potential for Energy Recovery and Greenhouse Gas Mitigation from Municipal Solid Waste Using Waste To Energy Approach

Soltaninejad A, Jazini M, Karimi K (2022) Sustainable bioconversion of potato peel wastes into ethanol and biogas using organosolv pretreatment. Chemosphere 291:133003. https://doi.org/https://doi.org/10.1016/j.chemosphere.2021.133003

Song J, Sun Y, Jin L (2017) PESTEL analysis of the development of the waste-to-energy incineration industry in China. Renew Sustain Energy Rev 80:276–289. https://doi.org/https://doi.org/10.1016/j.rser.2017.05.066

Song Y, Pei L, Chen G, et al. (2023) Recent advancements in strategies to improve anaerobic digestion of perennial energy grasses for enhanced methane production. Sci Total Environ 861:160552. https://doi.org/https://doi.org/10.1016/j.scitotenv.2022.160552

Srinivasan S, Sadasivam SK (2021) Biodegradation of textile azo dyes by textile effluent non-adapted and adapted Aeromonas hydrophila. Environ Res 194:110643. https://doi.org/https://doi.org/10.1016/j.envres.2020.110643

Srivastava A, Prasad R (2000) Triglycerides-based diesel fuels. Renew Sustain Energy Rev 4:111–133. https://doi.org/https://doi.org/10.1016/S1364-0321(99)00013-1

Sudhakar K, Suresh S, Premalatha M (2011) An overview of CO2 mitigation using algae cultivation technology. Int J Chem Res 3:110–117

Suksankraisorn K, Patumsawad S, Fungtammasan B (2010) Co-firing of Thai lignite and municipal solid waste (MSW) in a fluidised bed: Effect of MSW moisture content. Appl Therm Eng 30:2693–2697. https://doi.org/https://doi.org/10.1016/j.applthermaleng.2010.07.020

Suksankraisorn K, Patumsawad S, Fungtammasan B (2003) Combustion studies of high moisture content waste in a fluidised bed. Waste Manag 23:433–439. https://doi.org/https://doi.org/10.1016/S0956-053X(03)00060-6

Tan ST, Hashim H, Lim JS, et al (2014) Energy and emissions benefits of renewable energy derived from municipal solid waste: Analysis of a low carbon scenario in Malaysia. Appl Energy 136:797–804. https://doi.org/https://doi.org/10.1016/j.apenergy.2014.06.003

Tawfik A, El-Qelish M (2014) Key factors affecting on bio-hydrogen production from co-digestion of organic fraction of municipal solid waste and kitchen wastewater. Bioresour Technol 168:106–111. https://doi.org/https://doi.org/10.1016/j.biortech.2014.02.127

Tayibi S, Monlau F, Bargaz A, et al. (2021) Synergy of anaerobic digestion and pyrolysis processes for sustainable waste management: A critical review and future perspectives. Renew Sustain Energy Rev 152:111603. https://doi.org/https://doi.org/10.1016/j.rser.2021.111603

Tejaswini MSSR, Pathak P, Gupta DK (2022) Sustainable approach for valorization of solid wastes as a secondary resource through urban mining. J Environ Manage 319:115727. https://doi.org/https://doi.org/10.1016/j.jenvman.2022.115727

Thengane SK, Kung KS, Gomez-Barea A, Ghoniem AF (2022) Advances in biomass torrefaction: Parameters, models, reactors, applications, deployment, and market. Prog Energy Combust Sci 93:101040. https://doi.org/https://doi.org/10.1016/j.pecs.2022.101040

Thulasinathan B, Jayabalan T, Arumugam N, et al. (2022) Wastewater substrates in microbial fuel cell systems for carbon-neutral bioelectricity generation: An overview. Fuel 317:123369. https://doi.org/https://doi.org/10.1016/j.fuel.2022.123369

Tozlu A, Özahi E, Abuşoğlu A (2016) Waste to energy technologies for municipal solid waste management in Gaziantep. Renew Sustain Energy Rev 54:809–815. https://doi.org/https://doi.org/10.1016/j.rser.2015.10.097

Tremouli A, Karydogiannis I, Pandis PK, et al. (2019) Bioelectricity production from fermentable household waste extract using a single chamber microbial fuel cell. Energy Procedia 161:2–9. https://doi.org/https://doi.org/10.1016/j.egypro.2019.02.051

Tsai FM, Bui T-D, Tseng M-L, et al. (2020) Municipal solid waste management in a circular economy:

A data-driven bibliometric analysis. J Clean Prod 275:124132. https://doi.org/https://doi.org/10.1016/j.jclepro.2020.124132
Tsapekos P, Khoshnevisan B, Zhu X, et al. (2022) Lab- and pilot-scale anaerobic digestion of municipal bio-waste and potential of digestate for biogas upgrading sustained by microbial analysis. Renew Energy 201:344–353. https://doi.org/https://doi.org/10.1016/j.renene.2022.10.116
Turconi R, Butera S, Boldrin A, et al. (2011) Life cycle assessment of waste incineration in Denmark and Italy using two LCA models. Waste Manag Res 29:S78–S90
Ugwu CO, Ozoegwu CG, Ozor PA (2020) Solid waste quantification and characterization in university of Nigeria, Nsukka campus, and recommendations for sustainable management. Heliyon 6:e04255. https://doi.org/https://doi.org/10.1016/j.heliyon.2020.e04255
Ugwuanyi JO, Harvey LM, McNeil B (2004) Development of thermophilic populations, amylase and cellulase enzyme activities during thermophilic aerobic digestion of model agricultural waste slurry. Process Biochem 39:1661–1669. https://doi.org/https://doi.org/10.1016/S0032-9592(03)00309-1
Ugwuanyi JO, Harvey LM, McNeil B (2008) Diversity of thermophilic populations during thermophilic aerobic digestion of potato peel slurry. J Appl Microbiol 104:79–90
Usman M, Cheema SA, Farooq M (2020) Heterogeneous Fenton and persulfate oxidation for treatment of landfill leachate: A review supplement. J Clean Prod 256:120448. https://doi.org/https://doi.org/10.1016/j.jclepro.2020.120448
Van DP, Fujiwara T, Tho BL, et al. (2020) A review of anaerobic digestion systems for biodegradable waste: Configurations, operating parameters, and current trends. Environ Eng Res 25:1–17
Varjani S, Shahbeig H, Popat K, et al. (2022) Sustainable management of municipal solid waste through waste-to-energy technologies. Bioresour Technol 355:127247. https://doi.org/https://doi.org/10.1016/j.biortech.2022.127247
Vu HP, Nguyen LN, Wang Q, et al. (2022) Hydrogen sulphide management in anaerobic digestion: A critical review on input control, process regulation, and post-treatment. Bioresour Technol 346:126634. https://doi.org/https://doi.org/10.1016/j.biortech.2021.126634
Wang C, Jiang H (2019) Real-time monitoring of sediment bulking through a multi-anode sediment microbial fuel cell as reliable biosensor. Sci Total Environ 697:134009. https://doi.org/https://doi.org/10.1016/j.scitotenv.2019.134009
Wang S, Adekunle A, Tartakovsky B, Raghavan V (2021) Synthesizing developments in the usage of solid organic matter in microbial fuel cells: A review. Chem Eng J Adv 8:100140. https://doi.org/https://doi.org/10.1016/j.ceja.2021.100140
Wang X, Feng Y, Ren N, et al. (2009) Accelerated start-up of two-chambered microbial fuel cells: Effect of anodic positive poised potential. Electrochim Acta 54:1109–1114. https://doi.org/https://doi.org/10.1016/j.electacta.2008.07.085
Wang Y, Xiao G, Wang S, Su H (2023) Application of nanomaterials in dark or light-assisted fermentation for enhanced biohydrogen production: A mini-review. Bioresour Technol Reports 21:101295. https://doi.org/https://doi.org/10.1016/j.biteb.2022.101295
Wei J, Li H, Liu J (2022a) Curbing dioxin emissions from municipal solid waste incineration: China's action and global share. J Hazard Mater 435:129076. https://doi.org/https://doi.org/10.1016/j.jhazmat.2022.129076
Wei J, Li H, Liu J, Zhong R (2022b) National and provincial dioxin emissions from municipal solid waste incineration in China. Sci Total Environ 851:158128. https://doi.org/https://doi.org/10.1016/j.scitotenv.2022.158128
Wu D, Li L, Peng Y, et al. (2021) State indicators of anaerobic digestion: A critical review on process monitoring and diagnosis. Renew Sustain Energy Rev 148:111260. https://doi.org/https://doi.org/10.1016/j.rser.2021.111260
Xavier BB, Lammens C, Ruhal R, et al. (2016) Identification of a novel plasmid-mediated colistin-resistance gene, mcr-2, in Escherichia coli, Belgium, June 2016. Eurosurveillance 21:30280
Yan W, Hastings JT, Acharjee TC, et al. (2010) Mass and energy balances of wet torrefaction of lignocellulosic biomass. Energy & Fuels 24:4738–4742
Yap HY, Nixon JD (2015) A multi-criteria analysis of options for energy recovery from municipal solid waste in India and the UK. Waste Manag 46:265–277. https://doi.org/https://doi.org/10.1016/j.wasman.2015.08.002

Yin W, Li H, Shen Y, et al. (2017) Novel plasmid-mediated colistin resistance gene mcr-3 in Escherichia coli. MBio 8:e00543-17

Yong ZJ, Bashir MJK, Hassan MS (2021) Biogas and biofertilizer production from organic fraction municipal solid waste for sustainable circular economy and environmental protection in Malaysia. Sci Total Environ 776:145961. https://doi.org/https://doi.org/10.1016/j.scitotenv.2021.145961

Zahedi S, Solera R, García-Morales JL, Sales D (2016) Effect of the addition of glycerol on hydrogen production from industrial municipal solid waste. Fuel 180:343–347. https://doi.org/https://doi.org/10.1016/j.fuel.2016.04.063

Zaks DPM, Winchester N, Kucharik CJ, et al (2011) Contribution of anaerobic digesters to emissions mitigation and electricity generation under US climate policy. Environ Sci Technol 45:6735–6742

Zaman AU (2010) Comparative study of municipal solid waste treatment technologies using life cycle assessment method. Int J Environ Sci Technol 7:225–234

Zaman AU (2009) Life cycle environmental assessment of municipal solid waste to energy technologies. Glob J Environ Res 3:155–163

Zamri MFMA, Hasmady S, Akhiar A, et al. (2021) A comprehensive review on anaerobic digestion of organic fraction of municipal solid waste. Renew Sustain Energy Rev 137:110637. https://doi.org/https://doi.org/10.1016/j.rser.2020.110637

Zhang DQ, Tan SK, Gersberg RM (2010) Municipal solid waste management in China: Status, problems and challenges. J Environ Manage 91:1623–1633. https://doi.org/https://doi.org/10.1016/j.jenvman.2010.03.012

Zhang L, Bao Z, Xia S, et al. (2018) Catalytic pyrolysis of biomass and polymer wastes. Catalysts 8:659

Zhang P, Shao Y, Niu J, et al. (2022) Effect of low-nitrogen combustion system with flue gas circulation technology on the performance of NOx emission in waste-to-energy power plant. Chem Eng Process - Process Intensif 175:108910. https://doi.org/https://doi.org/10.1016/j.cep.2022.108910

Zhang Y, Angelidaki I (2014) Microbial electrolysis cells turning to be versatile technology: Recent advances and future challenges. Water Res 56:11–25. https://doi.org/https://doi.org/10.1016/j.watres.2014.02.031

Zhao Q, Ji M, Li R, Ren ZJ (2017) Long-term performance of sediment microbial fuel cells with multiple anodes. Bioresour Technol 237:178–185. https://doi.org/https://doi.org/10.1016/j.biortech.2017.03.002

Zhao X, Jiang G, Li A, Wang L (2016) Economic analysis of waste-to-energy industry in China. Waste Manag 48:604–618. https://doi.org/https://doi.org/10.1016/j.wasman.2015.10.014

Zhou M, Li X (2022) Influence of green finance and renewable energy resources over the sustainable development goal of clean energy in China. Resour Policy 78:102816. https://doi.org/https://doi.org/10.1016/j.resourpol.2022.102816

Zhou Y, Huang K, Jiao X, et al. (2021) Anaerobic co-digestion of organic fractions of municipal solid waste: Synergy study of methane production and microbial community. Biomass and Bioenergy 151:106137. https://doi.org/https://doi.org/10.1016/j.biombioe.2021.106137

Zuberi MJS, Ali SF (2015) Greenhouse effect reduction by recovering energy from waste landfills in Pakistan. Renew Sustain Energy Rev 44:117–131. https://doi.org/https://doi.org/10.1016/j.rser.2014.12.028

(2009) IEA World Energy Outlook 2008 changes tack. Renew Energy Focus 9:17. https://doi.org/https://doi.org/10.1016/S1755-0084(09)70023-7