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Review

Organic Waste Substrates for Bioenergy Production via Microbial Fuel Cells: A Key Point Review

Maria G. Savvidou [1,*,†], Pavlos K. Pandis [2], Diomi Mamma [1], Georgia Sourkouni [3] and Christos Argirusis [2,3,*]

1 Biotechnology Laboratory, School of Chemical Engineering, National Technical University of Athens, Zografou Campus, 9 Iroon Polytechniou Str., 15780 Athens, Greece; dmamma@chemeng.ntua.gr
2 Laboratory of Inorganic Materials Technology, School of Chemical Engineering, National Technical University of Athens, Zografou Campus, 9 Iroon Polytechniou Str., 15780 Athens, Greece; ppandis@chemeng.ntua.gr
3 TU Clausthal, Clausthal Centre of Materials Technology, Leibniz Str. 9, 38678 Clausthal-Zellerfeld, Germany; cogsa@tu-clausthal.de
* Correspondence: msavvid@central.ntua.gr (M.G.S.); amca@chemeng.ntua.gr (C.A.)
† Current address: Department of Biomedical Engineering, Tufts University, Medford, MA 02155, USA.

Abstract: High-energy consumption globally has raised questions about the low environmentally friendly and high-cost processes used until now for energy production. Microbial fuel cells (MFCs) may support alternative more economically and environmentally favorable ways of bioenergy production based on their advantage of using waste. MFCs work as bio-electrochemical devices that consume organic substrates in order for the electrogenic bacteria and/or enzyme cultures to produce electricity and simultaneously lower the environmental hazardous value of waste such as COD. The utilization of organic waste as fuels in MFCs has opened a new research path for testing a variety of by-products from several industry sectors. This review presents several organic waste substrates that can be employed as fuels in MFCs for bioenergy generation and the effect of their usage on power density, COD (chemical oxygen demand) removal, and Coulombic efficiency enhancement. Moreover, a demonstration and comparison of the different types of mixed waste regarding their efficiency for energy generation via MFCs are presented. Future perspectives for manufacturing and cost analysis plans can support scale-up processes fulfilling waste-treatment efficiency and energy-output densities.

Keywords: microbial fuel cells; organic waste; bioenergy; COD removal; upscaling MFC

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1. Introduction

Until now, fossil fuels have been the sovereign source of energy worldwide, accounting for 87% of global energy [1]. Their depletion and contribution to pollution led to alternatives such as energy from biomass or solar energy [2,3]. Biomass is an abundant source, benign with a reduced CO_2 fingerprint, and is considered to rank among the four global sources comprising 14% of the world's energy needs [4]. One of the advantages of biomass use is its ability to be converted into various energy products such as heat, gas, fuel, and electricity [3]. At a global level, research studies have been carried out on finding suitable biomass conversion technologies based on technologies that favor conversion from organic waste. The most commonly used among them are advanced oxidation [5,6] membrane processes [7], electrochemical [8,9] and physicochemical treatments (such as flocculation) [10], and of course anaerobic processes [11–14]. Because of the high levels of COD in waste, the biological treatments showed significant improvements when following a pretreatment step to make the waste more biodegradable [15].

Besides the above-mentioned processes, bioelectricity from biomass can be produced by two other technologies, Solid Oxide Fuel Cells (SOFCs) (working at high temperatures above 650 °C) or Microbial Fuel Cells (MFCs) [16,17], with the latter demonstrating the advantages of high theoretical energy efficiency and also mild operating conditions [18]. Practically, the amount of energy from MFCs is lower than other energy sources, but their ability to use organic waste makes them an ascendant motive for their increased usage in the future and anaerobic digestion and bioelectrical systems (MFCs and microbial electrolysis cells (MECs)) could become leaders in converting waste to bioenergy [19] (Figure 1).

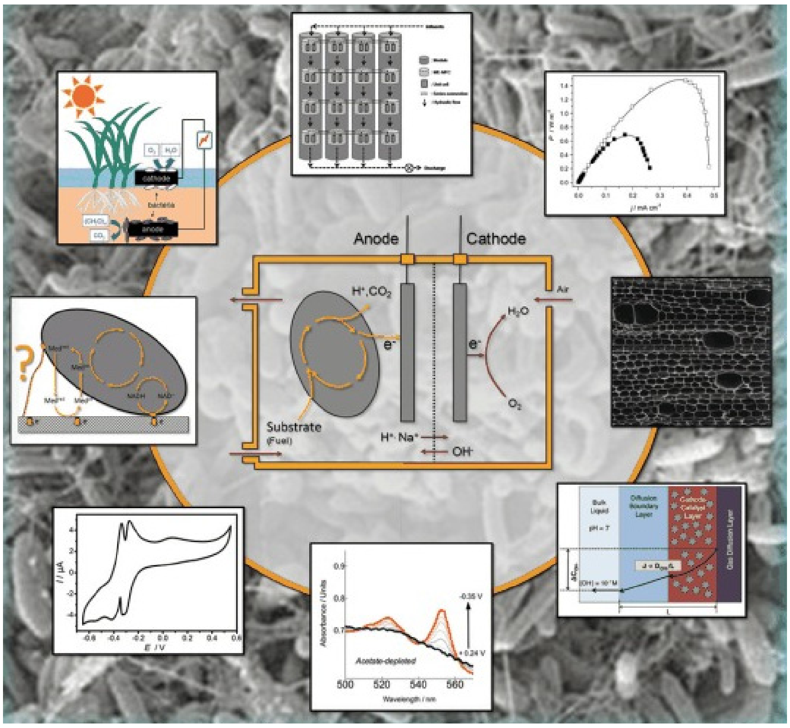

Figure 1. MFCs in the service of waste to energy conversion (Adapted with permission from Ref. [20]).

Organic waste can be also used in alternative ways for energy generation such as biogas production via food and agricultural animal and municipal waste. MFCs are advantageous compared to anaerobic digestion technologies since they can operate at ambient wastewater temperatures and do not require temperature control. A neutral pH is necessary for MFCs as in anaerobic digestion. In addition, MFC technology has eliminated the pretreatment of organic waste, which is a necessary step in anaerobic digestion technology.

On the other hand, MFCs can produce energy from non-purified organic materials and from materials derived from various environments giving them an advantage in their selection compared to other methods that can support bioenergy [21]. Furthermore, MFCs support the possibility of the simultaneous production of energy and other co-products such as bioethanol [22] or biohydrogen [23].

Microbial fuel cell (MFC) technology converts the chemical energy of organic compounds directly into electricity relying on the diverse metabolic pathways of unique microorganisms called electroactive microorganisms (EAMs) [24,25]. An MFC apparatus consists of an anode and a cathode chamber linked electrically via a circuit and separated by the proton exchange membrane [26] and is characterized as a dual-chamber MFC, whereas single-chamber MFCs lack the membrane and the cathode mostly acts as a mediator [17,27,28]. EAMs reside in the anode compartment, oxidize organic compounds, and generate electrons (e^-) and protons (H^+), which are transported through the membrane/mediator at the cathode and the external electronic circuit, respectively. Direct electron transfer, transfer through nanowire structures, and a mediator are the alternatives for releasing the electrons to the electrode [29]. Electrons and protons are consumed in the cathode by the reduction in soluble electron acceptors, for instance, oxygen or nitrate [29–31] (Figure 2).

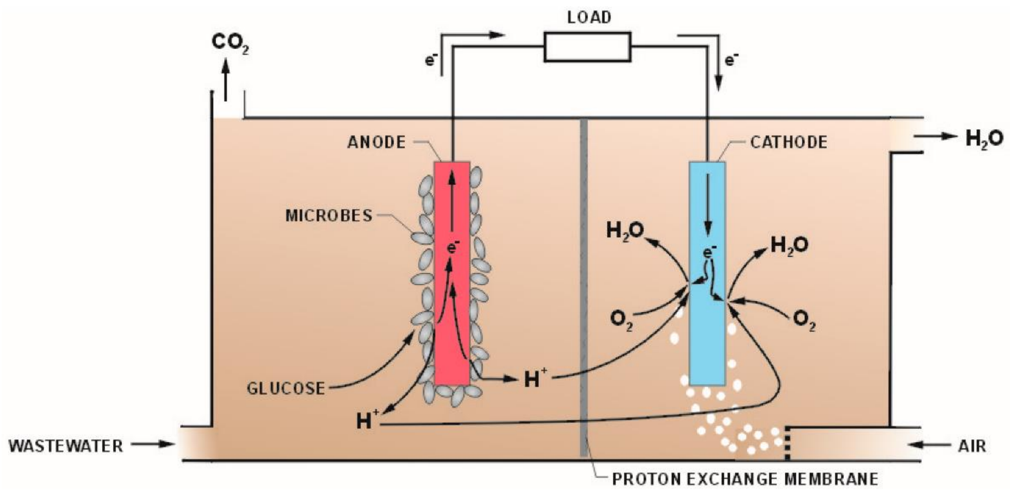

Figure 2. Operating principles of a microbial fuel cell (MFC) (Reprinted with permission from Ref. [32]).

Recently, new less expensive materials have been developed for the membranes such as clayware [33], ceramic [34], and natural rubber membranes [35], whereas new cost-effective cathodic electrodes have been introduced in order to minimize the total capital costs of MFCs [17,27,36–43].

Pure cultures of EAMs (bacteria, archaea, and eukaryotes) have been used in MFCs but the support of mixed cultures increased efficiency in complex feedstocks [3]. Recently, genetically engineered bacteria have been used in MFCs for governing the biosynthetic pathways providing proper electron numbers for enhanced energy efficiency [44–46]. In general, the pH, temperature, concentration of the electron donor, loading rate of the organic substrate, electrolytes, specific type of bacteria, design, and type of the membrane influence the efficiency of the MFCs [26,47]. The MFCs' electrical efficiency (power density, current density, Coulombic efficiency, and substrate reduction of COD) is calculated by comparing the electrical output to the chemical energy of the substrate used, and the current is calculated by converting the chemical oxygen demand of the substrate to electrons [19,29].

Various reviews have demonstrated the different types of MFCs that are suitable materials for the anode and cathode. Publications on MFCs illustrate at least 35 different types of waste used for energy production, some of which demonstrate advantages over others due to their moisture content, energy yield, bulk density size, and shape, as well as at least 13 different studies on the MFC reactors used for waste substrates [3,48,49] (Figure 3).

Here, we demonstrate a comprehensive review examining the various types of biomass waste in general categories and subcategories regarding bioenergy production via MFCs. Moreover, the presentation and discussion of mixed waste for more enhanced energy efficiency that are being reported in this study could shed light on the most energy-efficient waste for scale-up processes.

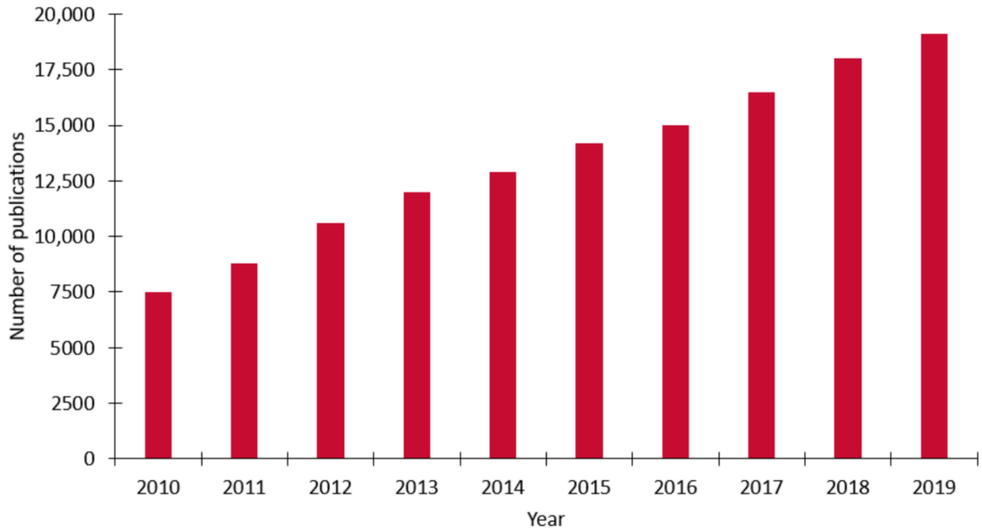

Figure 3. The number of publications per year found in the Google Scholar database using the search term "microbial fuel cells" (MFCs); (data acquired on 29 October 2020) (Reprinted with permission from Ref. [50]).

2. Energy Production Using Waste as MFC Substrate

Rapid growth or urbanization and industrialization produce tons of waste every year as a result of human needs, although no proper waste management plans are active. The crucial advantage of bioelectrical systems (BESs) is that they can produce energy from waste and at the same time protect the environment from pollutants by finding new ways for energy production [29,51]. Based on the type of waste, different organic substrates can be utilized in MFCs for energy generation. studies on food, wine, oil, soil, domestic, industry, and animal waste have been used to propose alternative sources for MFCs' bioenergy production. A comparison of the different types of waste regarding energy generation is difficult due to the different MFCs used in the various processes (working volume, operation mode, electrode material, type of MFC, mg/L of COD inserted into MFCs).

2.1. Food, Fruit, and Vegetable Waste and Wastewater

Food waste deriving from households, restaurants, canteens, and cafeterias., is one of the crucial environmental pollutants due to its large amount of organic matter, high salinity, and moisture [52]. Moreover, food waste is an inexhaustible source, with high levels of carbohydrates, protein, and lipids, rendering them a good source for energy production [15]. Mostly, but not exclusively, two-chamber MFCs have been used for energy production using food waste. The power density varies from 1 to hundreds of mW/m^2 based on the different types of food waste (Table A1). Studies using potato-processing wastewater in single-, two-, or three-chamber MFCs resulted in a maximum of 217 mW/m^2 in a single-chamber MFC with a 28 mL working volume, graphite fiber brushes as the anode material, and carbon cloth–Pt–PTFE as the cathode material [53] (Figure 4).

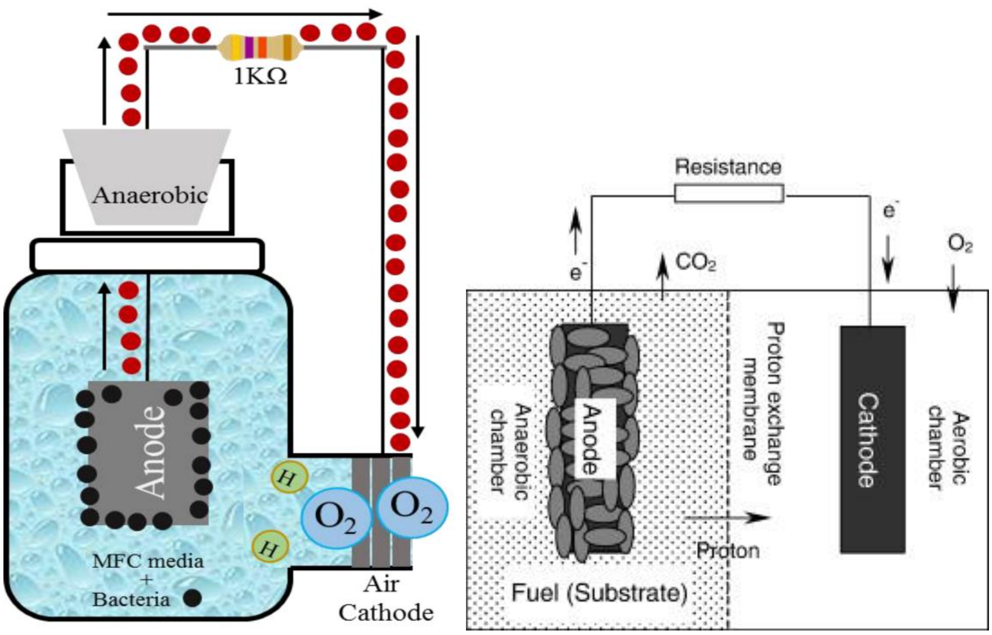

Figure 4. (**Left**) A conceptual diagram of a membrane-less single-chamber MFC (Reprinted with permission from Ref. [54]), (**Right**) A two-compartment MFC that can be used in food waste treatment (Reprinted with permission from Ref. [55]).

Similar studies were conducted with potato pulp [56], resulting in the maximum Coulombic efficiency of 56%, whereas a two-chamber MFC with a 240 mL working volume and carbon felt as the material for the anode and cathode produced a much lower power density (1.4–6.8 mW/m^2) but a maximum COD removal efficiency of 90% [57]. A three-chamber MFC using potato waste with an 800 mL working volume and graphite at the electrodes produced 250–400 µA of current density [58]. Using an acidic and organic-rich slurry of potato–shochu waste in a cassette-electrode MFC with a graphite anode and carbon cathode electrodes results in the maximum power density of 1.2 W/m^3 [59].

Culled (defective) tomatoes were used in a two-chamber MFC with graphite material as both the anode and cathode and the power density achieved (256 mW/m^2) was almost double compared to the same type of MFC using tomato seeds and skin [60]. Mohan et al. [61] studied bioelectricity generation from vegetable-based waste (different kinds of rotten vegetables) in a single-chamber MFC using non-catalyzed graphite plates as the electrodes. The power density of the system ranged from 57.38 to 215.71 mW/m^2 depending on the loading rate. With a similar feedstock but in a dual-chamber MFC with granular graphite and carbon paper as the anode and cathode, respectively, a maximum power density of 1019 mW/m^3 was attained after ultrasonic pretreatment of the samples [62]. Javed et al. [63] produced the highest power density of 88,990 mW/m^2 using vegetable waste extracts in an MFC constructed from polypropylene random pipes jointed in a U shape.

Fermented apple juice (a simulation of apple farm waste leachate) generated 78 mW/m^2 in a 500 mL two-chamber MFC with graphite felt as the anode and platinum mesh as the cathode [64]. Effluent from a Dissolved Air Flotation (DAF) unit receiving wastewater from a chilled food-production factory that was used in a tubular 1000 mL MFC system with carbon electrodes resulted in a maximum volumetric power density of 5.86 W/m^3 [65]. Bakery wastewater was fed into a single-chamber MFC with a 45 mL working volume and produced a 10 mW/m^2 current density, whereas baker's yeast effluent in a two-chamber MFC with a 100 mL working volume generated power density that ranged from 9.75 mW/m^2 to 18.41 mW/m^2 depending on the concentration of the exogenous redox mediator [66,67].

A mediator-less dual-chamber MFC with a 1.2 L working volume with carbon as the electrode material operating in fed-batch mode fed with food waste leachate gave 15.14 W/m^3 of power density [68]. A dual MFC unit with a 75.6 mL working volume using the same waste resulted in 1 W/m^3, whereas 1.86 W/m^3 power density was produced by food leachate in a single-chamber air-diffusion cathode MFC [69,70]. Soy-based food generated low power density but sufficient COD removal in a three-chamber MFC with carbon electrodes [71]. In general, food waste has been processed in single- or triple-chamber MFCs using carbon electrodes, maximizing the energy production by up to 371 mW/m^2 and the Coulombic efficiency by up to 95%, specifically in 250 mL single- or two-chamber MFCs [72–74]. The reported COD removal efficiency from food waste varies from 64–95%. A comparison between the fruit waste of oranges, bananas, and mangoes showed that oranges resulted in a high voltage output of 357 mV [75]. In a study conducted on a single-chamber air-cathode MFC, Frattini et al. observed that the factors that are crucial for energy production from food waste are the solid-to-liquid ratio and the membrane type. They reported that increased MFC energy efficiency was achieved in a low solid-to-liquid ratio and under Nafion membrane [76]. More recently, Xin et al. [77] reported on the development of an integrated process combining the ultra-fast hydrolysis of food waste by fungal mash (rich in hydrolytic enzymes in situ produced from food waste) and microbial fuel cell MFCs fed with the liquid fraction of hydrolysis. According to the authors' estimation, this process could result in 192.5 million kWh of electricity annually, whereas the solid fraction (accounting for 75 K tons annually) can be used as a biofertilizer.

Single-chamber MFCs generated the maximum energy amount of 1540 mW/m^2 using canteen waste leachate. Specifically, a 24 mL MFC with a graphite anode and carbon cathode resulted in the above-mentioned power density using biodegradable substrates in bio hydrogen fermentation (canteen waste leachate) and with a high COD removal efficiency of 85.1% as well as the highest Coulombic efficiency of 89% [78]. Similar studies on single-chamber MFCs with low working volumes, i.e., 22 mL with graphite fiber brush as the anode and carbon cloth–Pt as the cathode generated an enhanced power density (371–556 mW/m^2) and a COD removal efficiency of 86% compared to similar MFC types with higher working volumes such as 300 mL or 430 mL [79–81]. Diluted canteen waste in a 120 mL single-chamber MFC generated 5.6 mW/m^3 but a very sufficient COD removal efficiency of 80.8%, whereas a solid-phase MFC with graphite as the electrode material using undiluted canteen waste generated 41.8–170.81 mW/m^2 and only a 76% efficiency of COD removal [82]. The power density of the three-chamber MFCs was reduced compared to the single-chamber MFCs. The power efficiency of the three-chamber MFCs reached up to 123.8 mW/m^2 [83] in a 1500 mL MFC with graphite electrodes but despite the low power density, this system resulted in the highest COD removal efficiency of 99%. The graphite and copper electrodes in a 300 mL three-chamber MFC generated 19.151 mW/m^3 [84].

Cafeteria fermented waste resulted in a low power density at 15.3 mW/m^2 [85] in a two-chamber MFC with carbon electrodes. Asefi et al. [86] produced a 422 mW/m^2 power density with a high COD removal efficiency of almost 87% using canteen waste with permanganate as the cathode of the MFC. Food waste ethanol fermentation stillage in a 120 mL single-chamber MFC with graphite and titanium as the material electrodes at the anode and cathode generated 0.29 V and 1.4 mA with a medium percentage of COD removal efficiency of around 70% [87], whereas a better power efficiency was found in a study by Gao et al. [88] of 612 mW/m^2 with a 62% COD removal efficiency. Household and kitchen waste can also be a good source for MFC bioenergy production. Recent studies have verified sufficient energy efficiency using kitchen waste in a single air-cathode electrode with carbon rods as the anode and cathode (85.58 mW/m^2) [89] and even lower power density (29.6 mW/m^2) in a dual-chamber MFC [90]. In addition, food waste condensate concentration plays a critical role in energy production in single-chamber MFCs as it lowers the output power density to 14.4 mW/m^2 with a COD removal efficiency of 86% [91] regardless of the nature of the electrodes used in most cases [92]. Comparison studies have demonstrated that kitchen waste supports enhanced energy production; over 45 days, kitchen waste produced higher voltages and maintained this over time compared to bamboo waste [93].

2.2. Seafood Industry

Waste from the seafood industry has a high organic content, including fats, oils, and nitrates, and the industries that process seafood, as well as the cleaning of the equipment, have caused increased tons of wastewater [94]. Some previously mentioned studies (Table A2) on seafood waste in MFCs [95,96] calculated the maximum power density to be around 400 mW/m^2 for a two- and single-chamber with a 98 mL and 26 mL working volume MFC with a graphite rod and carbon cloth as the electrode materials, respectively, with the former having slightly higher Coulombic efficiency, and the latter having the maximum COD removal efficiency of 85%. Another similar study on a tubular 50 mL MFC with activated carbon as the electrodes managed a high COD removal efficiency of almost 83% [97]. A comparison of single- and two-chamber MFCs with the same working volume by Sun [96], showed that the single-chamber MFC achieved an enhanced COD removal and the two-chamber MFC had the highest Coulombic efficiency of 20%.

Recently, Jamal et al. [98], who examined the effect of halophiles from desalinated plants on seafood wastewater treatment in an MFC, stated that the increments in the organic load lead to an increased power density of 570 mW/m^2 and the COD removal reaches a maximum efficiency of 90%, which were the best results compared to previous studies [95–97]. The most efficient MFC with a power density of 2960.704 mW/m^2 was reported by Amrutha et al. [99] using a dual-chamber MFC with polypropylene as the electrodes and a 3 L working volume with a less efficient (compared to the above-mentioned studies) COD removal efficiency of around 77%.

2.3. Dairy Industry

The dairy industry is an endless source of wastewater, which includes a high concentration of lactose, proteins, lipids, and vitamins, as well as several pollutants such as nitrates, sulfates, phosphates, chlorides, and solids [29,100]. Nowadays, dairy wastewater treatment is managed by up-flow anaerobic filters or anaerobic reactors [101,102], but more recently, microbial fuel cells have gained increased interest since there has been an increase in the annual milk production rate of 3% [100]. Two-chamber MFCs are the commonly used reactors (Table A3). Yogurt waste was more efficient in a 500 mL three-chamber MFC with graphite felt and platinum mesh as the anode and cathode compared with the same MFC with platinum mesh at both electrodes resulting in 53.8 mW/m^2, whereas the second type of MFC led to a high COD removal efficiency of 91% [64,103]. Under alkaline conditions and in a single-chamber air-cathode MFC, Luo et al. [104] stated that yogurt waste produced the highest power density of 1143 mW/m^2 with the COD removal efficiency reaching 87% (Figure 5).

Dairy manure was not more efficient since the power density reached 189 mW/m^2 with a lower COD removal efficiency of around 70% compared to the yogurt waste but in different types of MFCs (single- or three-chamber MFCs) [53,105]. Synthetic dairy wastewater generated in a 480 mL two-chamber MFC with carbon electrodes led to 92 mW/m^2 power density and a sufficient COD removal efficiency of 63% [106], whereas the energy efficiency of activated sludge dairy waste was extremely low [107]. Cheese whey has also been used in single- or two-chamber MFCs with low or high working volumes, respectively, and using graphite electrodes reaching 324.8 μW and 1.19 mA [108,109] in a two-chamber MFC. Further, the maximum Coulombic efficiency of 49% in a single-chamber MFC was reached, which is the maximum referred Coulombic efficiency among the various dairy wastewater types used in MFCs.

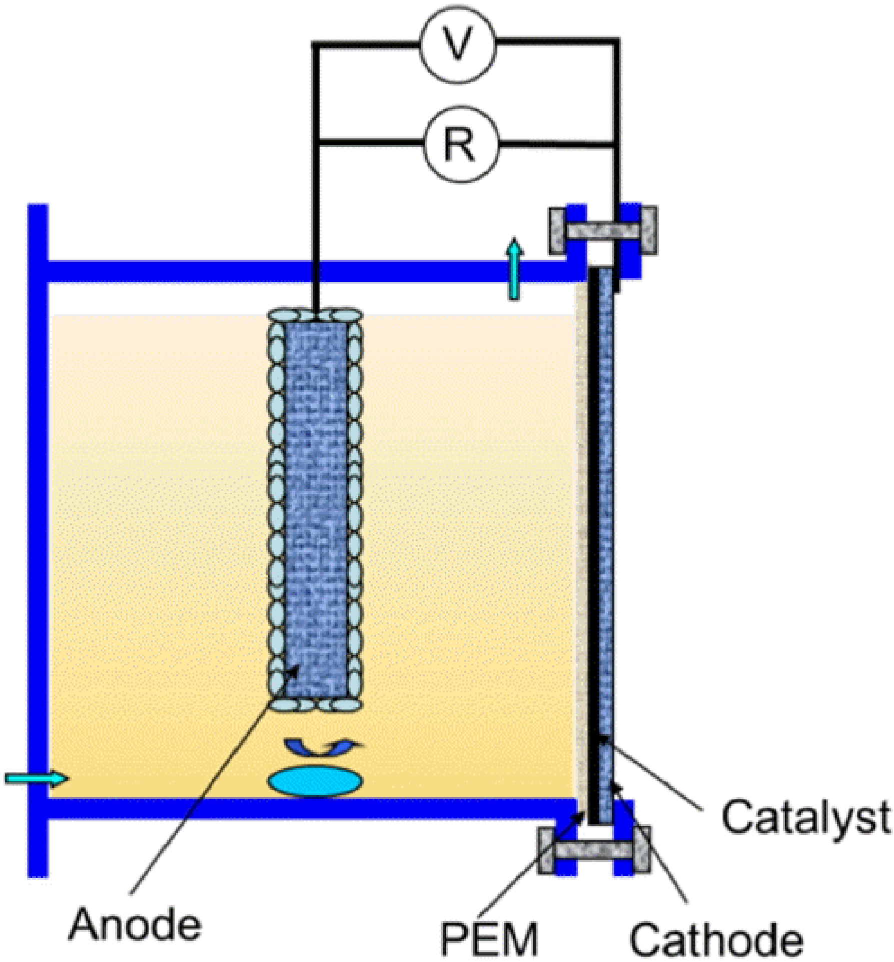

Figure 5. Schematic of the air-cathode MFC reactor (Reprinted with permission from Ref. [70]).

In general, dairy wastewater in two-chamber MFCs produced better power density and Coulombic efficiency, whereas single-chamber MFCs supported the maximum COD removal [66,72,102,110]. Specifically, Mansoorian et al. [111] using a 2000 mL two-chamber MFC with graphite electrodes produced 621.3 mW/m^2 and 38% Coulombic efficiency, and a 480 mL single-chamber MFC with graphite electrodes resulted in a 96% COD removal efficiency [102]. A lower working volume in a two-chamber MFC noticeably reduced the power density and Coulombic efficiency but not the COD removal [110]. A similar high COD removal efficiency of 94% and a power density of almost 38 μW generated using dairy wastewater in a continuous-flow-type two-chamber MFC [112] and also in a fed-batch MFC produced a high Coulombic efficiency of almost 32% [113]. Choudhury et al. [114] using three MFCs connected in a series with a 300 mL working volume in two of them and a 330 mL working volume in the third, generated a 1.745 V voltage. Furthermore, sufficient power density and COD removal produced in a two-chamber MFC with carbon electrodes [71], as well as in a two-chamber MFC with graphite brush and carbon cloth as the electrodes, reached 131 mW/m^2 and a 76% COD removal efficiency [115]. Recently, Sivakumar et al. [116] generated the highest power density of 1080 mW/m^2, surpassing the 621.3 mW/m^2 mentioned above, with an 86% COD removal efficiency and a high percentage for the removal of other pollutants using dairy wastewater in a double-chamber batch-mode salt-bridged MFC. An analogous MFC with graphite plates as the anode and cathode and an agar–salt bridge resulted in a higher COD removal efficiency of 92% than the previously mentioned salt-bridged MFC under acidic conditions [117]. Dairy waste has also been examined in an effort to reduce various pollutants such as dyes. The COD removal and reduction of Aid orange dye reached almost 90% [118].

2.4. Brewery and Winery Waste

Brewery and winery wastewater is rich in sugars, carbohydrates, nitrate, phosphorus, and heavy metals and is believed to be a powerful source of bioenergy production through the sequencing of batch reactors and up-flow sludge blankets. Anaerobic and aerobic, carbon nanotube, oxidation process, membrane filtration-based, and activated carbon are some of the types of treatment methods used nowadays [119–123] achieving up to a 98% COD removal efficiency but with high energy efficiency [124]. Especially for microalgae, as they are vastly implemented in MFCs [125], regardless of their applications or production processes [126–128], the COD removal efficiency of MFCs used as cathodes was above 85% [121]. Studies of winery waste mostly used two-chamber MFCs in various working volumes (Table A4). A tubular MFC with 170 mL and with carbon felts as the electrodes produced the highest power density of 890 mW/m^2 and at the same time the highest Coulombic efficiency of 42%, whereas a smaller working volume of 70 mL managed to perform the highest COD removal efficiency of almost 17% [129,130]. Wine lees in a 500 mL two-chamber MFC had a significantly reduced power density of only 0.8 mW/m^2 [64].

Regarding brewery wastewater, single-, two-, and three-chamber MFCs have been used for energy generation. Single-chamber MFCs led to the maximum power density, COD removal, or Coulombic efficiency in MFCs with different working volumes. Specifically, a carbon cloth single-chamber MFC managed a 98% COD removal efficiency [124], the same as the other methods used for brewery wastewater treatment mentioned above, verifying that MFCs can manage the treatment of brewery wastewater efficiently, and a similar type of MFC with carbon fiber as the anode and stainless steel/activated carbon as the cathode resulted in the maximum power density of 669 mW/m^2 [131]. Yu et al. [132] also produced a high-power density of 552 mW/m^2 in a higher-working-volume (225 mL) single-chamber MFC with graphite felt as the anode and carbon cloth as the cathode than the one in the study by Wen et al. [131], but at the same time achieved the highest Coulombic efficiency of 41%. An MFC similar to the one used in the study by Feng et al. [124], generated better power density and higher Coulombic efficiency of 38% using brewery wastewater as the feed for the MFCs [133]. A single-chamber 4000 mL MFC with a continuous operation mode generated a median power density of 304 mW/m^2 [123]. Studies on two-chamber MFCs resulted in a maximum COD removal efficiency of 80% and a 305 mW/m^2 power density [134], and other studies [135,136] produced noticeably lower values than the respective maximum values in the single-chamber MFCs. A three-chamber MFC with graphite plate electrodes and a 1200 mL working volume achieved a 93% COD removal efficiency [137] similar to other single-chamber MFCs [138] but with a lower power density. Earlier studies produced smaller values of COD removal or power density [66,139]. A study on a two-chamber MFC with copper mesh as the electrodes loaded with the inlet and outlet of an anaerobic digester of a brewery wastewater treatment generated almost 82% COD removal efficiency and 80 mW/m^2 from the influent and 18 mW/m^2 from the effluent [140]. Zhuang et al. [141] by scaling up the process in a 10 L MFC with continuous operation for 180 days produced 4.1 W/m^3 after 30 days, whereas the COD removal efficiency was more stable at around 85% for the duration of the 180 days, thus the removal of ammonia was enhanced, verifying the ability of the MFC to treat various types of wastewater. An industrial two-chamber MFC being able to treat 84 L/hr of wastewater was able to remove almost 92% COD and produce 26.4 KWh in power efficiency [142], reaching close to the maximum COD removal produced by lower-working-volume MFCs. An enhanced COD removal efficiency of almost 94% was generated by brewery wastewater in the simultaneous presence of glucose and sucrose [143].

2.5. Oil Industry

Oil waste is composed of solids, lipids, sugars, and nitrogen [94,144]. A comparison of the degradation of petroleum hydrocarbons between sediment MFCs and the anaerobic digestion method resulted in a 10 times higher efficiency than the first [145]. Studies (Table A5) of soybean oil wastewater in single-chamber MFCs with an 18 or 2 mL working volume verified the maximum power density of 2240 mW/m^2 using graphite felt as the anode and carbon cloth as the cathode in the higher working volume. In the lower working volume, a maximum COD removal efficiency of 96% and Coulombic efficiency of 33.6% were observed using graphite fiber s the anode and stainless steel as the cathode [146,147]. Palm and vegetable oil wastewater in a two-chamber MFC generated lower COD removal efficiency of 70% and 86%, respectively, and lower Coulombic efficiency of 24% for palm oil compared to soybean oil [148,149]. A study by Firdous et al. [150] using vegetable oil effluent verified a similar COD removal efficiency to the one from Abbasi et al. [149], whereas the Coulombic efficiency reached the one produced using soybean oil. The batch-mode operation of a single-chamber MFC managed a 48% COD removal efficiency using petroleum refinery wastewater [151], whereas in continuous mode, a higher COD removal and power density [152] were produced. A constructed wetland reactor with a microbial fuel cell reactor having an MnO_2-modified cathode produced a similar COD removal but a higher power density of 102 mW/m^2 compared to a simple MFC of 80 mW/m^2 using oil sewage [153]. Mineral oil wastewater in a single-chamber air-cathode MFC generated a 45 mW/m^3 power density and an 80% COD removal efficiency [154].

2.6. Animals and Meat Industry Waste

Global demands for meat have raised the waste quantities as well as the greenhouse gas emissions, and the high volumes of water used in slaughterhouses affect climate change [29,155]. The degradation of animal and meat waste is difficult and until now, anaerobic digestion has been the usual method for reducing waste with simultaneous treatment for the removal of organic and other nutrients [156]. Nowadays, MFCs are used with mostly high working volumes compared to the other types of waste previously discussed. Usually, two-chamber MFCs are used to perform the maximum power density, whereas the single-chamber MFCs generate the maximum Coulombic efficiency from meat waste, in general, and the highest COD removal has been achieved by a tubular MFC (Table A6). Swine as waste resulted in a maximum power density of 2300 mW/m^2 in a 70 mL working-volume single-chamber MFC with carbon felt and carbon paper as the anode and cathode, respectively, in batch-mode operation, and produced a high COD removal efficiency of 91% and the highest Coulombic efficiency of 47% [157]. Two-chamber MFCs generated much lower power density and COD removal efficiency of between 77 and 86% with much higher working volumes [158,159]. Graphite material as the anodes in a single-chamber MFC achieved a lower COD removal efficiency of around 75% [160] than the carbon referred to previously from Ichihashi [157]. Studies on the two single-chamber MFCS with a 100 mL working volume and graphite fiber brushes as the anode and activated carbon as the cathode generated a higher power density of 750 mW/m^2 and a reduced COD removal efficiency than a single-chamber MFC with carbon material as the electrodes [161], whereas a combination of a single- and a two-chamber MFC with a 250 mL working volume using carbon electrodes generated the highest COD removal efficiency of 92% than any other study referred to previously for swine waste [162]. Recently, Cheng et al. [163] achieved the maximum COD removal efficiency of more than 95% in a dual-chamber MFC using swine wastewater including antibiotics, and at the same time a high removal efficiency of the sulfonamides. The combination of a single-chamber air-cathode MFC with flocculation reached almost a 97% COD removal efficiency [10].

Swine farm waste and wastewater generated the highest power density in a two-chamber MFC than in a single-chamber MFC, both with carbon electrodes [164,165]. Furthermore, swine manure in a 28 mL single-chamber MFC with carbon paper as the anode and carbon–Pt as the cathode generated the maximum power density of 228 mW/m^2 with a COD removal efficiency of 84% [166] compared to a much higher volume two-chamber MFC [167], whereas the latter achieved the maximum Coulombic efficiency (24%). Diluted swine manure was also sufficient producing a high Coulombic efficiency of 24% similar to the undiluted swine manure in a 65 mL single-chamber MFC with carbon felt as the anode and commercial gas diffusion as the cathode but with a much lower power efficiency [168].

Swine manure with a lower loading rate achieved higher Coulombic efficiency and COD removal efficiency compared to that with a higher loading rate [169]. Swine slurry has been studied in only two-chamber MFCs with variable working solutions of 269 to 504 mL in batch- or continuous-operation mode [170–172]. The batch mode in a 504 mL MFC with carbon felt as the anode and stainless steel mesh as the cathode generated the maximum current density of 250 mA/m^2 [170], whereas an MFC with similar electrode materials but with a 336 mL working volume in continuous operation mode was more efficient for COD removal at 51% [171]. Cattle manure was less effective than swine manure in an H-type microbial fuel cell in terms of power density and COD removal, which was found to be approximately 60% [173]. A cassette-electrode MFC generated 16.3 W/m^3 energy efficiency after 26 days of operation in a study by Inoue et al. [174]. More productive, however, in terms of power density, was cattle dung in a two-chamber MFC generating 220 W/m^3 [175]. Scaling up the process using swine wastewater in a 1.5 L, 12 L, or 100 L single-chamber MFC demonstrated no differences in COD removal between the three different working volumes, which were found to be almost 70%. The 12 L working-volume MFC generated higher average and maximum electricity than the 1.5 L and 100 L working volumes, whereas the Coulombic efficiency was higher in the lower working volumes than in the 100 L one [176]. In even larger working volumes of 110 L in 12 MFCs with swine wastewater, 65% of COD removal was achieved after 200 days of continuous-mode operation [177].

Waste from slaughterhouses demonstrated the highest power density of 700 mW/m^2 in a two-chamber MFC with graphite as the anode and graphite, zinc, and copper as the cathode [169,178], whereas the maximum 99% COD removal efficiency for all the meat and animal industry waste and wastewater was reported by Ismail et al. [179], thus a similar COD removal efficiency was reached two years later by the same researchers in a novel MFC aerobic bioreactor [180]. A lower power density of 578 mW/m^2 compared to the Prabowo et al. [169] study was mentioned in 2012 by Katuri et al. [181], who used slaughterhouse wastewater but achieved high Coulombic efficiency. A lower but still sufficient COD removal efficiency (between 70 and 80%) compared to the studies by Ismail et al. [179] or Mohammed et al. [180] was reported by two studies in an MFC with an air-breathing cathode with a separator based on ionic liquid or in a two-chamber MFC, respectively, with slaughterhouse wastewater as the substrate [182,183]. Protein food industry waste as feed for bioenergy production in MFCs can generate a sufficient power density of 230 mW/m^2 in a 1500 mL two-chamber MFC with graphite sheets as electrodes and a Coulombic efficiency of 21% [184]. Goat rumen was the waste that exhibited the maximum power density out of all the other animal and meat industry waste at 42,110 mW/m^2 in a 2500 mL working volume in four two-chamber MFCs in a series or 9700 mW/m^2 from the same working volume but in a single two-chamber MFC [185]. Reduced energy efficiency was produced by cow urine or diluted manure, as well as meat packing waste, in two-chamber MFCs [186,187], whereas manure wash waste in an 1850 mL working volume two-chamber MFC was more efficient in terms of power density than undiluted manure [187]. A study by Wang et al. [188] stated that the higher the moisture content of the cow manure, the higher the energy production that can be achieved, for example, 350 mW/m^2 with 80% moisture, whereas with only 10% less moisture, the produced energy is reduced almost 10-fold. Dried blended farm manure in a membrane-less MFC produced a 5 mW/m^2 power density [189]. Moreover, the pretreatment of manure with dilution or selective absorption supports enhanced power efficiency more than the untreated liquid manure due to a lower anode and cathode inhibition [190].

2.7. Distillery and Sugar-Based Industries

Molasses is the main byproduct of sugar-based industries and is composed of sugars and salts, whereas wastewater, the main byproduct of the distillery industry surpassing ethanol, is composed of solids [94]. Similar to other waste, molasses and distillery wastewater are usually treated by anaerobic digestion but now MFCs are also being used. Both single- and two-chamber MFCs have been used for treating distillery and sugar-based industry waste (Table A7). Regarding molasses, a 300 mL working volume two-chamber MFC with carbon cloth as the electrodes generated the maximum power density of 2425 mW/m^2 [191], but the maximum COD removal efficiency of 90% was demonstrated by a 900 mL single-chamber MFC with carbon felt as the anode and an air-diffusion electrode as the cathode [192]. Moreover, Lee et al. [192] compared a single- and two-chamber MFC with 900 mL working volumes and as previously mentioned, the single-chamber MFC carbon felt anode and air-diffusion cathode generated the maximum COD removal efficiency of 90%, but the two-chamber MFC with carbon felt electrodes produced the maximum power density of 17 mW/m^2. Half of the power density values reported in the Ali et al. [191] study were generated in a membrane-less single-chamber MFC with a graphite rod as the anode and carbon paper as the cathode using high-strength molasses wastewater and generated a power density of around 1410 mW/m^2 [193]. Sugar mill waste in a 500 mL two-chamber MFC generated a lower power density than that in the Ali et al. study [191], but a higher power density than that in the Lee et al. [192] studies, whereas it generated the maximum Coulombic efficiency of 70% in terms of all the various types of waste from distillery and sugar-based industries [194].

A combination of crude sugarcane effluent along with anaerobic sludge generated the maximum power density of all the studies at 8314 mW/m^2, which is almost double compared to the density generated in the absence of anaerobic sludge [195]. A dual-chamber MFC with carbon cloth as the anode and an MnO_2-modified cathode using molasses wastewater as the MFC substrate achieved better power efficiency compared to the unmodified one [196], whereas modifications to the membrane of the MFC verified that the PVDF- or acetone-modified Nafion membrane resulted in higher power efficiency [197] compared to the unmodified membrane or even to the nanoscale polypyrrole proton exchange membrane [198]. Location modifications to the anode and cathode (parallel or vertical) in a single-chamber MFC resulted in the finding that using vertical mode generated more power than parallel mode [199]. Recent studies of sugarcane molasses as the substrate in a dual-chamber MFC demonstrated lower Coulombic efficiency with a high volume of organic load, whereas this specific study achieved a high COD removal efficiency of 81.7% [200]. A different type of MFC to the single- and two-chamber MFCs had the advantage of the highest COD removal efficiency of almost 96% at an increased tilt angle [201]. An anaerobic baffled stacking MFC with four units could not surpass the COD removal achieved in previously-mentioned studies in single- or two-chamber MFCs since it achieved at a 50–70% efficiency [202].

Bioenergy production and COD removal from distillery wastewater were more efficient in a 210 mL two-chamber MFC than in a 28 mL single-chamber MFC with graphite plate and carbon cloth electrodes, respectively [203,204]. Earlier studies comparing single- and two-chamber MFCs with graphite rod electrodes resulted in a higher power density of 28.15 mW/m^2 than the single-chamber MFC, whereas the dual-chamber MFC achieved a better COD removal efficiency of 64% [205]. Digested distillery wastewater in a 500 mL two-chamber MFC with graphite rod electrodes led to a more efficient COD removal of 61% than the undigested distillery wastewater in the single-chamber MFC (57%), but a less efficient COD removal than in the 210 mL two-chamber MFC mentioned above [206].

Digested distillery wastewater in a 500 mL two-chamber MFC with graphite rod electrodes led to a more efficient COD removal of 61% than the undigested wastewater in the single-chamber MFC (57%), but a less efficient COD removal than in the 210 mL two-chamber MFC mentioned above [207–209]. The total power produced by distillery wastewater in a two-chamber MFC with a salt–agar bridge (four in a series MFC connection) reached 347 mW [210]. Distilled fermentation broth from food waste used after pretreatment in a 120 mL single-chamber air-cathode MFC and graphite felt as the anode generated 0.29 V and 1.4 mA with a sufficient COD removal efficiency of 70% [87], whereas aromatic and humic-acid-like substances could not be degraded. Recent studies have verified that an enhanced organic load of distillery wastewater can increase power efficiency as well as organic matter degradation in a dual-chamber MFC with polyacrylic sheet electrodes [211], whereas others have demonstrated that lower-strength distillery wastewater can generate more power compared to full-strength wastewater [212]. Furthermore, a higher surface at the anode and the electron acceptor could increase power efficiency and reach an 85% efficiency of COD removal [213]. Regarding the mezcal industry, the higher the loading of organic matter, the lower the power efficiency but the higher the COD removal efficiency at almost 92% [214], demonstrated in a study which is in contrast to the one of Tiwari et al. [211].

The 70% COD removal efficiency stated by Ma et al. [87] was surpassed only by the Mohanakrishna et al. [215] study in a single-chamber MFC with plain graphite plates as the electrodes reaching almost 73%, whereas other studies mentioned a COD removal efficiency of between 54 and 68% [216–219]. Until now, a combination of anaerobic fluidized bed and MFC led to the maximum COD removal efficiency of 80–90% using alcohol distillery wastewater [220]. Despite the low COD removal efficiency, Hamza et al. [218] reported the maximum recorded power density of 25,194.8 mW/m^2 in a single-chamber MFC with plain graphite plates as the electrodes. The maximum Coulombic efficiency of alcohol distillery wastewater generated in a thermophilic MFC was almost 89% with a sufficient power density of 1000 mW/m^2 [221].

2.8. Agricultural—Plant Waste

Agricultural processes generate plant waste composed of cellulose, lignin, and hemicellulose. Until now, plant waste has been disposed of by composting and incineration [222]. Recently, cellulose biomass has been treated in single- or two-chamber MFCs (Table A8). The maximum power density of 1080 mW/m^2 was generated in a single-chamber MFC with graphite fiber brush as the anode electrode, whereas the same MFC reactor, as well as a two-chamber MFC, demonstrated the maximum COD removal efficiency of 70% [223]. Graphite plates and platinum sheets in single- or two-chamber MFCs achieved a lower energy efficiency and COD removal efficiency [224–226]. Three out of a series of two-chamber MFCs with carbon paper as the anode and cathode using rice straw powder as the substrate generated 490 mW/m^2 [227], whereas a U-tube MFC with carbon cloth as the anode material via cellulose biomass generated only 4.9 mW/m^2 [228]. Wheat straw waste in a two-chamber 300 mL MFC with carbon paper electrodes generated 123 mW/m^2 [229]. In all the above cases, both cellulolytic, as well as exoelectrogenic, microorganisms were necessary for energy generation.

Both above-mentioned microorganisms are also necessary for energy production based on lignocellulose, but an extra step in the degradation of these substrates to low-molecular-weight compounds is crucial [216]. Corn stover waste biomass with or without acid-steam-exploded hydrolysis, a process that converts hemicellulose to soluble sugars, used in an air-cathode MFC resulted in 367 mW/m^2 and 371 mW/m^2, respectively [230]. Gregoire et al. [231] generated 230 mW/m^3 using corn residues in a tubular air-cathode MFC with leach-bed bioreactors for converting cellulose to sugars supported by rumen fluid and oxygen. Agricultural waste from Vicia faba generated less energy than the corn stover in a two-chamber MFC but a higher COD removal efficiency than using cellulose as feed [232]. General studies on orange peel waste demonstrated an energy efficiency of almost 358.8 mW/m^2, similar to the corn stover but with a higher COD removal efficiency. A less important current generation was generated using only cellulose as a substrate, which exhibited the absence of cellulolytic bacteria, whereas pectin led to higher energy efficiency [233]. Starch wastewater in an air-cathode MFC generated a 239.4 mW/m^2 power density, which was lower than the corn stover, and an almost 80–90% COD removal efficiency [234].

2.9. Sludge, Sewage/Solid Waste

Recent studies have verified that solid substrates of a different kind can be used in MFCs for energy production. Commonly, two-chamber MFCs have been utilized for energy generation with sewage sludge as the substrate (Table A9), though maximum power density and COD removal have been achieved by a single-chamber air-cathode MFC at 320 W/m^2 with fermented primary sludge as the substrate [235], and an MFC similar to that previously mentioned exhibited a maximum power density of 53 W/m^3 and the maximum Coulombic efficiency [236] using anaerobic mesophilic sludge as the substrate. Six different studies all using two-chamber MFCs and sewage sludge generated a power density from 8.5 to 36.72 W/m^3 [237–242]. Digested sludge in a two-chamber MFC generated 12.67 W/m^2 [243], which was much lower than the power density stated by Yang et al. [235] in the single-chamber MFC, whereas digested sewage sludge led to a low power generation of 3.1 μW [244] in a two-chamber MFC. Activated sludge was more efficient in terms of energy production than digested sludge in a two-chamber MFC and generated 42 mW/m^2 [245], demonstrating that the microwave-treated sludge resulted in 55% for total and 85% for soluble COD removal. Anaerobic sewage sludge, as well as saline domestic sewage sludge, generated the same power density operating in similar two-chamber MFCs of around 37–41 W/m^3 [246,247]. Moreover, a study by Karthikeyan et al. [247], demonstrated the same maximum Coulombic efficiency of 28.6% as the Martin et al. [236] study mentioned previously. Livestock solid waste in a single-chamber MFC generated 36.6 mW/m^2 [248]. Increasing the sewage sludge quantities resulted in higher power generation in a constructed dual-chamber MFC [249].

Recently, sludge waste in a double-chamber MFC with graphite electrodes produced a higher power density, 312.98 mW/m^2, compared to a single-chamber MFC with titanium electrodes that resulted in 97.6 mW/m^2 [250]. The power density of 788 mW/m^2 generated in a single-chamber MFC with graphite modified with Mn [251] increased compared to the power density in the two-chamber MFC in the study by Ayol et al. [250], but a single-chamber MFC platinum-modified with polyaniline generated the maximum power density until now of 6000 mW/m^2 [28,252,253]. A lower power density than 6000 mW/m^2 has been achieved, and still highly efficient was the density produced by carbon content derived after the pyrolysis of sewage sludge in an air-cathode MFC [254,255]. Anaerobic sludge from a wastewater treatment plant generated after 15 days in a two-chamber MFC with carbon cloth as the anode and a platinum cathode generated 13.5 mW/cm^2 [256], whereas sludge from the sewage of a treatment plant in a single-chamber MFC generated 1108 mW/cm^2 with carbon electrodes at 25 °C, thus reducing the energy efficiency with the increase in temperature [257]. Sewage excess sludge as a second substrate with a mixed liquor-suspended solid generated 27.65 W/m^3 in an air-cathode MFC [258]. A three-chamber MFC led to a 13.2 W/m^3 power density, much lower than the 53 W/m^3 in the single-chamber MFC studied by Martin et al. [236], whereas the Coulombic efficiency was 19.4%, the COD removal efficiency was 40% [259], and the power density was 190 mW/m^2 [260]. A salt-bridge-based dual-chamber MFC with sewage sludge as the substrate produced a maximum voltage of 2.5 V [261].

2.10. Soil Waste

Crucial types of industrial waste include urea, urine, and synthetic nitrogen. Recent efforts have been made with the goal of creating compost soil microbial fuel cells for energy production (Table A10). An MFC with graphite electrodes and urea as the feed from the compost produces a 3.2 mW/m^2 power density [262]. Twenty-one air-cathode MFCs using various soil substrates produced a higher power density of between 16.4 and 28.6 mW/m^2 compared to the study by Magotra et al. [262], which demonstrated that soils with a higher organic load and lower pH generate better energy efficiency [263]. MFCs with platinum electrodes and soil as feed generated a higher power density than previously mentioned [262,263] of 32 mW/m^2 in soil, which has glucose as a base, whereas the energy efficiency was lower in straw-based soil [264]. Human urine led to a maximum power density of 124.16 mW/m^2 in a soil-based MFC with a carbon electrode [265]. A comparison of salt, silt, and clay verified that it is the best soil for energy production in a single-chamber MFC [266]. Furthermore, sand and clay soil with dried leaves generated 29.2 mW/m^2 and 23.8 mW/m^2, respectively, in a soil-based MFC [267]. A portable plugged-type soil-based MFC produced a low power density of 7.3 mW/m^2 [268]. A comparison of Brinjal-cultivated soil and sugarcane-cultivated soil verified that the former was more efficient in an agar–salt-bridged soil-based MFC [269].

2.11. Municipal/Solid Waste—Mixed Waste

Apart from the waste used in MFCs that has been analyzed above, mixed waste has also been examined (Table A11). Municipal waste is moreover a source of energy generation in various types of MFCs. In a single-chamber MFC, Cha et al. [270] generated 16.7 W/m^3 using raw municipal waste performing a Coulombic efficiency of 39.6%, whereas Nastro et al. [271] generated a lower power density than the Cha et al. [270] study. Domestic wastewater generated 10 W/m^3 and a 22% Coulombic efficiency [272] or 72 mW/m^2 and lower Coulombic efficiency of 6% [273]. An up-scaled 255 L MFC produced using municipal wastewater generated 78 mW/m^2 and an almost 57% COD removal efficiency [274]. Stacked MFCs (20 air-cathode MFCs) with municipal wastewater as the substrate generated the maximum power density of 1107 mW/m^2 in individual MFC units, or 79 mW/m^2 in total, and an 84% COD removal efficiency [275]. Municipal solid waste in a two-chamber MFCs was energetically more efficient than in a one–chamber MFC with carbon felt than other electrode materials in a two-chamber MFC [276], whereas municipal alkali hydrolysis as the pretreatment and K3Fe(CN)6 as the electron acceptor enhanced the maximum power density to 1817.88 mW/m^2.

Mixed mature municipal solid waste landfill leachate with dairy wastewater achieved an almost 85% COD removal efficiency with a low leachate/dairy mix, whereas the COD removal efficiency was reduced to 66.3% with a leachate/dairy mix ratio of 20%, achieving a 7.6% Coulombic efficiency [277]. In a recent study, Moqsud et al. [278] stated that cow dung produced a higher voltage than chicken droppings, whereas fruit waste was more efficient than food waste, as was rice bran than leaf waste. Artificial domestic wastewater and industrial wastewater in a cassette-electrode MFC achieved similar Coulombic efficiencies of 93% and 97% [279]. Ammonium with municipal wastewater in a dual-chamber MFC achieved an 85% COD removal efficiency [280], whereas municipal wastewater in the presence of ammonia in a bench-scale or a 45 L working-volume MFC showed a lower power efficiency compared to municipal wastewater alone in high ammonia concentrations [281]. Distillery wastewater after 20 days of MFC operation generated a 70% COD removal efficiency, whereas municipal, agro, and dairy wastewater demonstrated a higher COD removal efficiency of 99% [282].

Mixes of potato and sludge enhanced the power efficiency, reaching an almost 85% COD removal efficiency, and a comparison between them verified that sludge alone has better COD removal compared to potato alone [283]. Municipal wastewater treatment plant effluent in a cell-constructed wetland MFC generated a higher power density under xylan than in the presence of glucose [284]. Landfill leachate in both a smaller- and larger-working-volume MFC generated 31 mW/m^2 in the smaller MFC and 635 mV in the larger MFC, whereas the smaller-working-volume MFC achieved a 62% COD removal efficiency [285]. Mixed-wood hydrothermally treated wastewater combined with municipal wastewater led to an enhanced power efficiency compared to using the former alone, with an increase from 70 to 360 mW/m^2 [286]. One year of operation of a 1000 L working-volume MFC led to the generation of 7.58 W/m^2 using artificial wastewater, whereas municipal wastewater reduced the power efficiency to 3.64 W/m^2 [287]. A horizontal plug flow and stackable MFC using municipal wastewater generated 116 mV with an 86% COD removal efficiency [288]. Domestic wastewater in a cylindrical two-chambered MFC produced an almost ninefold higher power density than glucose alone [289]. A mix of olive oil mill wastewater and molasses generated a 36 W/m^2 power density with a 53% COD removal efficiency [290].

Other comparisons showed that distillery spent wash was more efficient regarding energy generation than molasses in a salt-bridged two-chamber MFC [291]. In a double-chamber mediator-less MFC, molasses generated 2.425 W/m^2 with a 67% COD removal efficiency, whereas black liquor from paper pulp generated 3.55 W/m^2 and a better COD removal efficiency of 78% was found [191]. Activated sludge and cattle manure slurry were more energetically efficient than domestic sewage in terms of the power density generated as well as COD removal [292]. The energy potential exhibited by onion waste was 1.01 mV, whereas mixing it with tomato and potato waste increased the voltage to 10.2 V [293]. Sewage sludge demonstrated a higher energy generation than carbon manure, wastewater, and cow manure [294,295]. Mixing cow manure and slurry produced 1.6136 mV of energy with a COD removal efficiency of 98% after 6 days of operation of the MFC [296]. Moreover, cow dung enhanced the energy production from distillery wastewater [297]. Cow manure, fruit waste, and soil generated 210 mW/m^2 [298]. Vegetable waste with molasses in a dual-chamber MFC produced almost 44,400 to 104,400 mW/m^2 based on different ratios, whereas the Coulombic efficiency was between 63.2 and 81.7% [299]. A comparison of molasses, whey, bulgur, and olive mill wastewater demonstrated that molasses was more efficient regarding voltage power followed by whey, olive mill wastewater, and finally bulgur wastewater [300].

Moreover, kitchen waste has higher energy potential than cow dung and palm kernel waste due to its higher carbohydrate content [301]. Recently, cattle manure in a dual-chamber graphite-electrode MFC generated 1.170 V and was enhanced further by yogurt and reached 1.122 V [302]. Multiple-chamber MFCs achieved almost 6 V by using dumping rubbish as the substrates [303]. A mix of dairy and distillery wastewater with cow dung produced in a double-chamber MFC generated 3.4 W/m^2 and 4.6 W/m^2 in a single-chamber MFC, with a 77% and 85% COD removal efficiency, respectively [304]. Distillery wastewater was more efficient since it produced a higher voltage than vermicompost [305]. Kitchen garbage generated a higher voltage than bamboo waste in a one-chamber MFC [93]. Sludge outperformed stored urine in a carbon veil anode and PTFE cathode MFC [306]. A single-chamber MFC with a graphite fiber brush anode and carbon cloth cathode demonstrated that garden waste could generate a higher COD removal efficiency and lower Coulombic efficiency than food waste and paper/cardboard waste, whereas the opposite happened using food waste. These three substrates with the same ratios created the maximum COD removal efficiency of 77.5% and Coulombic efficiency of 23.5% [307]. Mixes of sewage sludge and kitchen waste generated 263–918 mV in a single-chamber MFC [308].

3. Future Perspectives and Research Needs

The detailed analysis above of various types of waste used in MFCs for energy production verified that treated food waste dominated followed by dairy, brewery, and animal waste. Distillery waste is also a suitable candidate for energy generation in MFCs [203,216,297]. We believe due to the continuous availability of food, dairy, and brewery waste, that these are the types of waste that should be used and that MFC technology should be expanded to hold chambers with higher working volumes, especially for food waste to increase power densities [106,302]. Another reason is that these types of waste have resulted in some of the highest levels of energy production and since the highest chamber volumes have already been used, scale-up processes are needed. For brewery and winery waste, methanogenic control is required, and in combination with secondary processes, the efficient removal of contaminants would be supported [124,138]. These types of waste demonstrate similar performances to anaerobic technologies. Anaerobic fermentation is a pretreatment step for cafeteria and canteen waste and results in efficient energy generation via MFCs despite the high-strength waste. For dairy waste, low power densities have sometimes been achieved, but the increased COD removal indicates that the optimization of MFCs delivers high levels of energy generation. Methanogenic control and anaerobic fermentation as a pretreatment step are factors that need to be evaluated for sugar and distillery waste for enhanced power densities [101,149,217].

One of the challenges of MFCs is the cathode electrode material. Various materials have been tested but further evaluation is mandatory for enhanced energy efficiency and further studies could overcome the limitation of the need to use catalysts [92]. Moreover, the electron losses correlated with the lower required power input and higher energy generation should also be restricted. Factors such as microbial growth, substrate diffusion into the biofilm, and conversion of substrates in the cell environment, as well as losses in the microorganisms and losses due to concentration gradients, should be evaluated for all kinds of waste for better energy production [9,25,53,161,223,233,238]. A proper selection of waste substrates should always be based on the characteristics of the waste/substrates and a representative Table 1 is presented below.

Table 1. Waste properties and characteristics for MFC usage.

Waste	Properties/Important Characteristics for Their Usage	Refs.
Food	high moisture content, high content of organic components, salt, and low calorific value	[52,85,94,309]
Seafood	huge amount of chitin, a polysaccharide	[98,99,309,310]
Dairy	including lactose, protein, fat, oil, and grease; variable pH levels as sanitizing chemicals affect wastewater treatment	[311]
Brewery	contains a high concentration of organic matter	[124,138,140,312]
Agricultural	weight, volume, moisture content, total solids, volatile solids, fixed solids, dissolved solids, and suspended solids	[293,313]
Solid	moisture content, volatile solid, ash content, CHNSO contents, calorific value, and heavy metals	[314]
Municipal	particle size distribution, geometry, and classification of the waste, moisture and organic matter content, unit weight, and temperatures of the landfill waste	[285,315]
Distillery	contains heavy metals, also a rich source of organic matter and nutrients such as nitrogen, phosphorus, potassium, calcium, and sulfur	[203,211,216,218]

4. Prospects for Upscaling and Technology Readiness Level (TRL) Assessment

The progress in MFC technology means there are a lot of aspects to assess for the Technology Readiness Level (TRL) assessment, but the possibilities, risks, and future prospects for upscaling also need to be addressed. The upscaling and implementation of microbial fuel cell (MFC) systems into large applications can be considered a new line of interest from industry sectors. After successful implementations [316,317], trends focus on utilizing these bioelectrochemical systems in stacks in order to maximize energy power output. Although the high pollution and/or waste degradation rates of such systems are high (>85%), the energy generation is not sufficient to justify producing upscaled systems based on only one type of MFC technology (single- or dual-chamber) [198,318–320].

The main factors to consider in the upscaling possibilities for MFCs are the overpotential during activation, insufficient electrical contact between the bacteria and the anode, and the competition for electrons and substrates among the electroactive bacteria [321]. All the above result in a low electrical efficiency and a general degradation in performance over time. In order to upscale this technology, the focus must be on boosting the efficiency of MFCs, improving anodic and cathodic efficiency, modifying the electrodes, and using separators and decreasing internal resistance to obtain higher electrical performance. Primary efforts have been focused on improving the materials, designs, and components such as electrodes, electrolytes, and housing [25,56].

MFC technology is still in the laboratory use, analysis, and evaluation stage with some exceptions for ingenious designs for practical real-world implementation. Stackable units have been produced (Figure 6) in order to multiply the MFC components and enhance their efficiency.

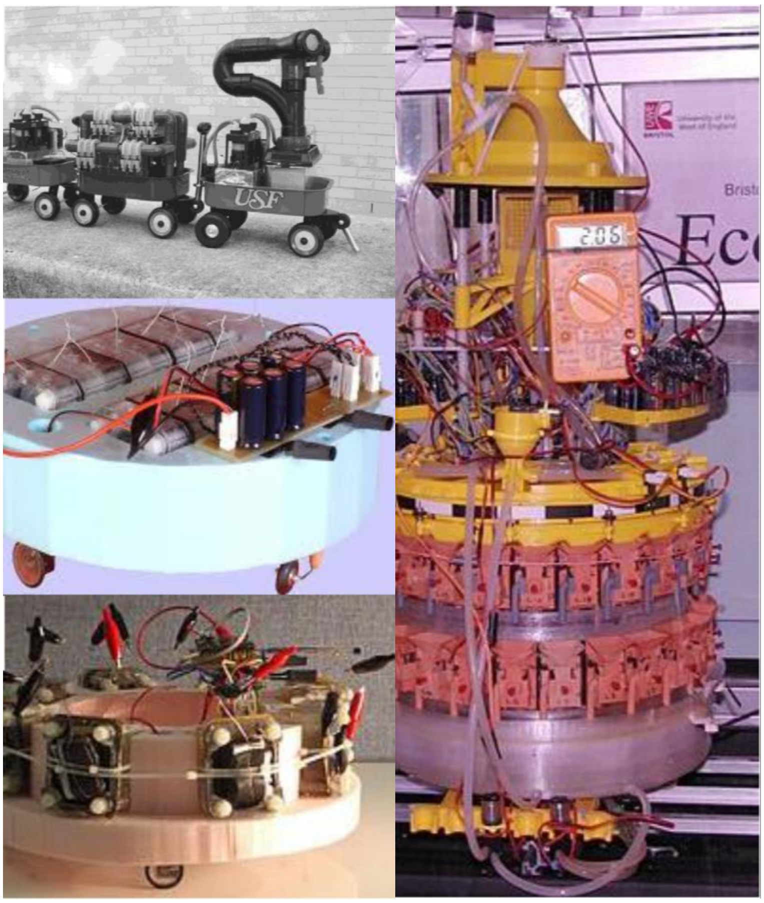

Figure 6. Scaled up construction of MFC (Adapted with permission from Ref. [316]).

However, the type of the connections used in these stacks plays an important role in power generation and waste treatment. Especially in series connections, the systems suffer from an open current voltage loss due to the parasitic current flow of an under-performing part of the stack, short circuits, and low efficiency [322].

The main obstacle to achieving high power densities is the system architecture and of less importance, is the ecosystem of the anode compartment. The bacterial community used for waste/substrate treatments is specified and used in accordance with the type of waste and the physiochemical parameters (a specific organic loading, pH, chemical composition, and salinity), as well as the electrode material, which would also affect the internal resistance of the system. For this reason, a prototype unit must be designed according to the specific task (sensing/power/treatment) and environment in which it will be installed and the type and flow rate of the substrate that will be processed [316–321,323–327].

To conclude, the main factors that still hinder the scaling up of this technology are the:

1. electrode costs.
2. biofouling effects on membranes and electrodes.
3. inconsistent power generation depending on the type of substrate and operational conditions.
4. acquisition methods of the power generated in the system.

Based on the technology analysis presented, MFCs are still in a peculiar position regarding the commercialization of the technology. Some operational and structural aspects are still in their technological infancy, whereas the research is focused on reducing operational and manufacturing costs. This leads to a low TRL level and premature commercialization readiness. Considering a life cycle assessment (LCA) plan, all the above factors are to be considered as this technology could be systematically scaled up to an extent that avoids and surpasses the above-mentioned obstacles [317–319,326,327].

In terms of manufacturing and cost analyses, all data are to be considered from a science lab-based perspective. The major challenge to calculating the economic scale is the factors that affect and control the manufacturing processes. Many parts are expensive, even at the prototype level (such as Pt electrodes). A further scientific challenge is the identification of alternatives to (i) perform equally well and for prolonged periods but most importantly (ii) be inexpensive and widely available [328–332].

5. Conclusions

This review extensively demonstrated the efforts in bioenergy production using various types of microbial fuel cells based on the usage of different types of waste. An effort to categorize the waste into general fields and to sub-categorize the various types of waste belonging to each field was achieved. We investigated mixed waste and specific perspectives for further studies especially with regard to the upscaling of the processes for enhanced energy production based on the most energy-efficient types of waste that have been examined. In general, MFCs had the same performance or better as other anaerobic technologies treating brewery and winery wastewater, whereas further treatment to remove various contaminants would benefit the final energy production. Similar treatments are necessary for improving the energy production of distillery wastewater. MFCs using canteen waste led to high COD removal, Coulombic efficiencies, and power densities, whereas with dairy waste and general food waste, MFCs demonstrated higher COD removal and lower power density compared to other waste. Animal waste has a high potential for energy generation via MFCs as well as oil, soil–plant, and solid waste. Specifically, for solid and oil waste, new designs for MFCs may support enhanced Coulombic efficiencies and better energy production, whereas the proper selection of the solid matter for degrading the bacteria is necessary for the proper pretreatment of solid waste. Global energy needs are increasing daily so further studies focused on the optimization of the necessary parameters can lead to successful upscaling processes for better energy efficiency. Proper combinations of the most efficient types of waste under the optimal conditions for each type of waste and MFCs would benefit higher energy production. The urge for self-sustainability and the need for upscaling MFC technology has pushed the research to achieve a TRL of four for practically all MFC current systems. All MFC technology seems to have practical applications at multiple small scales and in multiple environments but the need for commercialization has to overcome basic manufacturing costs with a simultaneous need to boost the power output. In such readiness assessments, the treatment of medium-to-low loaded waste/substrates can be treated with an average 350 W/m^2 power-density output value. In addition, stacking seems to solve the above limitation but leads to operational disadvantages. MFC technology has barely begun to solve the system integration issues and a lot of effort must be made in the future in order to overcome the immature state of MFC commercialization. From a funding/development perspective, MFCs remain a nascent technology, but through the continuous implementation of research findings, upscaled systems MFCs and their sustainability will play a significant role for future generations. All the above efforts would strengthen green energy production worldwide.

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Appendix A

Table A1. Summary of studies reporting use of food, fruit, and vegetable waste and wastewater in MFCs.

Waste Type Food, Fruit, and Vegetable Waste and Wastewater	MFC Type	Working Volume [mL]	Anode Material	Cathode Material	COD Removal [%]	Power-Density Voltage	Current Density Current	Coulombic Efficiency [%]	Refs.
potato	single-chamber	28	graphite fiber brushes	carbon cloth–Pt–PFTE	89%	217 mW/m^2	n/a	21	[53]
potato pulp	single-chamber	25	graphite fiber brushes	carbon cloth–Pt–PFTE	68.40%	32,100 mW/m^3	n/a	56	[56]
potato pulp	two-chamber	240	carbon felts	carbon felts	90%	1.4–6.8 mW/m^2	n/a	44	[57]
potato	three-chamber	800	graphite	graphite	80%	n/a	250–400 µA	n/a	[58]
potato–shochu	cassette-electrode	350	graphite felt	carbon cloth	68%	1.2 W/m^3	n/a	2	[59]
culled (defective) tomatoes	two-chamber	n/a	graphite felt	graphite felt	n/a	256 mW/m^2	n/a	n/a	[60]
tomato seeds and skin	two-chamber	n/a	graphite felt	graphite felt	n/a	132 mW/m^2	n/a	n/a	
natural vegetable waste	two-chamber	35	granular graphite	carbon paper	87%	596–1019 mW/m^3	n/a	33	[62]
composite vegetable waste	single-chamber	430	graphite plates	graphite plates	63%	57.38–215.71 mW/m^3	n/a	n/a	[61]
fermented apple juice	two-chamber	500	graphite felt	platinum mesh	n/a	10.2–78 mW/m^2	56.9–208 mA/m^2	n/a	[64]
yogurt waste	two-chamber	500	graphite felt	platinum mesh	n/a	n/a	250 mA/m^2	n/a	
chilled ready-to-eat food	tubular	1000	carbon veil	carbon cloth	84%	3.34–5.86 W/m^3	n/a	n/a	[65]
baker's yeast	two-chamber	100	carbon felts	carbon felts	less than 40%	9.75–18.41 mW/m^2	n/a	n/a	[67]
bakery wastewater	single-chamber	45	carbon cloth	carbon paper	86%	n/a	10–11 mA/m^2	n/a	[66]
vegetable waste	U-shaped	n/a	graphite rod	graphite rod	n/a	88 W/m^2	314.4 mA/m^2	n/a	[63]
food waste leachate	two-chamber	1200	carbon	carbon	90%	15,140 mW/m^3	n/a	n/a	[68]
food waste leachate	two-chamber	76	carbon felt	carbon felt	85.40%	1 mW/m^3	n/a	13	[69]

Table A1. *Cont.*

Waste Type Food, Fruit, and Vegetable Waste and Wastewater	MFC Type	Working Volume [mL]	Anode Material	Cathode Material	COD Removal [%]	Power-Density Voltage	Current Density Current	Coulombic Efficiency [%]	Refs.
food waste leachate	air-diffusion	234	carbon felt	ELAT gas diffusion electrode	95%	1.86 W/m^3	n/a	n/a	[70]
soy-based foods	three-chamber	n/a	carbon	carbon	71.40%	less than 100 mW/m^2	n/a	18	[71]
food waste	two-chamber	84	carbon cloth	carbon paper	n/a	1007 mW/m^3	5524 mA/m^3	12	[72]
food waste	two-chamber	84	carbon cloth	carbon paper	n/a	190.5 mW/m^3	853 mA/m^3	8	
food industry waste	two-chamber	250	carbon cloth	carbon cloth	64.20%	n/a	0.78 mA	n/a	[73]
food industry waste	single-chamber	250	carbon cloth	carbon cloth	63%	n/a	0.72 mA	n/a	
food processing waste	two-chamber	250	carbon paper	carbon–Pt	95%	371 mW/m^2	n/a	n/a	[74]
food processing waste	single-chamber	250	carbon paper	carbon–Pt	95%	81 mW/m^2	n/a	n/a	
oranges	n/a	felt disc	felt disc	n/a	n/a	357 mV	n/a	n/a	[75]
food waste	single-air-cathode	n/a	carbon brush	n/a	n/a	16–27 mW/m^2	n/a	n/a	[76]
liquid part of food waste	cylinder-type air-cathode single-chamber	n/a	n/a	n/a	n/a	125 million KWh	n/a	n/a	[77]
canteen waste leachate	single-chamber	24	graphite brush	carbon cloth	85.10%	1540 mW/m^2	n/a	89	[78]
canteen waste leachate	single-chamber	22	graphite fiber brush	carbon cloth–Pt	86%	371–556 mW/m^2	n/a	27	[79]
canteen waste leachate	single-chamber	300	graphite	graphite air-cathode	72%	162.4 mW/m^2	n/a	n/a	[80]
canteen waste leachate	single-chamber	430	graphite plates	graphite plates	65%	108 mW/m^2	390 mA/m^2	n/a	[81]
diluted canteen waste	single-chamber	120	carbon cloth	carbon cloth	80.80%	5.6 mW/m^3	15.3 mA/m^3	n/a	[333]
undilued canteen waste	solid-phase	500	graphite plates	graphite plates	76.00%	41.8–170.81 mW/m^2	n/a	n/a	[82]

Table A1. *Cont.*

Waste Type Food, Fruit, and Vegetable Waste and Wastewater	MFC Type	Working Volume [mL]	Anode Material	Cathode Material	COD Removal [%]	Power-Density Voltage	Current Density Current	Coulombic Efficiency [%]	Refs.
canteen waste	three-chamber	1500	graphite plates	graphite plates	99%	123.8 mW/m^2	54.3 mA/m^2	n/a	[83]
canteen waste	three-chamber	300	graphite	copper	44%	19151 mW/m^3	n/a	n/a	[84]
cafeteria fermented waste	two-chamber	n/a	carbon	carbon	n/a	15.3 mW/m^2	n/a	n/a	[85]
canteen waste food	n/a	n/a	n/a	permaganate	87%	422 mW/m^2	n/a	n/a	[86]
food waste ethanol fermentation stillage	single-chamber	120	graphite	titanium	70%	0.29 V	1.4 mA	n/a	[87]
food waste ethanol fermentation stillage	n/a	n/a	n/a	n/a	62%	612 mW/m^2	6.4 W/m^3	n/a	[88]
kitchen waste	single-chamber air-cathode	n/a	carbon rod	carbon rod	n/a	85.58 mW/m^2	n/a	n/a	[89]
kitchen waste	H-type dual-chamber	310	carbon paper	carbon cloth	n/a	29.6 mW/m^2	n/a	n/a	[90]
kitchen waste	single-chamber	n/a	carbon fiber	carbon fiber	n/a	620 mV	n/a	n/a	[93]

Table A2. Summary of studies reporting use of seafood waste in MFCs.

Waste Type Seafood Industry	MFC Type	Working Volume [mL]	Anode Material	Cathode Material	COD Removal [%]	Power-Density Voltage	Current Density Current	Coulombic Efficiency [%]	Refs.
seafood	two-chamber	98	graphite rod	graphite rod	28–80	16,200 mW/m^3	n/a	15	[95]
seafood	single-chamber	26	carbon cloth steel mesh	carbon cloth steel mesh	85	358.8 mW/m^2	n/a	14	[96]
seafood	tubular	50	activated carbon fiber felt	activated carbon fiber felt	83	105–22 mW/m^2	n/a	<30%	[97]
seafood	two-chamber	26	carbon cloth steel mesh	carbon cloth steel mesh	65	291.6 mW/m^2	n/a	20	[96]
seafood	air-cathode	n/a	n/a	n/a	90	570 mW/m^2	600 mA/m^2	52	[98]
seafood	dual-chamber	3000	polypropylene	polypropylene	77	2960.704 mW/m^2	2996.664 mA/m^2	n/a	[99]

Table A3. Summary of studies reporting use of dairy waste in MFCs.

Waste Type Dairy Industry	MFC Type	Working Volume [mL]	Anode Material	Cathode Material	COD Removal [%]	Power-Density Voltage	Current Density Current	Coulombic Efficiency [%]	Refs.
yogurt waste	three-chamber	500	graphite felt	platinum mesh	n/a	53.8 mW/m^2	n/a	n/a	[64]
yogurt waste	three-chamber	500	platinum mesh	platinum mesh	91	38 mW/m^2	n/a	n/a	[103]
yogurt	single-chamber air-cathode	28	stainless steel fiber felt	activated carbon	87	1143 mW/m^2	n/a	n/a	[104]
dairy manure	single-chamber	28	graphite fiber	graphite cloth	70	189 mW/m^2	n/a	12	[53]
dairy manure	three-chamber	617	graphite fiber brush	graphite fiber brush and granules	n/a	14000 mW/m^3	n/a	19	[105]
synthetic dairy wastewater	two-chamber	480	carbon	carbon	63	92 mW/m^2	665 mA/m^2	24	[106]
activated sludge dairy waste	two-chamber	600	graphite sheet	graphite sheet	n/a	0.715 mW/m^3	n/a	n/a	[107]
cheese whey	single-chamber	28	graphite fiber brush	graphite fiber cloth	n/a	22.3 mW/m^3	10 mA/m^3	49	[108]
cheese whey	two-chamber	800	graphite	graphite	n/a	324.8 µW	1.19 mA	n/a	[109]
dairy	two-chamber	2000	graphite	graphite	n/a	621.3 mW/m^2	3.74 mA	38	[111]
dairy	single-chamber	480	graphite plate	graphite plate	96	1.28 mW/m^2	n/a	14	[102]
dairy	two-chamber	30	graphite plates	graphite plates	91	197 mW/m^2	n/a	17	[110]
dairy	continuos-flow-type two-chamber	n/a	stainless steel	stainless steel	94	38 µW	n/a	n/a	[112]
dairy	single-chamber	n/a	n/a	n/a	95	62.27 mW/m^2	263 mA/m^2	32	[113]
dairy	three MFCs in a series	300-300-330	n/a	n/a	n/a	1.745 V	n/a	n/a	[114]
dairy	two-chamber	n/a	carbon felt	carbon	83	less than 450 mW/m^2	n/a	32	[71]
dairy	two-chamber	17	graphite brush	carbon cloth	76	131 mW/m^2	2.4 W/m^3	n/a	[115]

Table A3. *Cont.*

Waste Type Dairy Industry	MFC Type	Working Volume [mL]	Anode Material	Cathode Material	COD Removal [%]	Power-Density Voltage	Current Density Current	Coulombic Efficiency [%]	Refs.
dairy	double-chamber salt-bridged	n/a	n/a	n/a	86	1080 mW/m^2	n/a	n/a	[116]
dairy	double-chamber agar–salt-bridged	n/a	graphite plates	graphite plates	92	n/a	n/a	n/a	[117]
cheese	n/a	n/a	n/a	n/a	92	44.05 mW/m^2	n/a	2%	[118]
yogurt waste	n/a	n/a	n/a	n/a	86	n/a	n/a	n/a	
dairy	two-chamber	84	carbon paper	n/a	n/a	503 mW/m^3	1946 mA/m^3	<4%	[72]
dairy	two-chamber	84	carbon paper	n/a	n/a	38 mW/m^3	404 mA/m^3	<1%	
dairy	single-chamber	45	carbon cloth	carbon paper	82	n/a	25 mA/m^2	n/a	[66]

Table A4. Summary of studies reporting use of brewery and winery waste in MFCs.

Waste Type Brewery and Winery	MFC Type	Working Volume [mL]	Anode Material	Cathode Material	COD Removal [%]	Power-Density Voltage	Current Density Current	Coulombic Efficiency [%]	Refs.
winery	tubular	170	carbon felts	carbon felts	10	890 mW/m^2	n/a	42	[129]
winery	two-chamber	70	carbon felts	carbon felts	17	465 mW/m^2	n/a	15	[130]
wine lees	two-chamber	500	graphite felt	platinum mesh	n/a	0.8 mW/m^2	6.6 mA/m^2	n/a	[64]
brewery	single-chamber	n/a	carbon cloth	carbon cloth	98	205 mW/m^2	n/a	10	[124]
brewery	single-chamber	100	carbon fibers	stainless steel-activated carbon–PTFE	21	669 mW/m^2	n/a	2	[131]
brewery	single-chamber	225	graphite felt	carbon cloth–Pt	n/a	552 mW/m^2	n/a	41	[132]
brewery	single-chamber	n/a	carbon cloth	carbon cloth–Pt	87	483 mW/m^2	n/a	38	[133]
brewery	single-chamber	4000	carbon fiber brushses	activated carbon	75	304 mW/m^2	n/a	2	[123]
brewery	two-chamber	200	graphite felt	graphite cloth	80	305 mW/m^2	745 mA/m^2	n/a	[134]

Table A4. *Cont.*

Waste Type Brewery and Winery	MFC Type	Working Volume [mL]	Anode Material	Cathode Material	COD Removal [%]	Power-Density Voltage	Current Density Current	Coulombic Efficiency [%]	Refs.
brewery	two-chamber	n/a	carbon paper	carbon paper	n/a	38.4 mW/m^2	n/a	n/a	[135]
brewery	two-chamber	n/a	graphite felt	graphite felt–Pt	65	n/a	0.78 mA/m^2	n/a	[136]
brewery	three-chamber	1200	graphite plates	graphite plates	93	173 mW/m^2	370 mA/m^2	n/a	[137]
brewery	single-chamber	n/a	n/a	n/a	93	less than 300 mW/m^3	1100 mA/m^3	n/a	[138]
brewery	single-chamber	180	carbon fiber and graphite rods	stainless steel activated carbon–Pt–PTFE	43	264 mW/m^2	1.79 mA/m^2	20	[139]
brewery	single-chamber	45	carbon cloth	carbon cloth coated Pt–PTFE	85	n/a	10 mA/m^2	n/a	[66]
brewery	two-chamber	250	copper mesh	copper mesh	82	80 mW/m^2	n/a	n/a	[140]
brewery	serpentine-type	10,000	graphite felt	n/a	85	4.1 W/m^3	n/a	6–8	[141]
brewery	industrial two-chamber	n/a	graphite brush	carbon cloth	92	26.4 KWh	n/a	n/a	[142]
brewery	single-chamber	700	carbon paper	graphite	94	n/a	10.89 mA	n/a	[143]

Table A5. Summary of studies reporting use of oil industry waste in MFCs.

Waste Type Oil Industry	MFC Type	Working Volume [mL]	Anode Material	Cathode Material	COD Removal [%]	Power-Density Voltage	Current Density Current	Coulombic Efficiency [%]	Refs.
soybean oil	single-chamber	18	graphite felt	carbon cloth	78	2240 mW/m^2	658 mA/m^2	20	[146]
soybean oil	single-chamber	2	graphite felt	stainless steel	96	746 mW/m^2	n/a	34	[147]
palm	two-chamber	450	PACF carbon felt	PACF carbon felt	70	22 mW/m^2	180 mA/m^2	24	[148]
vegetable oil	two-chamber	500	carbon cloth	carbon cloth	86	n/a	n/a	n/a	[149]
vegetable oil effluent	dual-chamber	500	graphite rod	carbon cloth	80–90	5839 mV	n/a	37	[150]
petroleum refinery	single-chamber air-cathode membrane-less	350	carbon fiber brush	platinum-coated carbon cloth	48%	132 mW/m^2	n/a	n/a	[151]
petroleum refinery	single-chamber	n/a	n/a	n/a	85	225 W/m^2	n/a	2	[152]
oil sewage	constructed wetland reactor	2400	crushed stone, glass wool, activated carbon	MnO_2-modified	73–75	102 mW/m^2	n/a	n/a	[153]
oil sewage	simple MFC	2400	crushed stone, glass wool, activated carbon	n/a	73–75	80 mW/m^2	n/a	n/a	[153]
mineral oil	single-chamber air cathode	n/a	n/a	n/a	80	45 mW/m^3	n/a	n/a	[154]

Table A6. Summary of studies reporting use of animal and meat industry waste in MFCs.

Waste Type Animal and Meat Industry	MFC Type	Working Volume [mL]	Anode Material	Cathode Material	COD Removal [%]	Power-Density Voltage	Current Density Current	Coulombic Efficiency [%]	Refs.
swine	single-chamber	70	carbon felt	carbon paper	91	2300 mW/m^2	6000–7000 mA/m^2	47	[157]
swine	two-chamber	450 + 350	graphite granule and graphite rod	carbon felt	77	3.1–7.9 mW/m^3	1.7–2.8 mA	n/a	[158]
swine	two-chamber	1000	carbon	carbon rod	86	88.45 mW/m^2	0.49 mA	n/a	[159]
swine	single-chamber	n/a	graphite brush		75	n/a	n/a	n/a	[160]
swine	2 single-chambers	100	graphite fiber brushes	activated carbon–PVDF–carbon black	65	750 mW/m^2	1400–1600 mA/m^2	n/a	[161]
swine	combination of a single- and two-chamber	250	carbon paper	carbon–Pt	92	261 mW/m^2	1400 mA/m^2	8	[162]
swine	dual-chamber	350	carbon fiber brush	carbon fiber brush	95	n/a	n/a	n/a	[163]
swine	single-chamber air cathode with flocculation	n/a	carbon brush	nickel	97	37.5 W/m^3	n/a	22	[10]
swine farm waste and wastewater	two-chamber	n/a	carbon fiber brush	carbon cloth–Pt	n/a	880–1056 mW/m^2	n/a	n/a	[164]
swine farm waste and wastewater	single-chamber	128	carbon fiber	carbon fiber stainless steel mesh	72	256 mW/m^2	4400 mA/m^2	39	[165]
swine manure	single-chamber	28	carbon paper	carbon–Pt	84	228 mW/m^2	n/a	n/a	[166]
swine manure	two-chamber	420	granular graphite and graphite rod	granular graphite and graphite rod	n/a	20 mW/m^2	n/a	24	[167]
diluted swine manure	single-chamber	65	carbon felt	commercial gas diffusion	15	28 mW/m^2	n/a	24	[168]

Table A6. *Cont.*

Waste Type Animal and Meat Industry	MFC Type	Working Volume [mL]	Anode Material	Cathode Material	COD Removal [%]	Power-Density Voltage	Current Density Current	Coulombic Efficiency [%]	Refs.
swine manure	two-chamber	380	granular graphite	granular graphite	52	n/a	14.9 mA	70	[169]
swine slurry	two-chamber	504	carbon felt	stainless steel mesh	21	n/a	250 mA/m^2	n/a	[170]
swine slurry digested	two-chamber	504	carbon felt	stainless steel mesh	12	n/a	225 mA/m^2	n/a	
swine slurry liquid	two-chamber	336	carbon felt mesh	stainless steel mesh	51	46.1 mW/m^2	146.8 mA/m^2	7	[171]
swine slurry	two-chamber	269	granular graphite and carbon felt	stainless steel mesh	n/a	5623 mW/m^3	n/a	n/a	[172]
cattle manure	H-type	380	carbon cloth	carbon cloth	60	1.25 W/m^3	n/a	n/a	[173]
cattle manure	cassette-electrode	n/a	carbon felt	n/a	n/a	16.3 W/m^3	n/a	n/a	[174]
cattle dung	two-chamber	15,000	carbon brushes	n/a	74	220 W/m^3	n/a	3	[175]
swine	three single-chamber	1500	graphite rod	carbon cloth–Pt	85	1.5 W/m^3	n/a	15	[176]
swine	three single chamber	12,000	graphite rod	carbon cloth	50	4 W/m^3	n/a	15	
swine	two single-chamber	100,000	graphite rod	carbon cloth–Pt	52	2.2 W/m^3	n/a	10	
swine	12 MFCs	110,000	graphite fiber brush	gas air diffusion	65	42 mW/m^2	103 mA/m^2	n/a	[177]
slaughterhouse waste	two-chamber	n/a	graphite	graphite, zipper, zinc	n/a	700 mW/m^2	318 mA/m^2	n/a	[178]
slaughterhouse	tubular	n/a	n/a	n/a	99	165 mW/m^2	472 mA/m^2	n/a	[179]
slaughterhouse	MFC aerobic bioreactor	n/a	n/a	n/a	99	162.55 mW/m^2	n/a	13	[180]

Table A6. *Cont.*

Waste Type Animal and Meat Industry	MFC Type	Working Volume [mL]	Anode Material	Cathode Material	COD Removal [%]	Power-Density Voltage	Current Density Current	Coulombic Efficiency [%]	Refs.
slaughterhouse	H-type	n/a	carbon cloth	platinized titanium mesh	n/a	578 mW/m^2	n/a	64	[181]
slaughterhouse	MFC with air-breathing cathode	250	graphite rod	platinum Vulcan	n/a	37 mW/m^2	n/a	72	[182]
slaughterhouse	two-chamber	n/a	stainless steel	mild steel plate	80	2.1 V	n/a	n/a	[183]
protein food industry	two-chamber	1500	graphite sheets	graphite sheets	86	230 mW/m^2	527 mA/m^2	21	[184]
goat rumen fluid	four two-chamber	2500	copper	zinc	n/a	42,110 mW/m^2	0.82 mA/m^2	n/a	[185]
goat rumen fluid and hay	two-chamber	2500	copper	zinc	n/a	9700 mW/m^2	0.24 A	n/a	
cow urine	two-chamber	400	carbon felt	carbon felt	82	5.23 mW/m^3	14.42 mA/m^3	n/a	[186]
manure diluted	two-chamber	1850	graphite fiber brush	carbon cloth–Pt	n/a	93 mW/m^2	370–780 mA/m^2	5	[187]
manure wash waste	two-chamber	1850	graphite fiber brush	carbon cloth–Pt	n/a	216 mW/m^2	1380 mA/m^2	5	
high-moistrue cow manure	single-chamber air-cathode	n/a	carbon mesh	n/a	n/a	350 mW/m^2	n/a	n/a	[188]
dried, blended farm manure	membrane-less MFC	n/a	carbon cloth	carbon cloth	n/a	5 mW/m^2	n/a	n/a	[189]
high-strength liquid manure	single-chamber air cathode	150	carbon cloth	carbon cloth	n/a	28.2 µW	n/a	2	[190]

Table A7. Summary of studies reporting use of distillery and sugar-based industry waste in MFCs.

Waste Type Distillery and Sugar-Based Industry	MFC Type	Working Volume [mL]	Anode Material	Cathode Material	COD Removal [%]	Power-Density Voltage	Current Density Current	Coulombic Efficiency [%]	Refs.
molasses	two-chamber	300	carbon cloth	carbon cloth	67	2425 mW/m^2	2600 mA/m^2	n/a	[191]
molasses	single-chamber	900	carbon felt	air diffusion	90	7.9 mW/m^2	57.3 mW/m^2	n/a	[192]
molasses	two-chamber	900	carbon felt	carbon felt	89	7.5 mW/m^2	56.7 mA/m^2	n/a	
molasses	two-chamber	900	carbon felt	carbon felt	50	17 mW/m^2	80.2 mA/m^2	n/a	
high strength molasses	up-flow anaerobic sludge blanket reactor–microbial fuel cell–biological aerated filter	n/a	graphite rod	carbon paper	53	1410 mW/m^2	4947.9 mA/m^2	n/a	[193]
sugar mill	two-chamber	500	carbon felt	carbon felt	56	140 mW/m^2	50 mA/m^2	70	[194]
crude sugarcane effluent with anaerobic sludge	dual-chamber	100	mild steel coated with Fe_2TiO_5	stainless steel	n/a	8314 mW/m^2	n/a	n/a	[195]
molasses	dual-chamber	n/a	carbon cloth	carbon cloth MnO_2 modified	n/a	6.8–10.33 mW/m^2	n/a	n/a	[196]
molasses	dual-chamber	n/a	carbon cloth	carbon felt MnO_2-modified	n/a	3.6–31.37 mW/m^2	n/a	n/a	[196]
molasses	dual-chamber	500	carbon felt	carbon felt	67	0.21 V	n/a	n/a	[197]
molasses	dual-chamber	500	carbon cloth	carbon cloth	29	8.4 mV	n/a	n/a	[198]
molasses	single-chamber	n/a	carbon cloth	carbon cloth/vertical	67	122 µW	n/a	n/a	[199]
molasses	single-chamber	n/a	carbon cloth	carbon cloth/horizontal	n/a	115 µW	n/a	n/a	
sugarcane molasses	H-type dual-chamber	250	n/a	n/a	82	188.5 mW/m^2	n/a	28–60	[200]
molasses	membrane electrode assembly (HEM) with MFC/increased tilt angle	n/a	n/a	n/a	96	16.1 mW/m^2	n/a	n/a	[201]

Table A7. *Cont.*

Waste Type Distillery and Sugar-Based Industry	MFC Type	Working Volume [mL]	Anode Material	Cathode Material	COD Removal [%]	Power-Density Voltage	Current Density Current	Coulombic Efficiency [%]	Refs.
molasses	single-chamber	n/a	n/a	n/a	n/a	1070–1085 mV	n/a	n/a	[84]
molasses	anaerobic baffled stacking of four MFCs	n/a	carbon felt	carbon cloth	50–70	115.7 mW/m^2	n/a	1	[202]
distillery	single-chamber	28	carbon cloth	carbon cloth	57	5.46 mW/m^3	77.7 mA/m^2	n/a	[204]
distillery	single-chamber	n/a	graphite rod	graphite rod	61	28.5 mW/m^2	0.84 mA	n/a	[205]
distillery	two-chamber	n/a	graphite rod	graphite rod	64	17.76 mW/m^2	0.36 mA	n/a	
distillery	two-chamber	500	graphite rod	graphite rod	61	31490 mW/m^3	n/a	n/a	[118]
undigested distillery	single-chamber	500	graphite rod	graphite rod	57	n/a	n/a	n/a	
corn stover powder	single-chamber	n/a	carbon paper	carbon cloth–Pt	n/a	343 mW/m^2	n/a	n/a	[207]
chitin solution	single-chamber	300	carbon brush	carbon cloth–Pt	n/a	272 mW/m^2	n/a	56	[208]
fermented chitin	two-chamber	100	carbon felt	carbon felt	n/a		8.77 µA/cm^2	n/a	[209]
distillery	two-chamber salt–agar-bridged	500	graphite rod	graphite rod	n/a	349 mW	n/a	n/a	[210]
distilled food ethanol fermentation stillage	single-chamber air-cathode	120	graphite felt	n/a	70	0.29 V	1.4 mA	n/a	[87]
distillery	dual-chamber	19	carbon felt	nickel foam-coated carbon ink	55–64	4.3 W/m^3	n/a	n/a	[211]
distillery	n/a	n/a	n/a	n/a	69	2.63 W/m^3	n/a	n/a	[212]
distillery	n/a	n/a	n/a	n/a	85	0.625 V	2.9 mA	31	[214]
mezcal industry	dual-chamber	900	graphite felt	stainless steel plate	83–92	5.83–80.64 W/m^3	n/a	n/a	[214]
distillery	single-chamber	n/a	graphite plate	graphite plate	73	325 mV	400 mA/m^2	n/a	[215]
distillery spend	dual-chamber	n/a	graphite rod	graphite rod	64–84	18.35 mW/m^2	0.27 mA	n/a	[216]
distillery	dual-chamber	n/a	graphite rod	graphite rod	64	18.35 mW/m^2	0.36 mA	n/a	[217]

Table A7. *Cont.*

Waste Type Distillery and Sugar-Based Industry	MFC Type	Working Volume [mL]	Anode Material	Cathode Material	COD Removal [%]	Power-Density Voltage	Current Density Current	Coulombic Efficiency [%]	Refs.
distillery	single-chamber	2600	graphite plate	graphite plate	n/a	25194.8 mW/m^2	123.5 mA/m^2	47	[218]
distillery	single-chamber	n/a	n/a	n/a	80–81	29 mW/m	84 mA/m	n/a	[219]
alcohol distillery	anaerobic fluidized bed with MFC	n/a	n/a	n/a	80–90	124.03 mW/m^2	n/a	n/a	[220]
alcohol distillery	plate-type thermophilic MFC	40	graphite felt	graphite felt	89	1000 mW/m^2	2.3 A/m^2	89	[221]

Table A8. Summary of studies reporting use agricultural and plant waste in MFCs.

Waste Type Agricultural-Plant Waste	MFC Type	Working Volume [mL]	Anode Material	Cathode Material	COD Removal [%]	Power-Density Voltage	Current Density Current	Coulombic Efficiency [%]	Refs.
cellulose	single-chamber membrane-less	42	ammonia gas treated graphite fiber brush	Pt–PTFE gas diffusion	70	1080 mW/m^2	n/a	25–50	[223]
cellulose	two-chamber	42	ammonia gas treated graphite fiber brush	Pt–PTFE gas diffusion	70	880 mW/m^2	n/a	25–50	
cellulose	three-electrode MFC	n/a	platinum sheet	platinum sheet	n/a	n/a	130 mA/L	n/a	[224]
cellulose	two-chamber	n/a	graphite plates	carbon paper–Pt	27–38	59.2–143 mW/m^2	n/a	39–47	[225]
cellulose	two-chamber	800	graphite plates	graphite plates	n/a	55 mW/m^2	n/a	n/a	[226]
rice straw powder	3 in a series H-type two-chamber	n/a	carbon paper	carbon paper	n/a	490 mW/m^2	n/a	45–54	[227]
cellulose	U-tube two-chamber MFC	40	carbon cloth	carbon fiber	n/a	4.9–5.4 mW/m^2	n/a	n/a	[228]

Table A8. *Cont.*

Waste Type Agricultural-Plant Waste	MFC Type	Working Volume [mL]	Anode Material	Cathode Material	COD Removal [%]	Power-Density Voltage	Current Density Current	Coulombic Efficiency [%]	Refs.
corn stover	air-cathode single-chamber MFC	28	carbon paper	carbon cloth	60–70	367–371 mW/m^2	n/a	n/a	[230]
corn residue	tubular air-cathode MFC	n/a	grahite rod /graphite granule	carbon cloth	n/a	230 mW/m^2	n/a	n/a	[231]
vocia faba agricultural waste	two-chamber	n/a	carbon	carbon	78	283 mW/m^2	1255.93 mA/m^2	n/a	[232]
orange peel	dual-chamber	n/a	graphite felt	platinum coated graphite cloth	78	358.8 mW/m^2	847 mA/m^2	n/a	[233]
starch wastewater	air-cathode MFC	n/a	carbon paper	carbon paper–Pt	80–90	239.4 mW/m^2	893.3 mA/m^2	n/a	[234]
wheat straw waste	two-chamber	300	carbon paper	carbon paper	n/a	123 mW/m^2	n/a	16–37	[229]

Table A9. Summary of studies reporting use of sludge, sewage, solid waste in MFCs.

Waste Type Sludge, Sewage/Solid Waste	MFC Type	Working Volume [mL]	Anode Material	Cathode Material	COD Removal [%]	Power-Density Voltage	Current Density Current	Coulombic Efficiency [%]	Refs.
fermented sewage sludge	single-chamber	25	graphite fiber brushes	carbon cloth	84–94	320 W/m^2	n/a	18–57	[235]
anaerobic mesophilic sludge	single-chamber	110	carbon felt	gas diffusion–Pt	53	53 W/m^3	n/a	28	[236]
sewage sludge	two-chamber	n/a	graphite fiber brush	graphite fiber brush	47	8.5 W/m^3	n/a	n/a	[237]
sewage sludge	two-chamber	2310	stainless steel mesh	stainless steel mesh	n/a	15.5–36.72 W/m^3	n/a	n/a	[238]
sewage sludge	two-chamber	n/a	graphite fiber brush	graphite fiber brush	61	10.3–12.5 W/m^3	n/a	n/a	[239]

Table A9. *Cont.*

Waste Type Sludge, Sewage/Solid Waste	MFC Type	Working Volume [mL]	Anode Material	Cathode Material	COD Removal [%]	Power-Density Voltage	Current Density Current	Coulombic Efficiency [%]	Refs.
sewage sludge	two-chamber	960	graphite fiber brush	graphite fiber brush	66	10.2 W/m^3	n/a	n/a	[241]
sewage sludge	two-chamber	n/a	graphite fiber brush	graphite fiber brush	n/a	9.1 W/m^3	n/a	19	[240]
sewage sludge	two-chamber	n/a	graphite fiber brush	graphite fiber brush	60	12 W/m^3	n/a	n/a	[242]
digested sludge	two-chamber	n/a	graphite rod	graphite rod	n/a	12.67 W/m^2	29.5–45.68%	n/a	[243]
digested sewage sludge	two-chamber	2500	carbon felts	carbon felts	n/a	3.1 µW	n/a	n/a	[244]
activated sludge	two-chamber	n/a	carbon cloth	carbon cloth	55–85	42 mW/m^2	n/a	n/a	[245]
anaerobic sewage sludge	two-chamber	n/a	n/a	n/a	60	38.1 W/m^3	n/a	n/a	[246]
saline domestic sewage sludge	four two-chamber	75.6	carbon felt	carbon felt	59	41 W/m^3	n/a	28	[247]
livestock solid waste	single-chamber	n/a	platinum	platinum	n/a	36.6 mW/m^2	n/a	n/a	[248]
sewage sludge	dual-chamber	n/a	carbon	carbon	n/a	499 mV	n/a	n/a	[249]
sludge waste	dual-chamber	300	graphite	graphite	n/a	312.98 mW/m^2	39.07 µA/cm^2	n/a	[250]
sludge waste	single-chamber	60	titanium	titanium	n/a	97.6 mW/m^2	17.63 µA/cm^2	n/a	
sludge waste	single-chamber	n/a	graphite felt modified with Mn	n/a	n/a	788 mW/m^2	1750 mA/m^2	n/a	[251]
sludge	single-chamber	n/a	platinum modified with polyanilineco	n/a	n/a	6000 mW/m^2	n/a	n/a	[255]
sewage sludge after pyrolysis	air-cathode single-chamber MFC	n/a	n/a	carbon felt	n/a	1120 mW/m^2	n/a	n/a	[254]

Table A9. *Cont.*

Waste Type Sludge, Sewage/Solid Waste	MFC Type	Working Volume [mL]	Anode Material	Cathode Material	COD Removal [%]	Power-Density Voltage	Current Density Current	Coulombic Efficiency [%]	Refs.
anaerobic sewage sludge from wastetwater treatment plant	two-chamber	n/a	carbon cloth	platinum	n/a	13.5 mW/cm^2	n/a	5	[256]
sludge from the sewage of treatment plant	six single-chamber	n/a	carbon	copper	30	1108 mW/cm^2	n/a	n/a	[257]
sewage sludge mixed with liquor-suspended solid	air-cathode MFC	n/a	n/a	n/a	n/a	27.65 W/m^3	473.5 mA/m^3	n/a	[258]
sludge	three-chamber	n/a	graphite granule	graphite brush	40	13.2 W/m^3	n/a	19	[259]
sludge	submersible MFC	n/a	carbon paper	carbon paper	78	190 mW/m^2	n/a	3	[260]
sewage sludge	salt-bridged dual-chamber	2000	n/a	n/a	n/a	2.5 V	n/a	n/a	[261]

Table A10. Summary of studies reporting use of soil waste in MFCs.

Waste Type Soil Waste	MFC Type	Working Volume [mL]	Anode Material	Cathode Material	COD Removal [%]	Power-Density Voltage	Current Density Current	Coulombic Efficiency [%]	Refs.
urea	coin cell system of a soil-based MFC	n/a	graphite	graphite	n/a	3.2 mW/m^2	n/a	n/a	[262]
soil substrates	21 air-cathode MFCs	n/a	platinized carbon paper	platinized carbon paper	n/a	16.4–28.6 mW/m^2	n/a	n/a	[263]
soil glucose	single-chamber	n/a	platinum	platinum	n/a	32 mW/m^2	100 mA/m^2	n/a	[264]
straw-based soil	single-chamber	n/a	platinum	platinum	n/a	10.6–10.8 mW/m^2	60–80 mA/m^2	n/a	
human urine	soil-based MFC	n/a	carbon	carbon	n/a	124.16 mW/m^2	n/a	n/a	[265]

Table A10. *Cont.*

Waste Type Soil Waste	MFC Type	Working Volume [mL]	Anode Material	Cathode Material	COD Removal [%]	Power-Density Voltage	Current Density Current	Coulombic Efficiency [%]	Refs.
salt	single-chamber	n/a	carbon	carbon	n/a	336 mV	n/a	n/a	[266]
silt	single-chamber	n/a	carbon	carbon	n/a	348 mV	n/a	n/a	
clay	single-chamber	n/a	carbon	carbon	n/a	644 mV	n/a	n/a	
sand with dried leaves	soil-based MFC	n/a	n/a	n/a	n/a	29.2 mW/m^2	n/a	n/a	[267]
clay with dried leaves	soil-based MFC	n/a	n/a	n/a	n/a	23.8 mW/m^2	n/a	n/a	
soil	portable, plugged-type soil-based MFC	n/a	carbon	carbon	n/a	7.3 mW/m^2	n/a	n/a	[268]
Brinjal-cultivated soil	agar salt-bridged soil-based MFC	n/a	carbon	carbon	n/a	12.8 mW/m^2	23.6 mA/m^2	n/a	[269]

Table A11. Summary of studies reporting use of municipal, solid, and mixed waste in MFCs.

Waste Type Municipal, Solid, Mixed Waste	MFC Type	Working Volume [mL]	Anode Material	Cathode Material	COD Removal [%]	Power-Density Voltage	Current Density Current	Coulombic Efficiency [%]	Refs.
raw municipal waste	single-chamber submerged into aeration chamber	144	graphite felt	graphite felt	n/a	16.7 W/m^3	n/a	40	[270]
municipal	single-chamber	n/a	n/a	n/a	n/a	10 mW/m^2	n/a	n/a	[271]
domestic	n/a	390	graphite granule	woven grahite mat	n/a	10 W/m^3	n/a	22	[272]
municipal	flat plate microbial fuel cell	n/a	carbon paper	carbon cloth	42–79	72 mW/m^2	n/a	6	[273]
municipal	single-chamber membrane-less MFC	255,000	graphite fiber brush	stainless steel	57	78 mW/m^2	n/a	44	[274]

Table A11. *Cont.*

Waste Type Municipal, Solid, Mixed Waste	MFC Type	Working Volume [mL]	Anode Material	Cathode Material	COD Removal [%]	Power-Density Voltage	Current Density Current	Coulombic Efficiency [%]	Refs.
municipal	20 air-cathode MFCs	16,000	carbon felt	copper	84	1107 mW/m^2	n/a	n/a	[275]
municipal	two-chamber	n/a	carbon felt	carbon felt	n/a	30.47 mW/m^2	n/a	n/a	[276]
municipal	two-chamber	n/a	carbon felt	carbon felt	n/a	1817.88 mW/m^2	n/a	n/a	
municipal solid waste landfill leachate with dairy wastewater	two dual-chamber	1600	granular grahite	granular graphite	66–85	n/a	n/a	8	[277]
cow dung vs. chicken droppings	single-chamber	n/a	carbon fiber	carbon felt	n/a	340–450 mV	n/a	n/a	[278]
fruit waste vs. food waste	single-chamber	n/a	carbon fiber	carbon felt	n/a	300–380 mV	n/a	n/a	
rice bran vs. leaf waste	single-chamber	n/a	carbon fiber	carbon felt	n/a	300–320 mV	n/a	n/a	
artificial domestic wastewater	cassette-electrode MFC	1500	graphite felt	air-cathode	93	140 mW/m^2	n/a	20	[279]
artificial industrial wastewater	cassette-electrode MFC	1500	graphite felt	air-cathode	97	175 mW/m^2	n/a	20	
ammonium with municipal wastewater	dual-chamber	n/a	graphite felt	carbon fiber brush	85	230.17 mW/m^2	n/a	n/a	[280]
ammonia with municipal wastewater vs. municipal wastewater	bench-scale/45 L MFC	45,000	graphite felt brush	platinum-coated carbon cloth	55–87	145 mW/m^2	n/a	n/a	[281]

Table A11. *Cont.*

Waste Type Municipal, Solid, Mixed Waste	MFC Type	Working Volume [mL]	Anode Material	Cathode Material	COD Removal [%]	Power-Density Voltage	Current Density Current	Coulombic Efficiency [%]	Refs.
distillery wastewater	two-chamber	1000	copper	copper	70	n/a	n/a	n/a	[282]
municipal or agro or diary wastewater	two-chamber	1000	copper	copper	99	n/a	n/a	n/a	
potato and sludge	eleven two-chamber	275	carbon felt	carbon felt	85	n/a	250 mA/m^2	54–93	[283]
municipal wastewater plants xylan vs. glucose	cell-constructed wetland MFC	n/a	graphite	graphite	n/a	2.91–6.09 mW/m^2	n/a	n/a	[284]
landfill leachate	circular MFC	934	graphite plate	waterproof woven carbon cloth	62	24–31 mW/m^2	n/a	n/a	[285]
landfill leachate	large, circular MFC	18,300	graphite plate	waterproof woven carbon cloth	n/a	635 mV	n/a	n/a	
wood hydrothermal treatment wastewater with municipal wastewater	single-chamber	28	carbon fiber brush	carbon paper	75	70–360 mW/m^2	n/a	40	[286]
artificial wastewater vs. municipal wastewater	50 stacked MFCs	1000	coal GAC	coal GAC	70–90	3.64–7.58 mW/m^2	n/a	n/a	[287]
municipal	horizontal plug flow and stackable MFC	250,000	carbon brush	carbon mesh	86	116 mV	0.435 A	n/a	[288]
domestic wastewater vs. glucose	cylindrical two-chamber	805	carbon fiber	carbon fiber	n/a	13.6–91 mW/m^3	n/a	n/a	[289]

Table A11. *Cont.*

Waste Type Municipal, Solid, Mixed Waste	MFC Type	Working Volume [mL]	Anode Material	Cathode Material	COD Removal [%]	Power-Density Voltage	Current Density Current	Coulombic Efficiency [%]	Refs.
olive oil and molasses	n/a	n/a	n/a	n/a	53	36 mW/m^2	n/a	n/a	[290]
distillery spend wash vs. molasses	salt-bridged two-chamber	500	graphite	graphite	n/a	35.42–65.92 mW/m^2	n/a	n/a	[291]
molasses	double-chamber mediator-less MFC	300	carbon cloth	carbon cloth	67	2.425 W/m^2	n/a	n/a	[191]
black liquor from paper pulp	double-chamber mediator-less MFC	300	carbon cloth	carbon cloth	78	3.55 W/m^2	n/a	n/a	
activated sludge with cattle manure slurry vs. domestic sewage with cattle manure slurry	single-chamber air-cathode	n/a	graphite fiber	activated carbon with PTFE	n/a	520–577 mV	n/a	65–70	[283]
onion vs. onions with tomatoes and potatoes	single-chamber	n/a	zinc	copper	n/a	1.01 mV–10.2 V	n/a	n/a	[284]
sewage sludge vs. carbon manure vs. cow manure	salt-bridged two-chamber	n/a	n/a	n/a	n/a	229–2500 mV/L	n/a	n/a	[285,286]
cow manure with slurry	pilot MFC	n/a	n/a	n/a	98	1.6136 mV	n/a	n/a	[287]
cow dung vs. distillery wastewater	n/a	n/a	n/a	n/a	n/a	230–2300 mV/L	n/a	n/a	[288]
cow manure with fruit and soil waste	two-chamber	n/a	graphite rod	graphite rod	n/a	210 mW/m^2	n/a	n/a	[298]
vegetable waste with molasses	six U-shaped dual-chamber	n/a	graphite rod	graphite rod	n/a	44,400–104,400 mW/m^2	n/a	63–82	[299]

Table A11. *Cont.*

Waste Type Municipal, Solid, Mixed Waste	MFC Type	Working Volume [mL]	Anode Material	Cathode Material	COD Removal [%]	Power-Density Voltage	Current Density Current	Coulombic Efficiency [%]	Refs.
molasses vs. whey, bulgur, olive mill wastewater	single-chamber	n/a	n/a	n/a	n/a	0.37–0.55 V	n/a	n/a	[300]
kitchen waste vs. cow dung vs. palm kernel	single-chamber air-cathode	n/a	n/a	n/a	n/a	47.9–279.52 mW/m^2	n/a	n/a	[301]
cattle manure with or without yogurt	dual-chamber	n/a	graphite, aluminium	graphite, aluminium	n/a	1.170–1.122 V	n/a	n/a	[302]
dumping rubbish	multiple-chamber MFCs	n/a	n/a	n/a	n/a	5.78 V	5.03 A	n/a	[303]
dairy and distillery wastewater with cow dung	dual-chamber	n/a	graphite rod	air-cathode	77	3.4 W/m^2	n/a	n/a	[304]
dairy and distillery wastewater with cow dung	single-chamber	n/a	graphite rod	air-cathode	85	4.6 W/m^2	n/a	n/a	
distillery wastewater vs. vermi compost	n/a	n/a	n/a	n/a	99	131–699 mV	n/a	n/a	[305]
kitchen garbage vs. bamboo waste	single-chamber	n/a	carbon fiber	carbon fiber	n/a	540–620 mV	n/a	n/a	[93]
sludge vs. urine	single-chamber	n/a	carbon veil	PTFE over carbon veil	n/a	40.38 mW/m^2	n/a	n/a	[306]

Table A11. *Cont.*

Waste Type Municipal, Solid, Mixed Waste	MFC Type	Working Volume [mL]	Anode Material	Cathode Material	COD Removal [%]	Power-Density Voltage	Current Density Current	Coulombic Efficiency [%]	Refs.
garden waste	single-chamber	n/a	graphite fiber brush	carbon cloth	84	n/a	n/a	20	[307]
food waste	single-chamber	n/a	graphite fiber brush	carbon cloth	69	n/a	n/a	25	
paper/cardboard waste	single chamber	n/a	graphite fiber brush	carbon cloth	76	n/a	n/a	21	
garden with food and paper/cardboard waste	single-chamber	n/a	graphite fiber brush	carbon cloth	78	n/a	n/a	24	
sewage sludge and kitchen waste	single-chamber	n/a	zinc plate	copper plate	n/a	263–918 mV	n/a	n/a	[308]

References

1. Tollefson, J.; Monastersky, R. Awash in carbon. *Nature* **2012**, *491*, 654–655. [CrossRef] [PubMed]
2. Liu, W.; Mu, W.; Liu, M.; Zhang, X.; Cai, H.; Deng, Y. Solar-induced direct biomass-to-electricity hybrid fuel cell using polyoxometalates as photocatalyst and charge carsrier. *Nat. Commun.* **2014**, *5*, 3208. [CrossRef] [PubMed]
3. Moradian, J.M.; Fang, Z.; Yong, Y.-C. Recent advances on biomass-fueled microbial fuel cell. *Bioresour. Bioprocess.* **2021**, *8*, 14. [CrossRef]
4. O'Mahoney, A.; Thorne, F.; Denny, E. A cost-benefit analysis of generating electricity from biomass. *Energy Policy* **2013**, *57*, 347–354. [CrossRef]
5. Sauer, T.P.; Casaril, L.; Oberziner, A.L.B.; José, H.J.; Moreira, R.d.F.P.M. Advanced oxidation processes applied to tannery wastewater containing direct black 38—Elimination and degradation kinetics. *J. Hazard. Mater.* **2006**, *135*, 274–279. [CrossRef] [PubMed]
6. Pandis, P.K.; Kalogirou, C.; Kanellou, E.; Vaitsis, C.; Savvidou, M.G.; Sourkouni, G.; Zorpas, A.A.; Argirusis, C. Key points of advanced oxidation processes (aops) for wastewater, organic pollutants and pharmaceutical waste treatment: A mini review. *Chem Eng.* **2022**, *6*, 8. [CrossRef]
7. Suthanthararajan, R.; Ravindranath, E.; Chits, K.; Umamaheswari, B.; Ramesh, T.; Rajamam, S. Membrane application for recovery and reuse of water from treated tannery wastewater. *Desalination* **2004**, *164*, 151–156. [CrossRef]
8. Oturan, M.A. Electrochemical advanced oxidation technologies for removal of organic pollutants from water. *Environ. Sci. Pollut. Res.* **2014**, *21*, 8333–8335. [CrossRef]
9. Costa, C.R.; Botta, C.M.R.; Espindola, E.L.G.; Olivi, P. Electrochemical treatment of tannery wastewater using dsa® electrodes. *J. Hazard. Mater.* **2008**, *153*, 616–627. [CrossRef]
10. Ding, W.; Cheng, S.; Yu, L.; Huang, H. Effective swine wastewater treatment by combining microbial fuel cells with flocculation. *Chemosphere* **2017**, *182*, 567–573. [CrossRef]
11. Kazimierowicz, J.; Dzienis, L.; Dębowski, M.; Zieliński, M. Optimisation of methane fermentation as a valorisation method for food waste products. *Biomass Bioenergy* **2021**, *144*, 105913. [CrossRef]
12. Caruso, M.; Braghieri, A.; Capece, A.; Napolitano, F.; Romano, P.; Galgano, F.; Altieri, G.; Genovese, F. Recent updates on the use of agro-food waste for biogas production. *Appl. Sci.* **2019**, *9*, 1217. [CrossRef]
13. Ellacuriaga, M.; García-Cascallana, J.; Gómez, X. Biogas production from organic wastes: Integrating concepts of circular economy. *Fuels* **2021**, *2*, 144–167. [CrossRef]
14. Nwokolo, N.; Mukumba, P.; Obileke, K.; Enebe, M. Waste to energy: A focus on the impact of substrate type in biogas production. *Processes* **2020**, *8*, 1224. [CrossRef]
15. Singh, H.; Tomar, S.; Qureshi, K.A.; Jaremko, M.; Rai, P.K. Recent advances in biomass pretreatment technologies for biohydrogen production. *Energies* **2022**, *15*, 999. [CrossRef]
16. Lima, R.B.; Raza, R.; Qin, H.; Li, J.; Lindström, M.E.; Zhu, B. Direct lignin fuel cell for power generation. *RSC Adv.* **2013**, *3*, 5083–5089. [CrossRef]
17. Rabaey, K.; Verstraete, W. Microbial fuel cells: Novel biotechnology for energy generation. *Trends Biotechnol.* **2005**, *23*, 291–298. [CrossRef]
18. Mathuriya, A.S.; Yakhmi, J.V. Microbial fuel cells—Applications for generation of electrical power and beyond. *Crit. Rev. Microbiol.* **2016**, *42*, 127–143. [CrossRef]
19. Beegle, J.R.; Borole, A.P. Energy production from waste: Evaluation of anaerobic digestion and bioelectrochemical systems based on energy efficiency and economic factors. *Renew. Sustain. Energy Rev.* **2018**, *96*, 343–351. [CrossRef]
20. Schröder, U. Cover picture: Microbial fuel cells and microbial electrochemistry: Into the next century! (chemsuschem 6/2012). *ChemSusChem* **2012**, *5*, 957. [CrossRef]
21. Tommasi, T.; Salvador, G.P.; Quaglio, M. New insights in microbial fuel cells: Novel solid phase anolyte. *Sci. Rep.* **2016**, *6*, 29091. [CrossRef] [PubMed]
22. Offei, F.; Mensah, M.; Kemausuor, F.; Thygesen, A. A biorefinery approach to bioethanol and bioelectricity co-production from tropical seaweeds. *J. Appl. Phycol.* **2019**, *31*, 3899–3913. [CrossRef]
23. Moradian, J.M.; Xu, Z.A.; Shi, Y.T.; Fang, Z.; Yong, Y.C. Efficient biohydrogen and bioelectricity production from xylose by microbial fuel cell with newly isolated yeast of cystobasidium slooffiae. *Int. J. Energy Res.* **2019**, *44*, 325–333. [CrossRef]
24. Kiely, P.D.; Regan, J.M.; Logan, B.E. The electric picnic: Synergistic requirements for exoelectrogenic microbial communities. *Curr. Opin. Biotechnol.* **2011**, *22*, 378–385. [CrossRef]
25. Yu, Y.Y.; Wang, Y.Z.; Fang, Z.; Shi, Y.T.; Cheng, Q.W.; Chen, Y.X.; Shi, W.; Yong, Y.C. Single cell electron collectors for highly efficient wiring-up electronic abiotic/biotic interfaces. *Nat. Commun.* **2020**, *11*, 4087. [CrossRef] [PubMed]
26. Xu, C.; Poon, K.; Choi, M.M.; Wang, R. Using live algae at the anode of a microbial fuel cell to generate electricity. *Environ. Sci. Pollut. Res. Int.* **2015**, *22*, 15621–15635. [CrossRef] [PubMed]
27. Das, S.; Mangwani, N. Recent developments in microbial fuel cells: A review. *J. Sci. Ind. Res.* **2010**, *69*, 727–732.
28. Rahimnejad, M.; Bakeri, G.; Ghasemi, M.; Zirehpour, A. A review on the role of proton exchange membrane on the performance of microbial fuel cell. *Polym. Adv. Technol.* **2014**, *25*, 1426–1432. [CrossRef]
29. Ziara, R.M.M.; Dvorak, B.I.; Subbiah, J. Sustainable waste-to-energy technologies: Bioelectrochemical systems. In *Sustainable Food Waste-To-Energy Systems*; Academic Press: Cambridge, MA, USA, 2018; Chapter 7; pp. 111–140.

30. Chaturvedi, V.; Verma, P. Microbial fuel cell: A green approach for the utilization of waste for the generation of bioelectricity. *Bioresour. Bioprocess.* **2016**, *3*, 38. [CrossRef]
31. Kondaveeti, S.; Mohanakrishna, G.; Pagolu, R.; Kim, I.W.; Kalia, V.C.; Lee, J.K. Bioelectrogenesis from raw algal biomass through microbial fuel cells: Effect of acetate as co-substrate. *Indian J. Microbiol.* **2019**, *59*, 22–26. [CrossRef]
32. Wlodarczyk, P.P.; Wlodarczyk, B. Wastewater treatment and electricity production in a microbial fuel cell with cu–b alloy as the cathode catalyst. *Catalysts* **2019**, *9*, 572. [CrossRef]
33. Rajesh, P.P.; Noori, M.T.; Ghangrekar, M.M. Controlling methanogenesis and improving power production of microbial fuel cell by lauric acid dosing. *Water Sci. Technol.* **2014**, *70*, 1363–1369. [CrossRef] [PubMed]
34. Walter, X.A.; Greenman, J.; Ieropoulos, I.A. Intermittent load implementation in microbial fuel cells improves power performance. *Bioresour. Technol.* **2014**, *172*, 365–372. [CrossRef] [PubMed]
35. Winfield, J.; Chambers, L.D.; Rossiter, J.; Greenman, J.; Ieropoulos, I. Towards disposable microbial fuel cells: Natural rubber glove membranes. *Int. J. Hydrogen Energy* **2014**, *39*, 21803–21810. [CrossRef]
36. Winfield, J.; Greenman, J.; HusOn, D.; Ieropoulos, I.A. Comparing terracotta and earthenware for multiple functionalities in microbial fuel cells. *Bioprocess Biosyst. Eng.* **2013**, *36*, 1913–1921. [CrossRef] [PubMed]
37. Yousefi, V.; Mohebbi-Kalhoru, D.; Samini, A. Ceramic-based microbial fuel cells (mfcs): A review. *Int. J. Hydrogen Energy* **2017**, *42*, 1672–1690. [CrossRef]
38. Zhou, L.; Liao, C.; Li, T.; Du, Q.; Wan, L.; Li, N.; Pan, X.; Wang, X. Regeneration of activated carbon air-cathodes by half-wave rectified alternating fields in microbial fuel cells. *Appl. Energy* **2018**, *219*, 199–206. [CrossRef]
39. Chen, S.; Patil, S.A.; Schroder, U. A high-performance rotating graphite fiber brush air-cathode for microbial fuel cells. *Appl. Energy* **2018**, *211*, 1089–1094. [CrossRef]
40. Tremouli, A.; Karydogiannis, I.; Pandis, P.K.; Papadopoulou, K.; Argirousis, C.; Stathopoulos, V.N.; Lyberatos, G. Bioelectricity production from fermentable household waste extract using a single chamber microbial fuel cell. *Energy Procedia* **2019**, *161*, 2–9. [CrossRef]
41. Tremouli, A.; Pandis, P.K.; Kamperidis, T.; Stathopoulos, V.N.; Argirousis, C.; Lyberatos, G. Performance assessment of a four-air cathode membraneless microbial fuel cell stack for wastewater treatment and energy extraction. *E3S Web Conf. EDP Sci.* **2019**, *116*, 93. [CrossRef]
42. Tremouli, A.; Pandis, P.K.; Karydogiannis, I.; Stathopoulos, V.N.; Argirusis, C.; Lyberatos, G. Operation and electro (chemical) characterization of a microbial fuel cell stack fed with fermentable household waste extract. *Glob. NEST J.* **2019**, *21*, 253–257.
43. Tremouli, A.; Kamperidis, T.; Pandis, P.K.; Argirusis, C.; Lyberatos, G. Exploitation of digestate from thermophilic and mesophilic anaerobic digesters fed with fermentable food waste using the mfc technology. *Waste Biomass Valorization* **2021**, *12*, 5361–5370. [CrossRef]
44. Alfonta, L. Genetically engineered microbial fuel cells. *Electroanalysis* **2010**, *22*, 822–831. [CrossRef]
45. Li, F.; An, X.; Wu, D.; Xu, J.; Chen, Y.; Li, W.; Cao, Y.; Guo, X.; Lin, X.; Li, C.; et al. Engineering microbial consortia for high-performance cellulosic hydrolyzates-fed microbial fuel cells. *Front. Microbiol.* **2019**, *10*, 409. [CrossRef]
46. Zhao, J.; Li, F.; Cao, Y.; Zhang, X.; Chen, T.; Song, H.; Wang, Z. Microbial extracellular electron transfer and strategies for engineering electroactive microorganisms. *Biotechnol. Adv.* **2020**, *53*, 107682. [CrossRef]
47. Shanmuganathan, P.; Ramachandra, M.A.; Rajasulochana, A. Factors affecting the performance of microbial fuel cells. *Int. J. Mech. Eng. Technol.* **2018**, *9*, 137–148.
48. Tursi, A. A review on biomass: Importance, chemistry, classification, and conversion. *Biofuel Res. J.* **2019**, *6*, 962–979. [CrossRef]
49. Dowdy, F.R.; Kawakita, R.; Lange, M.; Simmons, C.W. Meta-analysis of microbial fuel cells using waste substrates. *Appl. Biochem. Biotechnol.* **2018**, *185*, 221–232. [CrossRef]
50. Nosek, D.; Jachimowicz, P.; Cydzik-Kwiatowska, A. Anode modification as an alternative approach to improve electricity generation in microbial fuel cells. *Energies* **2020**, *13*, 6596. [CrossRef]
51. Pant, D.; Van Bogaert, G.; Diels, L.; Vanbroekhoven, K. A review of the substrates used in microbial fuel cells (mfcs) for sustainable energy production. *Bioresour. Technol.* **2010**, *101*, 1533–1543. [CrossRef]
52. Mamma, D. Food wastes: Feedstock for value-added products. *Fermentation* **2020**, *6*, 47. [CrossRef]
53. Kiely, P.D.; Cusick, R.; Call, D.F.; Selembo, P.A.; Regan, J.M.; Logan, B.E. Anode microbial communities produced by changing from microbial fuel cell to microbial electrolysis cell operation using two different wastewaters. *Bioresour. Technol.* **2011**, *102*, 388–394. [CrossRef]
54. Flimban, S.G.A.; Ismail, I.M.I.; Kim, T.; Oh, S.-E. Overview of recent advancements in the microbial fuel cell from fundamentals to applications: Design, major elements, and scalability. *Energies* **2019**, *12*, 3390. [CrossRef]
55. Du, Z.; Li, H.; Gu, T. A state of the art review on microbial fuel cells: A promising technology for wastewater treatment and bioenergy. *Biotechnol. Adv.* **2007**, *25*, 464–482. [CrossRef]
56. Tian, Y.; Mei, X.; Liang, Q.; Wu, D.; Ren, N.; Xing, D. Biological degradation of potato pulp waste and microbial community structure in microbial fuel cells. *RSC Adv.* **2017**, *7*, 8376–8380. [CrossRef]
57. Du, H.; Li, F. Size effects of potato waste on its treatment by microbial fuel cell. *Environ. Technol.* **2016**, *37*, 1305–1313. [CrossRef]
58. Durruty, I.; Bonanni, P.S.; Gonzalez, J.F.; Busalmen, J.P. Evaluation of potato-processing wastewater treatment in a microbial fuel cell. *Bioresour. Technol.* **2012**, *105*, 81–87. [CrossRef]

59. Iigatani, R.; Ito, T.; Watanabe, F.; Nagamine, M.; Suzuki, Y.; Inoue, K. Electricity generation from sweet potato-shochu waste using microbial fuel cells. *J. Biosci. Bioeng.* **2019**, *128*, 56–63. [CrossRef]
60. Shrestha, N.; Fogg, A.; Wilder, J.; Franco, D.; Komisar, S.; Gadhamshetty, V. Electricity generation from defective tomatoes. *Bioelectrochemistry* **2016**, *112*, 67–76. [CrossRef] [PubMed]
61. Mohan, S.V.; Mohanakrishna, G.; Sarma, P.N. Composite vegetable waste as renewable resource for bioelectricity generation through non-catalyzed open-air cathode microbial fuel cell. *Bioresour. Technol.* **2010**, *101*, 970–976. [CrossRef]
62. Tao, K.; Quan, X.; Quan, Y. Composite vegetable degradation and electricity generation in microbial fuel cell with ultrasonic pretreatment. *Environ. Eng. Manag. J.* **2013**, *12*, 1423–1427.
63. Javed, M.M.; Nisar, M.A.; Muneer, B.; Ahmad, M.U. Production of bioelectricity from vegetable waste extract by designing a u-shaped microbial fuel cell. *Pak. J. Zool.* **2017**, *49*, 711–716. [CrossRef]
64. Cercado-Quezada, B.; Delia, M.L.; Bergel, A. Testing various food-industry wastes for electricity production in microbial fuel cell. *Bioresour. Technol.* **2010**, *101*, 2748–2754. [CrossRef] [PubMed]
65. Boghani, H.; Kim, J.R.; Dinsdale, R.M.; Guwy, A.J.; Premier, G.C. Reducing the burden of food processing washdown wastewaters using microbial fuel cells. *Biochem. Eng. J.* **2017**, *117*, 210–217. [CrossRef]
66. Velasquez-Orta, S.B.; Head, I.M.; Curtis, T.P.; Scott, K. Factors affecting current production in microbial fuel cells using different industrial wastewaters. *Bioresour. Technol.* **2011**, *102*, 5105–5112. [CrossRef] [PubMed]
67. Liakos, T.I.; Sotiropoulos, S.; Lazaridis, N.K. Electrochemical and bio-electrochemical treatment of baker's yeast effluents. *J. Environ. Chem. Eng.* **2017**, *5*, 699–708. [CrossRef]
68. Rikame, S.S.; Mungray, A.A.; Mungray, A.K. Electricity generation from acidogenic food waste leachate using dual chamber mediator less microbial fuel cell. *Int. Biodeterior. Biodegrad.* **2012**, *75*, 131–137. [CrossRef]
69. Li, X.M.; Cheng, K.Y.; Wong, J.W. Bioelectricity production from food waste leachate using microbial fuel cells: Effect of nacl and ph. *Bioresour. Technol.* **2013**, *149*, 452–458. [CrossRef] [PubMed]
70. Wang, Z.J.; Lim, B.S. Electric power generation from treatment of food waste leachate using microbial fuel cell. *Environ. Eng. Res.* **2017**, *22*, 157–161. [CrossRef]
71. Pant, D.; Van Bogaert, G.; Alvarez-Gallego, Y.; Diels, L.; Vanbroekhoven, K. Evaluation of bioelectrogenic potential of four industrial effluents as substrate for low cost microbial fuel cells operation. *Environ. Eng. Manag. J.* **2016**, *15*, 1897–1904. [CrossRef]
72. Mohamed, H.O.; Obaid, M.; Khalil, K.A.; Barakat, N.A. Power generation from unconditioned industrial wastewaters using commercial membranes-based microbial fuel cells. *Int. J. Hydrogen Energy* **2016**, *41*, 4251–4263. [CrossRef]
73. Zuraidah, R.; Nur, S.; Norilhamiah, Y.; Aida, S.A.; Amelia, M.; Muhammad, F.M. Microbial fuel cell for conversion of chemical energy to electrical energy from food industry wastewater. *J. Environ. Sci. Technol.* **2016**, *9*, 481–485.
74. Oh, S.E.; Logan, B.E. Hydrogen and electricity production from a food processing wastewater using fermentation and microbial fuel cell technologies. *Water Res.* **2005**, *39*, 4673–4682. [CrossRef]
75. Rahman, W.; Yusup, S.; Mohammad, S.N.A.A. Screening of fruit waste as substrate for microbial fuel cell (mfc). In Proceedings of the 4th Internationa Sciences, Technology and Engineering conference (ISTEC), Exploring materials for the future, Brescia, Italy, 8–10 April 2020.
76. Frattini, D.; Falcuccia, G.; Minutilloa, M.; Feronea, C.; Cioffia, R.; Jannellia, E. On the effect of different configurations in air-cathode mfcs fed by composite food waste for energy harvesting. *Chem. Eng.* **2016**, *49*, 85–90.
77. Xin, X.; Ma, Y.; Liu, Y. Electric energy production from food waste: Microbial fuel cells versus anaerobic digestion. *Bioresour. Technol.* **2018**, *255*, 281–287. [CrossRef] [PubMed]
78. Choi, J.; Ahn, Y. Enhanced bioelectricity harvesting in microbial fuel cells treating food waste leachate produced from biohydrogen fermentation. *Bioresour. Technol.* **2015**, *183*, 53–60. [CrossRef]
79. Jia, J.; Tang, Y.; Liu, B.; Wu, D.; Ren, N.; Xing, D. Electricity generation from food wastes and microbial community structure in microbial fuel cells. *Bioresour. Technol.* **2013**, *144*, 94–99. [CrossRef]
80. Chandrasekhar, K.; Amulya, K.; Mohan, S.V. Solid phase bio-electrofermentation of food waste to harvest value-added products associated with waste remediation. *Waste Manag.* **2015**, *45*, 57–65. [CrossRef]
81. Goud, R.K.; Babu, P.S.; Mohan, S.V. Canteen based composite food waste as potential anodic fuel for bioelectricity generation in single chambered microbial fuel cell (mfc): Bio-electrochemical evaluation under increasing substrate loading condition. *Int. J. Hydrogen Energy* **2011**, *36*, 6210–6218. [CrossRef]
82. Mohan, S.V.; Chandrasekhar, K. Solid phase microbial fuel cell (smfc) for harnessing bioelectricity from composite food waste fermentation: Influence of electrode assembly and buffering capacity. *Bioresour. Technol.* **2011**, *102*, 7077–7085. [CrossRef] [PubMed]
83. Sangeetha, T.; Muthukumar, M. Catholyte performance as an influencing factor on electricity production in a dual-chambered microbial fuel cell employing food processing wastewater. *Energy Sources Part A Recovery Util. Environ. Eff.* **2011**, *33*, 1514–1522. [CrossRef]
84. Hou, Q.; Pei, H.; Hu, W.; Jiang, L.; Yu, Z. Mutual facilitations of food waste treatment, microbial fuel cell bioelectricity generation and chlorella vulgaris lipid production. *Bioresour. Technol.* **2016**, *203*, 50–55. [CrossRef] [PubMed]
85. Choi, J.D.; Chang, H.N.; Han, J.I. Performance of microbial fuel cell with volatile fatty acids from food wastes. *Biotechnol. Lett.* **2011**, *33*, 705–714. [CrossRef] [PubMed]

86. Asefi, B.; Li, S.L.; Moreno, H.A.; Sanchez-Torres, V.; Hu, A.; Li, J.; Yu, C.P. Characterization of electricity production and microbial community of food waste-fed microbial fuel cells. *Process Saf. Environ. Prot.* **2019**, *125*, 83–91. [CrossRef]
87. Ma, H.; Peng, C.; Jia, Y.; Wang, Q.; Tu, M.; Gao, M. Effect of fermentation stillage of food waste on bioelectricity production and microbial community structure in microbial fuel cells. *R Soc. Open. Sci.* **2018**, *5*, 180457. [CrossRef] [PubMed]
88. Gao, M.; Li, H.; Ma, H.; Peng, C.; Wu, W.; Yu, Z.; Wang, Q. Electricity enhancement by mfcs from food waste ethanol fermentation recycle stillage effect of dilution ratio and addition of tween 80. *Chem. Sel.* **2020**, *5*, 5701–5705. [CrossRef]
89. Abedule, A.P.; Aderiye, B.I.; Adebayo, A.A. Improving bioelectricity generation of microbial fuel cell (mfc) with mediators using kitchen waste as substrate. *Ann. Appl. Microbiol. Biotechnol. J.* **2018**, *2*, 1008.
90. Chatzikonstantinou, D.; Tremouli, A.; Papadopoulou, K.; Kanellos, G.; Lampropoulos, I.; Lyberatos, G. Bioelectricity production from fermentable household waste in a dual-chamber microbial fuel cell. *Waste Manag. Res.* **2018**, *36*, 1037–1042. [CrossRef]
91. Kamperidis, T.; Pandis, P.K.; Argirusis, C.; Lyberatos, G.; Tremouli, A. Effect of food waste condensate concentration on the performance of microbial fuel cells with different cathode assemblies. *Sustainability* **2022**, *14*, 2625. [CrossRef]
92. Pandis, P.K.; Kamperidis, T.; Bariamis, K.; Vlachos, I.; Argirusis, C.; Stathopoulos, V.N.; Lyberatos, G.; Tremouli, A. Comparative study of different production methods of activated carbon cathodic electrodes in single chamber mfc treating municipal landfill leachate. *Appl. Sci.* **2022**, *12*, 2991. [CrossRef]
93. Moqsud, M.A.; Omine, K.; Yasufuku, N.; Bushra, Q.S.; Hyodo, M.; Nakata, Y. Bioelectricity from kitchen and bamboo waste in a microbial fuel cell. *Waste Manag. Res.* **2014**, *32*, 124–130. [CrossRef]
94. Kosseva, M.R. Sources, characterization, and composition of food industry wastes. In *Food Industry Wastes*; Academic Press: Cambridge, MA, USA, 2013; Chapter 3; pp. 37–60.
95. You, S.-J.; Zhang, J.-N.; Yuan, Y.-X.; Ren, N.-Q.; Wang, X.-H. Development of microbial fuel cell with anoxic/oxic design for treatment of saline seafood wastewater and biological electricity generation. *J. Chem. Technol. Biotechnol.* **2010**, *85*, 1077–1083. [CrossRef]
96. Sun, H.-L. Electricity generation from seafood wastewater in a single- and dual-chamber microbial fuel cell with cotmpp oxygen-reduction electrocatalyst. *J. Chem. Technol. Biotechnol.* **2012**, *87*, 1167–1172. [CrossRef]
97. Jayashree, C.; Tamilarasan, K.; Rajkumar, M.; Arulazhagan, P.; Yogalakshmi, K.N.; Srikanth, M.; Banu, J.R. Treatment of seafood processing wastewater using upflow microbial fuel cell for power generation and identification of bacterial community in anodic biofilm. *J. Environ. Manag.* **2016**, *180*, 351–358. [CrossRef] [PubMed]
98. Jamal, M.T.; Pugazhendi, A.; Jeyakumar, R.B. Application of halophiles in air cathode mfc for seafood industrial wastewater treatment and energy production under high saline condition. *Environ. Technol. Innov.* **2020**, *20*, 101119. [CrossRef]
99. Amrutha, K.M.; Aswathi, M. Bioelectricity production from seafood processing wastewater using microbial fuel cell. *Int. Res. J. Eng. Technol.* **2019**, *6*, 376–379.
100. Dongre, A.; Sogani, M.; Sonu, K.; Syed, Z.; Sharma, G. Treatment of dairy wastewaters: Evaluating microbial fuel cell tools and mechanism. In *Environmental Change and Sustainability*; IntechOpen: London, UK, 2020.
101. Demirel, B.; Yenigun, O.; Onay, T.T. Anaerobic treatment of dairy wastewaters: A review. *Process Biochem.* **2005**, *40*, 2583–2595. [CrossRef]
102. Mohan, S.V.; Mohanakrishna, G.; Velvizhi, G.; Babu, V.L.; Sarma, P.N. Bio-catalyzed electrochemical treatment of real field dairy wastewater with simultaneous power generation. *Biochem. Eng. J.* **2010**, *51*, 32–39. [CrossRef]
103. Cercado-Quezada, B.; Delia, M.-L.; Bergel, A. Treatment of dairy wastes with a microbial anode formed from garden compost. *J. Appl. Electrochem.* **2010**, *40*, 225–232. [CrossRef]
104. Luo, H.; Xu, G.; Lu, Y.; Liu, G.; Zhang, R.; Li, X.; Zheng, X.; Yu, M. Electricity generation in a microbial fuel cell using yogurt wastewater under alkaline conditions. *RSC Adv.* **2017**, *7*, 32826–32832. [CrossRef]
105. Zhang, G.; Zhao, Q.; Jiao, Y.; Lee, D.J. Long-term operation of manure-microbial fuel cell. *Bioresour. Technol.* **2015**, *180*, 365–369. [CrossRef] [PubMed]
106. Faria, A.; Gonçalves, L.; Peixoto, J.M.; Peixoto, L.; Brito, A.G.; Martins, G. Resources recovery in the dairy industry: Bioelectricity production using a continuous microbial fuel cell. *J. Clean. Prod.* **2017**, *140*, 971–976. [CrossRef]
107. Jayashree, C.; Janshi, G.; Yeom, I.T.; Adish Kumar, S.; Rajesh Banu, R. Effect of low temperature thermo-chemical pretreatment of dairy waste activated sludge on the performance of microbial fuel cell. *Int. J. Electrochem. Sci.* **2014**, *9*, 5732–5742.
108. Rago, L.; Baeza, J.A.; Guisola, A. Bioelectrochemical hydrogen production with cheese whey as sole substrate. *J. Chem. Technol. Biotechnol.* **2017**, *92*, 173–179. [CrossRef]
109. Nasirahmadi, S.; Safekordi, A.A. Whey as a substrate for generation of bioelectricity in microbial fuel cell using *E.coli*. *Int. J. Environ. Sci. Tech.* **2011**, *8*, 823–830. [CrossRef]
110. Elakkiya, E.; Matheswaran, M. Comparison of anodic metabolisms in bioelectricity production during treatment of dairy wastewater in microbial fuel cell. *Bioresour. Technol.* **2013**, *136*, 407–412. [CrossRef] [PubMed]
111. Mansoorian, H.J.; Mahvi, A.H.; Jafari, A.J.; Khanjani, N. Evaluation of dairy industry wastewater treatment and simultaneous bioelectricity generation in a catalyst-less and mediator-less membrane microbial fuel cell. *J. Saudi Chem. Soc.* **2016**, *20*, 88–100. [CrossRef]
112. Drisya, C.M.; Manjunath, N.T. Dairy wastewater treatment and electricity generation using microbial fuel cell. *Int. Res. J. Eng. Technol.* **2017**, *4*, 1293–1296.

113. Choudhury, P.; Ray, R.N.; Tiwari, O.N.; Bandyopadhyay, T.K.; Muthurai, M.; Bhunia, B. Strategies for improvement of microbial fuel cell performance via stable power generation from real dairy wastewater. *Fuel* **2021**, *288*, 119653. [CrossRef]
114. Choudhury, P.; Bhunia, B.; Bandyopadhyay, T.K.; Ray, R.N. The overall performance improvement of microbial fuel cells connected in series with dairy wastewater treatment. *J. Electrochem. Sci. Technol.* **2021**, *12*, 101–111. [CrossRef]
115. Retnaningrum, E.; Wilopo, W. Performance and bacterial composition of anodic biofilms in microbial fuel cell using dairy wastewater. *AIP Conf. Proc.* **2016**, *1744*, 20018. [CrossRef]
116. Sivakumar, D. Pollution reduction and electricity production from dairy industry wastewater with microbial fuel cell. *Glob. J. Environ. Sci. Manag.* **2020**, *6*, 145–164.
117. Al-saned, A.J.O.; Kitafa, B.A.; Badday, A.S. Microbial fuel cells (mfc) in the treatment of dairy wastewater. In Proceedings of the Materials Science and Engineering, Volume 1067, 4th International Conference on Engineering Sciences (ICES 2020), Kerbala, Iraq, 5–6 December 2020; p. 1067.
118. Khajeh, R.T.; Aber, S.; Nofouzi, K.; Ebrahimi, S. Treatment of mixed dairy and dye wastewater in anode of microbial fuel cell with simultaneous electricity generation. *Environ. Sci. Pollut. Res.* **2020**, *27*, 43711–43723. [CrossRef] [PubMed]
119. Jaiyeola, A.T.; Bwapwa, J.K. Treatment technology for brewery wastewater in a water-scarce country: A review. *South Afr. J. Sci.* **2015**, *112*, 8.
120. Simate, G.S.; Cluett, J.; Iyuke, S.E.; Musapatika, E.T.; Ndlovu, S.; Walubita, L.F.; Alvarez, A.E. The treatment of brewery wastewater for reuse: State of the art. *Desalination* **2011**, *273*, 235–247. [CrossRef]
121. Amenorfenyo, D.K.; Huang, X.; Zhang, Y.; Zeng, Q.; Zhang, N.; Ren, J.; Huang, Q. Microalgae brewery wastewater treatment: Potentials, benefits and the challenges. *Int. J. Environ. Res. Public Health* **2019**, *16*, 1910. [CrossRef]
122. Ainebyona, P.; Banadda, N.; Kiggundu, N. Extracting economic value from breweries wastewater: A review. *MOJ Ecol. Environ. Sci.* **2021**, *6*, 8–13. [CrossRef]
123. Wang, H.; Qu, Y.; Li, D.; Ambuchi, J.J.; He, W.; Zhou, X.; Liu, J.; Feng, Y. Cascade degradation of organic matters in brewery wastewater using a continuous stirred microbial electrochemical reactor and analysis of microbial communities. *Sci. Rep.* **2016**, *6*, 27023. [CrossRef]
124. Feng, Y.; Wang, X.; Logan, B.E.; Lee, H. Brewery wastewater treatment using air-cathode microbial fuel cells. *Appl. Microbiol. Biotechnol.* **2008**, *78*, 873–880. [CrossRef]
125. Arun, S.; Sinharoy, A.; Pakshirajan, K.; Lens, P.N.L. Algae based microbial fuel cells for wastewater treatment and recovery of value-added products. *Renew. Sustain. Energy Rev.* **2020**, *132*, 110041. [CrossRef]
126. Savvidou, M.G.; Katsabea, A.; Kotidis, P.; Mamma, D.; Lymperopoulou, T.V.; Kekos, D.; Kolisis, F.N. Studies on the catalytic behavior of a membrane-bound lipolytic enzyme from the microalgae *Nannochloropsis oceanica* CCMP1779. *Enzym. Microb. Technol.* **2018**, *116*, 64–71. [CrossRef]
127. Savvidou, M.G.; Banis, G.; Ferraro, A.; Molino, A.J.; Karatza, D.; Chianese, S.; Musmarra, D.; Kolisis, F.N.; Hristoforou, E. Production of magnetic modified microalgae using iron oxide nanoparticles and electroporation technique. *Chem. Eng. Trans.* **2019**, *73*, 13–18.
128. Savvidou, M.G.; Ferraro, A.; Hristoforou, E.; Mamma, D.; Kekos, D.; Kolisis, F.N. Incorporation of magnetic nanoparticles into protoplasts of microalgae haematococcus pluvialis: A tool for biotechnological applications. *Molecules* **2020**, *25*, 5068. [CrossRef]
129. Penteado, E.D.; Fernandez-Marchante, C.M.; Zaiat, M.; Canizares, P.; Gonzalez, E.R.; Rodrigo, M.A. Influence of sludge age on the performance of mfc treating winery wastewater. *Chemosphere* **2016**, *151*, 163–170. [CrossRef]
130. Penteado, E.D.; Fernandez-Marchante, C.M.; Zaiat, M.; Cañizares, P.; Gonzalez, E.R.; Rodrigo, M.A.R. Energy recovery from winery wastewater using a dual chamber microbial fuel cell. *J. Chem. Technol. Biotechnol.* **2016**, *91*, 1802–1808. [CrossRef]
131. Wen, Q.; Wu, Y.; Zhao, L.; Sun, Q. Production of electricity from the treatment of continuous brewery wastewater using a microbial fuel cell. *Fuel* **2010**, *89*, 1381–1385. [CrossRef]
132. Yu, J.; Park, Y.; Kim, B.; Lee, T. Power densities and microbial communities of brewery wastewater-fed microbial fuel cells according to the initial substrates. *Bioprocess Biosyst. Eng.* **2015**, *38*, 85–92. [CrossRef]
133. Wang, X.; Feng, Y.J.; Lee, H. Electricity production from beer brewery wastewater using single chamber microbial fuel cell. *Water Sci. Technol.* **2008**, *57*, 1117–1121. [CrossRef]
134. Miran, W.; Nawaz, M.; Kadam, A.; Shin, S.; Heo, J.; Jang, J.; Lee, D.S. Microbial community structure in a dual chamber microbial fuel cell fed with brewery waste for azo dye degradation and electricity generation. *Environ. Sci. Pollut. Res. Int.* **2015**, *22*, 13477–13485. [CrossRef]
135. Mshoperi, E.; Fogel, R.; Limson, J. Application of carbon black and iron phthalocyanine composites in bioelectricity production at a brewery wastewater fed microbial fuel cell. *Acta* **2014**, *128*, 311–317. [CrossRef]
136. Pisutpaisal, N.; Sirisukpoca, U. Bioelectricity Generation from Wastewaters in Microbial Fuel Cells. In *Advanced Materials Research*; Trans Tech Publications Ltd.: Freienbach, Switzerland, 2012; Volume 512, pp. 1456–1460.
137. Zhang, X.; Zhu, F.; Chen, L.; Zhao, Q.; Tao, G. Removal of ammonia nitrogen from wastewater using an aerobic cathode microbial fuel cell. *Bioresour. Technol.* **2013**, *146*, 161–168. [CrossRef] [PubMed]
138. Angosto, J.M.; Fernandez-Lopez, J.A.; Godinez, C. Brewery and liquid manure wastewaters as potential feedstocks for microbial fuel cells: A performance study. *Environ. Technol.* **2015**, *36*, 68–78. [CrossRef] [PubMed]
139. Wen, Q.; Wu, Y.; Cao, D.; Zhao, L.; Sun, Q. Electricity generation and modeling of microbial fuel cell from continuous beer brewery wastewater. *Bioresour. Technol.* **2009**, *100*, 4171–4175. [CrossRef] [PubMed]

140. Çetinkaya, A.Y.; Köroğlu, E.O.; Demir, N.M.; Baysoy, D.Y.; Özkaya, B.; Çakmakçı, M. Electricity production by a microbial fuel cell fueled by brewery wastewater and the factors in its membrane deterioration. *Chin. J. Catal.* **2015**, *36*, 1068–1076. [CrossRef]
141. Zhuang, L.; Yuan, Y.; Wang, Y.; Zhou, S. Long-term evaluation of a 10-L serpentine-type microbial fuel cell stack treating brewery wastewater. *Bioresour. Technol.* **2012**, *123*, 406–412. [CrossRef]
142. Dannys, E.; Green, T.; Wettlaufer, A.; Madhurnathakam, C.M.R.; Elkamel, A. Wastewater treatment with microbial fuel cells: A design and feasibility study for scale-up in microbreweries. *J. Bioprocess. Biotech.* **2016**, *6*, 1–6.
143. Mathuriya, A.S.; Sharma, V.N. Treatment of brewery wastewater and production of electricity through microbial fuel cell technology. *Int. J. Biotechnol. Biochem.* **2010**, *6*, 71–78.
144. Hung, Y.T.; Salman, H.; Awad, A. Olive Oil Waste Treatment. In *Waste Treatment in the Food Processing Industry*; CRC Press: Boca Raton, FL, USA, 2005; pp. 119–192.
145. Guo, H.; Tang, S.; Xie, S.; Wang, P.; Huang, C.; Geng, X.; Jia, X.; Huo, H.; Li, X.; Zhang, J.; et al. The oil removal and the characteristics of changes in the composition of bacteria based on the oily sludge bioelectrochemical system. *Sci. Rep.* **2020**, *10*, 15474. [CrossRef]
146. Hamamoto, K.; Miyahara, M.; Kouzuma, A.; Matsumoto, A.; Yoda, M.; Ishiguro, T.; Watanabe, K. Evaluation of microbial fuel cells for electricity generation from oil-contaminated wastewater. *J. Biosci. Bioeng.* **2016**, *122*, 589–593. [CrossRef]
147. Yu, N.; Xing, D.; Li, W.; Yang, Y.; Li, Z.; Li, Y.; Ren, N. Electricity and methane production from soybean edible oil refinery wastewater using microbial electrochemical systems. *Int. J. Hydrogen Energy* **2017**, *42*, 96–102. [CrossRef]
148. Baranitharan, E.; Khan, M.R.; Prasad, D.M.; Teo, W.F.; Tan, G.Y.; Jose, R. Effect of biofilm formation on the performance of microbial fuel cell for the treatment of palm oil mill effluent. *Bioprocess Biosyst. Eng.* **2015**, *38*, 15–24. [CrossRef] [PubMed]
149. Abbasi, U.; Jin, W.; Pervez, A.; Bhatti, Z.A.; Tariq, M.; Shaheen, S.; Iqbal, A.; Mahmood, Q. Anaerobic microbial fuel cell treating combined industrial wastewater: Correlation of electricity generation with pollutants. *Bioresour. Technol.* **2016**, *200*, 1–7. [CrossRef] [PubMed]
150. Firdous, S.; Jin, W.; Shahid, N.; Bhatti, Z.A.; Iqbal, A.; Abbasi, U.; Mahmood, Q.; Ali, A. The performance of microbial fuel cells treating vegetable oil industrial wastewater. *Environ. Technol. Innov.* **2018**, *10*, 143–151. [CrossRef]
151. Mohanakrishna, G.; Abu-Reesh, I.M.; Kondaveeti, S.; Al-Raoush, R.I.; He, Z. Enhanced treatment of petroleum refinery wastewater by short-term applied voltage in single chamber microbial fuel cell. *Bioresour. Technol.* **2018**, *253*, 16–21. [CrossRef] [PubMed]
152. Srikanth, S.; Kumar, M.; Singh, D.; Singh, M.P.; Das, B.P. Electro-biocatalytic treatment of petroleum refinery wastewater using microbial fuel cell (mfc) in continuous mode operation. *Bioresour. Technol.* **2016**, *221*, 70–77. [CrossRef]
153. Yang, Q.; Wu, Z.; Liu, L.; Zhang, F.; Liang, S. Treatment of oil wastewater and electricity generation by integrating constructed wetland with microbial fuel cell. *Materials* **2016**, *9*, 885. [CrossRef]
154. Addi, H.; Mateo-Ramírez, F.; Ortiz-Martínez, V.M.; Salar-García, M.J.; Hernández-Fernández, F.J.; Pérez de los Ríos, A.; Godinez, C.; Lofti, L.M.; El Mahhi, M.; Blanco, L.J.L. Treatment of mineral oil refinery wastewater in microbial fuel cells using ionic liquid based separators. *Appl. Sci.* **2018**, *8*, 438. [CrossRef]
155. Caro, D.; Davis, S.J.; Bastianoni, S.; Caldeira, K. Greenhouse Gas Emissions due to Meat Production in the Last Fifty Years. In *Quantification of Climate Variability, Adaptation and Mitigation for Agricultural Sustainability*; Springer: Berlin/Heidelberg, Germany, 2017; pp. 27–37.
156. Banks, C.J.; Wang, Z. Treatment of Meat Wastes. In *Handbook of Industrial and Hazardous Wastes Treatment*; CRC Press: Boca Raton, FL, USA, 2004; pp. 750–787.
157. Ichihashi, O.; Hirooka, K. Removal and recovery of phosphorus as struvite from swine wastewater using microbial fuel cell. *Bioresour. Technol.* **2012**, *114*, 303–307. [CrossRef]
158. Xu, N.; Zhou, S.; Yuan, Y.; Qin, H.; Zheng, Y.; Shu, C. Coupling of anodic biooxidation and cathodic bioelectro-fenton for enhanced swine wastewater treatment. *Bioresour. Technol.* **2011**, *102*, 7777–7783. [CrossRef]
159. Egbadon, E.; Akujobi, C.O.; Nweke, C.O.; Braide, W.; Akaluka, C.K.; Adeleye, S.A. Simultaneous generation of bioelectricity and treatment of swine wastewater in a microbial fuel cell. *Int. Lett. Nat. Sci.* **2016**, *54*, 100–107. [CrossRef]
160. Wagner, R.C.; Regan, J.M.; Oh, S.E.; Zuo, Y.; Logan, B.E. Hydrogen and methane production from swine wastewater using microbial electrolysis cells. *Water Res.* **2009**, *43*, 1480–1488. [CrossRef] [PubMed]
161. Kim, K.Y.; Yang, W.; Evans, P.J.; Logan, B.E. Continuous treatment of high strength wastewaters using air-cathode microbial fuel cells. *Bioresour. Technol.* **2016**, *221*, 96–101. [CrossRef] [PubMed]
162. Min, B.; Kim, J.; Oh, S.; Regan, J.M.; Logan, B.E. Electricity generation from swine wastewater using microbial fuel cells. *Water Res.* **2005**, *39*, 4961–4968. [CrossRef] [PubMed]
163. Cheng, D.; Ngo, H.H.; Guo, W.; Lee, D.; Nghiem, D.L.; Zhang, J.; Liang, S.; Varjani, S.; Wang, J. Performance of microbial fuel cell for treating swine wastewater containing sulfonamide antibiotics. *Bioresour. Technol.* **2020**, *311*, 123588. [CrossRef]
164. Ma, J.; Ni, H.; Su, D.; Meng, X. Bioelectricity generation from pig farm wastewater in microbial fuel cell using carbon brush as electrode. *Int. J. Hydrogen Energy* **2016**, *41*, 16191–16195. [CrossRef]
165. Estrada-Arriaga, E.B.; García-Sánchez, L.; Garzón-Zuñiga, M.A.; González-Rodríguez, J.G. Utilization of microbial fuel cells for the treatment of wastewater from a pig farm. *Fresenius Environ. Bull.* **2015**, *24*, 2512–2518.
166. Kim, J.R.; Dec, J.; Bruns, M.A.; Logan, B.E. Removal of odors from swine wastewater by using microbial fuel cells. *Appl. Environ. Microbiol.* **2008**, *74*, 2540–2543. [CrossRef]
167. Vilajeliu-Pons, A.; Puig, S.; Pous, N.; Salcedo-Davila, I.; Baneras, L.; Balaguer, M.D.; Colprim, J. Microbiome characterization of mfcs used for the treatment of swine manure. *J. Hazard Mater.* **2015**, *288*, 60–68. [CrossRef]

168. Vogl, A.; Bischof, F.; Wichern, M. Single chamber microbial fuel cells for high strength wastewater and blackwater treatment—A comparison of idealized wastewater, synthetic human blackwater, and diluted pig manure. *Biochem. Eng. J.* **2016**, *115*, 64–71. [CrossRef]
169. Capodaglio, A.G.; Molognoni, D.; Puig, S.; Balaguer, M.D.; Colprim, J. Role of operating conditions on energetic pathways in a microbial fuel cell. *Energy Procedia* **2015**, *74*, 728–735. [CrossRef]
170. Cerrillo, M.; Oliveras, J.; Vinas, M.; Bonmati, A. Comparative assessment of raw and digested pig slurry treatment in bioelectrochemical systems. *Bioelectrochemistry* **2016**, *110*, 69–78. [CrossRef] [PubMed]
171. Sotres, A.; Cerrillo, M.; Vinas, M.; Bonmati, A. Nitrogen recovery from pig slurry in a two-chambered bioelectrochemical system. *Bioresour. Technol.* **2015**, *194*, 373–382. [CrossRef] [PubMed]
172. Sotres, A.; Tey, L.; Bonmati, A.; Vinas, M. Microbial community dynamics in continuous microbial fuel cells fed with synthetic wastewater and pig slurry. *Bioelectrochemistry* **2016**, *111*, 70–82. [CrossRef] [PubMed]
173. Najafpour, G.D.; Sahne, F. *Power Generation and Cattle Manure Leachate Treatment in Continuous Operation of Microbial Fuel Cell*; Biotechnology Research Lab., Noshirvani University of Technology: Babol, Iran, 2017.
174. Inoue, K.; Ito, T.; Kawano, Y.; Iguchi, A.; Miyahara, M.; Suzuki, Y.; Watanabe, K. Electricity generation from cattle manure slurry by cassette-electrode microbial fuel cells. *J. Biosci. Bioeng.* **2013**, *116*, 610–615. [CrossRef]
175. Zhao, G.; Ma, F.; Wei, L.; Chua, H.; Chang, C.C.; Zhang, X.J. Electricity generation from cattle dung using microbial fuel cell technology during anaerobic acidogenesis and the development of microbial populations. *Waste Manag.* **2012**, *32*, 1651–1658. [CrossRef] [PubMed]
176. Goto, Y.; Yoshida, N. Scaling up microbial fuel cells for treating swine wastewater. *Water* **2019**, *11*, 1803. [CrossRef]
177. Babanova, S.; Jones, J.; Phadke, S.; Lu, M.; Angulo, C.; Garcia, J.; Carpenter, K.; Cortese, R.; Chen, S.; Phan, T.; et al. Continuous flow, large-scale, microbial fuel cell system for the sustained treatment of swine waste. *Water Environ. Res.* **2020**, *92*, 60–72. [CrossRef] [PubMed]
178. Prabowo, A.K.; Tiatasukma, A.P.; CHristwardana, M.; Arivanti, D. Microbial fuel cells for simultaneous electricity generation and organic degradation from slaughterhouse wastewater. *Int. J. Renew. Energy Dev.* **2016**, *5*, 107–112.
179. Ismail, Z.Z.; Mohammed, A.J. Biotreatment of slaughterhouse wastewater accompanied with sustainable electricity generation in microbial fuel cell. *Syst. Cybern. Inform.* **2016**, *14*, 30–35.
180. Mohammed, A.J.; Ismail, Z.Z. Slaughterhouse wastewater biotreatment associated with bioelectricity generation and nitrogen recovery in hybrid system of microbial fuel cell with aerobic and anoxic bioreactors. *Ecol. Eng.* **2018**, *125*, 119–130. [CrossRef]
181. Katuri, K.P.; Enright, A.M.; O'Flaherty, V.; Leech, D. Microbial analysis of anodic biofilm in a microbial fuel cell using slaughterhouse wastewater. *Bioelectrochemistry* **2012**, *87*, 164–171. [CrossRef] [PubMed]
182. Mateo-Ramírez, F.; Addi, H.; Hernández-Fernández, F.J.; Godínez, C.; Pérez de los Ríos, A.; Lotfi, E.M.; El Mahi, M.; Lozano Blanco, L.J. Air breathing cathode-microbial fuel cell with separator based on ionic liquid applied to slaughterhouse wastewater treatment and bio-energy production. *J. Chem. Technol. Biotechnol.* **2017**, *92*, 642–648. [CrossRef]
183. Boopathi, A.; Pauline, S. Treatment of slaughterhouse wastewater using microbial fuel cell. *Int. J. Adv. Res. Ideas Innov. Technol.* **2018**, *4*, 228–230.
184. Mansoorian, H.J.; Mahvi, A.H.; Jafari, A.J.; Amin, M.M.; Rajabizadeh, A.; Khanjani, N. Bioelectricity generation using two chamber microbial fuel cell treating wastewater from food processing. *Enzyme Microb. Technol.* **2013**, *52*, 352–357. [CrossRef] [PubMed]
185. Meignanalakshmi, S.; Kumar, S.V. Bioelectricity production by using goat (capra hircus) rumen fluid from slaughterhouse waste in mediator-less microbial fuel cells. *Energy Sources Part A Recovery Util. Environ. Eff.* **2016**, *38*, 1364–1369. [CrossRef]
186. Jadhav, D.A.; Jain, S.C.; Ghangrekar, M.M. Cow's urine as a yellow gold for bioelectricity generation in low cost clayware microbial fuel cell. *Energy* **2016**, *113*, 76–84. [CrossRef]
187. Zheng, X.; Nirmalakhandan, N. Cattle wastes as substrates for bioelectricity production via microbial fuel cells. *Biotechnol. Lett.* **2010**, *32*, 1809–1814. [CrossRef]
188. Wang, X.; Tang, J.; Cui, J.; Liu, Q.; Giesy, J.P. Synergy of electricity generation and waste disposal in solid-state microbial fuel cell (mfc) of cow manure composting. *Int. J. Electrochem. Sci.* **2014**, *9*, 3144–3157.
189. Scott, K.; Murano, C. A study of a microbial fuel cell battery using manure sludge waste. *J. Chem. Technol. Biotechnol.* **2007**, *82*, 809–817. [CrossRef]
190. Lin, H.; Wu, X.; Nelson, C.; Miller, C.; Zhu, J. Electricity generation and nutrients removal from high-strength liquid manure by air-cathode microbial fuel cells. *J. Environ. Sci. Health A Tox Hazard Subst. Environ. Eng.* **2016**, *51*, 240–250. [CrossRef] [PubMed]
191. Ali, N.; Yousaf, S.; Anam, M.; Bangash, Z.; Maleeha, S. Evaluating the efficiency of a mixed culture biofilm for the treatment of black liquor and molasses in a mediator-less microbial fuel cell. *Environ. Technol.* **2016**, *37*, 2815–2822. [CrossRef] [PubMed]
192. Lee, Y.Y.; Kim, T.G.; Cho, K.S. Characterization of the cod removal, electricity generation, and bacterial communities in microbial fuel cells treating molasses wastewater. *J. Environ. Sci. Health A Tox Hazard Subst. Environ. Eng.* **2016**, *51*, 1131–1138. [CrossRef] [PubMed]
193. Zhang, B.; Zhao, H.; Zhou, S.; Shi, C.; Wang, C.; Ni, J. A novel uasb–mfc–baf integrated system for high strength molasses wastewater treatment and bioelectricity generation. *Bioresour. Technol.* **2009**, *100*, 5687–5693. [CrossRef] [PubMed]
194. Kumar, R.; Singh, L.; Zularisam, A.W. Bioelectricity generation and treatment of sugar mill effluent using a microbial fuel cell. *J. Clean Energy Technol.* **2015**, *4*, 249–252. [CrossRef]

195. Sreelekshmy, B.R.; Basheer, R.; Sivaraman, S.; Casudevan, V.; Elias, L.; Shibli, S.M.A. Sustainable electric power generation from live anaerobic digestion of sugar industry effluents using microbial fuel cells. *J. Mater. Chem. A* **2020**, *8*, 6041–6056. [CrossRef]
196. Fan, L.P.; Xu, D.D.; Li, C.; Xue, S. Molasses wastewater treatment by microbial fuel cell with mno2-modified cathode. *Polish J. Environ. Stud.* **2016**, *25*, 2349–2356. [CrossRef]
197. Fan, L.; Shi, J.; Xi, Y. Pvdf-modified nafion membrane for improved performance of mfc. *Membranes* **2020**, *10*, 185. [CrossRef]
198. Fan, L.-P. Applications of nanoscale polypyrrole proton exchange membrane in microbial fuel cells. *Int. J. Electrochem. Sci.* **2019**, *14*, 470–480. [CrossRef]
199. Obaid, Z.S.; Hussein, W.N. Anode-cathode arrangement and its effect on microbial uel cell performance using date paste as a substrate. *J. Eng. Sci. Technol.* **2017**, *12*, 2691–2699.
200. Hassan, S.H.A.; el Nasser, A.; Zohri, A.; Kassim, R.M.F. Electricity generation from sugarcane molasses using microbial fuel cell technologies. *Energy* **2019**, *178*, 538–543. [CrossRef]
201. Wu, C.H.; Liu, S.H.; Chu, H.L.; Li, Y.C.; Lin, C.W. Feasibility study of electricity generation and organics removal for a molasses wastewater by a waterfall-type microbial fuel cell. *J. Taiwan Inst. Chem. Eng.* **2017**, *78*, 150–156. [CrossRef]
202. Zhong, C.; Zhang, B.; Kong, L.; Xue, A.; Ni, J. Electricity generation from molasses wastewater by an anaerobic baffled stacking microbial fuel cell. *J. Chem. Technol. Biotechnol.* **2011**, *86*, 406–413. [CrossRef]
203. Samsudeen, N.; Radhakrishnan, T.K.; Matheswaran, M. Effect of isolated bacterial strains from distillery wastewater on power generation in microbial fuel cell. *Process Biochemistry* **2016**, *51*, 1876–1884. [CrossRef]
204. Tanikkul, P.; Pisutpaisal, N. Performance of a membrane-less air-cathode single chamber microbial fuel cell in electricity generation from distillery wastewater. *Energy Procedia* **2015**, *79*, 646–650. [CrossRef]
205. Hampannavar, U.S.; Pradeep, N.V. Treatment of distillery wastewater using single chamber and double chambered mfc. *Int. J. Environ. Sci.* **2011**, *2*, 114.
206. Deval, A.S.; Parikh, H.A.; Kadier, A.; Chandrasekhar, K.; Bhagwat, A.M.; Dikshit, A.K. Sequential microbial activities mediated bioelectricity production from distillery wastewater using bio-electrochemical system with simultaneous waste remediation. *Int. J. Hydrogen Energy* **2017**, *42*, 1130–1141. [CrossRef]
207. Wang, X.; Feng, Y.; Wang, H.; Qu, Y.; Yu, Y.; Ren, N.; Li, N.; Wang, E.; Lee, H.; Logan, B. Bioaugmentation for electricity generation from corn stover biomass using microbial fuel cells. *Environ. Sci. Technol.* **2009**, *43*, 6088–6093. [CrossRef]
208. Rezaei, F.; Richard, T.L.; Logan, B.E. Analysis of chitin particle size on maximum power generation, power longevity, and coulombic efficiency in solid–substrate microbial fuel cells. *J. Power Sources* **2009**, *192*, 304–309. [CrossRef]
209. Li, S.W.; He, H.; Zeng, R.J.; Sheng, G.P. Chitin degradation and electricity generation by aeromonas hydrophila in microbial fuel cells. *Chemosphere* **2017**, *168*, 293–299. [CrossRef]
210. Deval, A.S.; Dikshit, A.K. Enhanced energy recovery from anaerobically digested distillery wastewater through microbial fuel cell connected in series. *South Indian J. Biol. Sci.* **2016**, *2*, 287–291. [CrossRef]
211. Tiwari, B.R.; Ghangrekar, M.M. Electricity production during distillery wastewater treatment in a microbial fuel cell equipped with low cost pva-nafion-borosilicate membrane. *J. Clean Energy Technol.* **2018**, *6*, 155–158. [CrossRef]
212. Singh, A.; Kaushik, A. Suitability of wetland microbial consortium for enhanced and sustained power generation from distillery effluent in microbial fuel cell. *Energy Sources, Part A Recover. Util. Environ. Eff.* **2020**, 1–17. [CrossRef]
213. Geetha, K.; Raj, S.A. Biomass-electrochemical integrated system for distillery wastewater treatment with electricity generation using anaerobic mixed consortium in microbial fuel cells. *Int. J. Environ. Waste Manag.* **2015**, *15*, 217–234. [CrossRef]
214. Santos, M.L.V.; Valadéz, F.J.R.; Solís, V.M.; Nava, C.G.; Martell, A.J.C.; Hensel, O. Performance of a microbial fuel cell operated with vinasses using different cod concentrations. *Rev. Int. de Contam. ón Ambient.* **2017**, *33*, 521–528. [CrossRef]
215. Mohanakrishna, G.; Venkata Mohan, S.; Sarma, P.N. Bio-electrochemical treatment of distillery wastewater in microbial fuel cell facilitating decolorization and desalination along with power generation. *J. Hazard. Mater.* **2010**, *177*, 487–494. [CrossRef]
216. Anupama, P.N.; Hampannavar, U.S. Microbial fuel cell an alternative for cod removal of distillery wastewater. *J. Res. Biol.* **2011**, *6*, 419–423.
217. Anupama, S.; Pradeep, N.V.; Hampannavar, U.S. Anaerobic followed by aerobic treatment approaches for spentwash using mfc and rbc. *Sugar Technol.* **2013**, *15*, 197–202. [CrossRef]
218. Hamza, H.M.C.; Duraisamy, P.; Periyasamy, S.; Pokkiladathu, H.; Muthuchamy, M. Simultaneous electricity generation and heavy metals reduction from distillery effluent by microbial fuel cell. *Indian J. Sci. Technol.* **2017**, *10*, 1–13. [CrossRef]
219. Nimje, V.R.; Labrath, Y.P.; Gaikar, V.G. Development of microbial fuel cell using distillery spent wash: Evaluation of current generation and cod removal with respect to ph. *Iran. J. Energy Environ.* **2013**, *4*, 348–356. [CrossRef]
220. Huang, J.; Yang, P.; Guo, Y.; Zhang, K. Electricity generation during wastewater treatment: An approach using an afb-mfc for alcohol distillery wastewater. *Desalination* **2011**, *276*, 373–378. [CrossRef]
221. Ha, P.T.; Lee, T.K.; Rittmann, B.E.; Park, J.; Chang, I.S. Treatment of alcohol distillery wastewater using a bacteroidetes-dominant thermophilic microbial fuel cell. *Environ. Sci. Technol.* **2012**, *46*, 3022–3030. [CrossRef] [PubMed]
222. Li, X.; Abu-Reesh, I.; He, Z. Development of bioelectrochemical systems to promote sustainable agriculture. *Agriculture* **2015**, *5*, 367–388. [CrossRef]
223. Cheng, S.; Kiely, P.; Logan, B.E. Pre-acclimation of a wastewater inoculum to cellulose in an aqueous-cathode mec improves power generation in air-cathode mfcs. *Bioresour. Technol.* **2011**, *102*, 367–371. [CrossRef] [PubMed]

224. Niessen, J.; Schroder, U.; Harnisch, F.; Scholz, F. Gaining electricity from in situ oxidation of hydrogen produced by fermentative cellulose degradation. *Lett. Appl. Microbiol.* **2005**, *41*, 286–290. [CrossRef]
225. Ren, Z.; Ward, T.; Regan, J. Electricity production from cellulose in a microbial fuel cell using a defined binary culture. *Environ. Sci. Technol.* **2007**, *41*, 4781–4786. [CrossRef] [PubMed]
226. Rismani-Yazdi, H.; Christy, A.D.; Dehority, B.A.; Morrison, M.; Yu, Z.; Tuovinen, O.H. Electricity generation from cellulose by rumen microorganisms in microbial fuel cells. *Biotechnol. Bioeng.* **2007**, *97*, 1398–1407. [CrossRef]
227. Hassan, S.H.A.; Gad El-Rab, S.M.F.; Rahimnejad, M.; Ghasemi, M.; Joo, J.-H.; Sik-Ok, Y.; Kim, I.S.; Oh, S.-E. Electricity generation from rice straw using a microbial fuel cell. *Int. J. Hydrogen Energy* **2014**, *39*, 9490–9496. [CrossRef]
228. Rezaei, F.; Xing, D.; Wagner, R.; Regan, J.M.; Richard, T.L.; Logan, B.E. Simultaneous cellulose degradation and electricity production by enterobacter cloacae in a microbial fuel cell. *Appl. Environ. Microbiol.* **2009**, *75*, 3673–3678. [CrossRef]
229. Zhang, Y.; Min, B.; Huang, L.; Angelidaki, I. Generation of electricity and analysis of microbial communities in wheat straw biomass-powered microbial fuel cells. *Appl. Environ. Microbiol.* **2009**, *75*, 3389–3395. [CrossRef]
230. Zuo, Y.; Maness, P.C.; Logan, B.E. Electricity production from steam-exploded corn stover biomass. *Energy Fuels* **2006**, *20*, 1716–1721. [CrossRef]
231. Gregoire, K.P.; Becker, J.G. Design and characterization of a microbial fuel cell for the conversion of a lignocellulosic crop residue to electricity. *Bioresour. Technol.* **2012**, *119*, 208–215. [CrossRef] [PubMed]
232. Mamani-Asqui, L.J.; Peredo-Berlanga, L.N.; Roque Rodríguez, F.J.; Salazar-Banda, G.R. Vicia faba crop residues for sustainable electricity generation using a sludge-based microbial fuel cell. *Chem. Biochem. Eng. Q.* **2021**, *34*, 289–296. [CrossRef]
233. Miran, W.; Nawaz, M.; Jang, J.; Lee, D.S. Conversion of orange peel waste biomass to bioelectricity using a mediator-less microbial fuel cell. *Sci. Total Environ.* **2016**, *547*, 197–205. [CrossRef]
234. Lu, N.; Zhou, S.-G.; Zhuang, L.; Zhang, J.-T.; Ni, J.-R. Electricity generation from starch processing wastewater using microbial fuel cell technology. *Biochem. Eng. J.* **2009**, *43*, 246–251. [CrossRef]
235. Yang, F.; Ren, L.; Pu, Y.; Logan, B.E. Electricity generation from fermented primary sludge using single-chamber air-cathode microbial fuel cells. *Bioresour. Technol.* **2013**, *128*, 784–787. [CrossRef] [PubMed]
236. Martin, E.; Savadogo, O.; Guiot, S.R.; Tartakovsky, B. The influence of operational conditions on the performance of a microbial fuel cell seeded with mesophilic anaerobic sludge. *Biochem. Eng. J.* **2010**, *51*, 132–139. [CrossRef]
237. Jiang, J.; Zhao, Q.; Zhang, J.; Zhang, G.; Lee, D.J. Electricity generation from bio-treatment of sewage sludge with microbial fuel cell. *Bioresour. Technol.* **2009**, *100*, 5808–5812. [CrossRef] [PubMed]
238. Behera, M.; Ghangrekar, M.M. Performance of microbial fuel cell in response to change in sludge loading rate at different anodic feed ph. *Bioresour. Technol.* **2009**, *100*, 5114–5121. [CrossRef]
239. Jiang, J.Q.; Zhao, Q.L.; Wang, K.; Wei, L.L.; Zhang, G.D.; Zhang, J.N. Effect of ultrasonic and alkaline pretreatment on sludge degradation and electricity generation by microbial fuel cell. *Water. Sci. Technol.* **2010**, *61*, 2915–2921. [CrossRef]
240. Jiang, J.; Zhao, Q.; Wei, L.; Wang, K. Extracellular biological organic matters in microbial fuel cell using sewage sludge as fuel. *Water Res.* **2010**, *44*, 2163–2170. [CrossRef]
241. Chen, Y.; Jiang, J.; Zhao, Q. Freezing/thawing effect on sewage sludge degradation and electricity generation in microbial fuel cell. *Water Sci. Technol.* **2014**, *70*, 444–449. [CrossRef] [PubMed]
242. Jiang, J.; Zhao, Q.; Wei, L.; Wang, K.; Lee, D.J. Degradation and characteristic changes of organic matter in sewage sludge using microbial fuel cell with ultrasound pretreatment. *Bioresour. Technol.* **2011**, *102*, 272–277. [CrossRef] [PubMed]
243. Oh, S.E.; Yoon, J.Y.; Gurung, A.; Kim, D.J. Evaluation of electricity generation from ultrasonic and heat/alkaline pretreatment of different sludge types using microbial fuel cells. *Bioresour. Technol.* **2014**, *165*, 21–26. [CrossRef]
244. Fischer, F.; Bastian, C.; Happe, M.; Mabillard, E.; Schmidt, N. Microbial fuel cell enables phosphate recovery from digested sewage sludge as struvite. *Bioresour. Technol.* **2011**, *102*, 5824–5830. [CrossRef] [PubMed]
245. Yusoff, M.Z.; Hu, A.; Feng, C.; Maeda, T.; Shirai, Y.; Hassan, M.A.; Yu, C.P. Influence of pretreated activated sludge for electricity generation in microbial fuel cell application. *Bioresour. Technol.* **2013**, *145*, 90–96. [CrossRef] [PubMed]
246. Wang, Z.; Ma, J.; Xu, Y.; Yu, H.; Wu, Z. Power production from different types of sewage sludge using microbial fuel cells: A comparative study with energetic and microbiological perspectives. *J. Power Sources* **2013**, *235*, 280–288. [CrossRef]
247. Karthikeyan, R.; Selvam, A.; Cheng, K.Y.; Wong, J.W. Influence of ionic conductivity in bioelectricity production from saline domestic sewage sludge in microbial fuel cells. *Bioresour. Technol.* **2016**, *200*, 845–852. [CrossRef]
248. Lee, Y.; Nirmalakhandan, N. Electricity production in membrane-less microbial fuel cell fed with livestock organic solid waste. *Bioresour. Technol.* **2011**, *102*, 5831–5835. [CrossRef]
249. Utomo, H.D.; Yu, L.S.; Yi, D.C.Z.; Jun, O.J. Recycling solid waste and bioenergy generation in mfc dual- chamber model. *Energy Procedia* **2017**, *143*, 424–429. [CrossRef]
250. Ayol, A.; Biryol, İ.; Taşkan, E.; Hasar, H. Enhanced sludge stabilization coupled with microbial fuel cells (mfcs). *Int. J. Hydrogen Energy* **2020**, *46*, 29529–29540. [CrossRef]
251. Park, D.H.; Zeikus, J.G. Improved fuel cell and electrode designs for producing electricity from microbial degradation. *Biotechnol. Bioeng.* **2003**, *81*, 348–355. [CrossRef] [PubMed]
252. Schroder, U.; Niessen, J.; Scholz, F. A generation of microbial fuel cells with current outputs boosted by more than one order of magnitude. *Angew. Chem. Int. Ed. Engl.* **2003**, *42*, 2880–2883. [CrossRef] [PubMed]
253. Franks, A.E.; Nevin, K.P. Microbial fuel cells, a current review. *Energies* **2010**, *3*, 899–919. [CrossRef]

254. Huang, J.; Feng, H.; Jia, Y.; Shen, D.; Xu, Y. Sewage sludge-derived carbon-doped manganese as efficient cathode catalysts in microbial fuel cells. *Water Sci. Technol.* **2019**, *80*, 1399–1406. [CrossRef] [PubMed]
255. Rahimnejad, M.; Adhami, A.; Darvari, S.; Zirepour, A.; Oh, S.-E. Microbial fuel cell as new technology for bioelectricity generation: A review. *Alex. Eng. J.* **2015**, *54*, 745–756. [CrossRef]
256. Passos, V.F.; Aquino Neto, S.; Andrade, A.R.D.; Reginatto, V. Energy generation in a microbial fuel cell using anaerobic sludge from a wastewater treatment plant. *Sci. Agric.* **2016**, *73*, 424–428. [CrossRef]
257. Sonu, K. Generation of bio-electricity from sewage sludge using single chamber microbial fuel cell. *J. Environ. Sci. Public Health* **2017**, *1*, 68–74. [CrossRef]
258. Raad, N.K.; Farrokhi, F.; Mousavi, S.A.; Darvishi, P.; Mahmoudi, A. Simultaneous power generation and sewage sludge stabilization using an air cathode-mfcs. *Biomass Bioenergy* **2020**, *140*, 105642. [CrossRef]
259. Zhang, G.; Zhao, Q.; Jiao, Y.; Wang, K.; Lee, D.J.; Ren, N. Efficient electricity generation from sewage sludge using biocathode microbial fuel cell. *Water Res.* **2012**, *46*, 43–52. [CrossRef]
260. Zhang, Y.; Olias, L.G.; Kongjan, P.; Angelidaki, I. Submersible microbial fuel cell for electricity production from sewage sludge. *Water Sci. Technol.* **2011**, *64*, 50–55. [CrossRef]
261. Parkash, A.; Aziz, S.; Soomro, S.A. Utilization of sewage sludge for production of electricity using mediated salt bridge based dual chamber microbial fuel cell. *J. Bioprocess. Biotech.* **2015**, *5*, 1. [CrossRef]
262. Magotra, V.K.; Kumar, S.; Kang, T.W.; Inamdar, A.I.; Aqueel, A.T.; Im, H.; Ghodake, G.; Shinde, S.; Waghmode, D.P.; Jeon, H.C. Compost soil microbial fuel cell to generate power using urea as fuel. *Sci. Rep.* **2020**, *10*, 4154. [CrossRef] [PubMed]
263. Jiang, Y.B.; Zhong, W.H.; Han, C.; Deng, H. Characterization of electricity generated by soil in microbial fuel cells and the isolation of soil source exoelectrogenic bacteria. *Front. Microbiol.* **2016**, *7*, 1776. [CrossRef]
264. Wolinska, A.; Stepniewska, Z.; Bielecka, A.; Ciepielski, J. Bioelectricity production from soil using microbial fuel cells. *Appl. Biochem. Biotechnol.* **2014**, *173*, 2287–2296. [CrossRef] [PubMed]
265. Simeon, M.I.; Asoiro, F.U.; Aliyu, M.; Raji, O.A.; Freitag, R. Polarization and power density trends of a soil-based microbial fuel cell treated with human urine. *Int. J. Energy Res.* **2020**, *44*, 5968–5976. [CrossRef]
266. Fosso-Kankeu, E.; Marx, s.; Waanders, F.; Jacobs, V. Impact of soil type on electricity generation from a microbial fuel cell. In Proceedings of the 7th International Conference on Latest Trends in Engineering and Technology (ICLTET'2015), Irene, Pretoria, South Africa, 26–27 November 2015.
267. Sathyanarayanan, S.S.; Gariepy, Y.; Raghavan, V.G.S. Effect of soil types on nitrogen cycling and electricity production from microbial fuel cells with leaves. In Proceedings of the 4th International conference on Green Energy and Expo & 6th International Conference on Recycling, Reduce, Reuse, Recycle, Las Vegas, NV, USA, 6–8 November 2017.
268. Nguyen, H.-U.-D.; Nguyen, D.-T.; Taguchi, K. A novel design portable plugged-type soil microbial fuel cell for bioelectricity generation. *Energies* **2021**, *14*, 553. [CrossRef]
269. Prathipa, R. Production of electrical soil sources using microbial fuel energy. *J. Chem. Pharm. Sci.* **2015**, *7*, 338–340.
270. Cha, J.; Choi, S.; Yu, H.; Kim, H.; Kim, C. Directly applicable microbial fuel cells in aeration tank for wastewater treatment. *Bioelectrochemistry* **2010**, *78*, 72–79. [CrossRef]
271. Nastro, R.A.; Dumontet, S.; Ulgiati, S.; Falcucci, G.; Vadursi, M.; Jannelli, E.; Minutillo, M.; Cozzolino, R.; Trifuoggi, M.; Erme, G.; et al. Microbial fuel cells fed by solid organic waste: A preliminar experimental study. In Proceedings of the 5th European Fuel Cell Piero Lunghi Conference, Rome, Italy, 11–13 December 2013.
272. Rabaey, K.; Clauwaert, P.; Aelterman, P.; Verstraete, W. Tubular microbial fuel cells for efficient electricity generation. *Environ. Sci. Technol.* **2005**, *39*, 8077–8082. [CrossRef]
273. Min, B.; Logan, B.E. Continuous electricity generation from domestic wastewater and organic substrates in a flat plate microbial fuel cell. *Environ. Sci. Technol.* **2004**, *38*, 5809–5814. [CrossRef] [PubMed]
274. Hiegemann, H.; Littfinski, T.; Krimmler, S.; Lubken, M.; Klein, D.; Schmelz, K.G.; Ooms, K.; Pant, D.; Wichern, M. Performance and inorganic fouling of a submergible 255l prototype microbial fuel cell module during continuous long-term operation with real municipal wastewater under practical conditions. *Bioresour. Technol.* **2019**, *294*, 122227. [CrossRef] [PubMed]
275. Estrada-Arriaga, E.B.; Guillen-Alonso, Y.; Morales-Morales, C.; Garcia-Sanchez, L.; Bahena-Bahena, E.O.; Guadarrama-Perez, O.; Loyola-Morales, F. Performance of air-cathode stacked microbial fuel cells systems for wastewater treatment and electricity production. *Water Sci. Technol.* **2017**, *76*, 683–693. [CrossRef] [PubMed]
276. Chiu, H.Y.; Pai, T.Y.; Liu, M.H.; Chang, C.A.; Lo, F.C.; Chang, T.C.; Lo, H.M.; Chiang, C.F.; Chao, K.P.; Lo, W.Y.; et al. Electricity production from municipal solid waste using microbial fuel cells. *Waste Manag. Res.* **2016**, *34*, 619–629. [CrossRef] [PubMed]
277. Bolognesi, S.; Cecconet, D.; Callegari, A.; Capodaglio, A.G. Bioelectrochemical treatment of municipal solid waste landfill mature leachate and dairy wastewater as co-substrates. *Environ. Sci. Pollut. Res. Int.* **2021**, *28*, 24639–24649. [CrossRef] [PubMed]
278. Moqsud, M.A. Bioelectricity from organic solid waste. *Strateg. Sustain. Solid Waste Manag.* **2021**, *129*. [CrossRef]
279. Asai, Y.; Miyahara, M.; Kouzuma, A.; Watanabe, K. Comparative evaluation of wastewater-treatment microbial fuel cells in terms of organics removal, waste-sludge production, and electricity generation. *Bioresour. Bioprocess* **2017**, *4*, 30. [CrossRef] [PubMed]
280. Ye, Y.; Ngo, H.H.; Guo, W.; Chang, S.W.; Nguyen, D.D.; Liu, Y.; Ni, B.J.; Zhang, X. Microbial fuel cell for nutrient recovery and electricity generation from municipal wastewater under different ammonium concentrations. *Bioresour. Technol.* **2019**, *292*, 121992. [CrossRef] [PubMed]

281. Hiegemann, H.; Lubken, M.; Schulte, P.; Schmelz, K.G.; Gredigk-Hoffmann, S.; Wichern, M. Inhibition of microbial fuel cell operation for municipal wastewater treatment by impact loads of free ammonia in bench- and 45l-scale. *Sci. Total Environ.* **2018**, *624*, 34–39. [CrossRef]
282. Parkash, A. Utilization of different types of wastewater for production of electricity using non mediated microbial fuel cell. *MOJ Proteom. Bioinform* **2016**, *4*, 107. [CrossRef]
283. Du, H.; Guo, J.; Xu, Y.; Wu, Y.; Li, F.; Wu, H. Enhancing microbial fuel cell (mfc) performance in treatment of solid potato waste by mixed feeding of boiled potato and waste activated sludge. *Water Sci. Technol.* **2018**, *78*, 1054–1063. [CrossRef]
284. Tao, M.; Guan, L.; Jing, Z.; Tao, Z.; Wang, Y.; Luo, H.; Wang, Y. Enhanced denitrification and power generation of municipal wastewater treatment plants (wwtps) effluents with biomass in microbial fuel cell coupled with constructed wetland. *Sci. Total Environ.* **2020**, *709*, 136159. [CrossRef] [PubMed]
285. Damiano, L.; Jambeck, J.R.; Ringelberg, D.B. Municipal solid waste landfill leachate treatment and electricity production using microbial fuel cells. *Appl. Biochem. Biotechnol.* **2014**, *173*, 472–485. [CrossRef] [PubMed]
286. Toczylowska-Maminska, R.; Szymona, K.; Kloch, M. Bioelectricity production from wood hydrothermal-treatment wastewater: Enhanced power generation in mfc-fed mixed wastewaters. *Sci. Total Environ.* **2018**, *634*, 586–594. [CrossRef] [PubMed]
287. Liang, P.; Duan, R.; Jiang, Y.; Zhang, X.; Qiu, Y.; Huang, X. One-year operation of 1000-L modularized microbial fuel cell for municipal wastewater treatment. *Water Res.* **2018**, *141*, 1–8. [CrossRef] [PubMed]
288. Feng, Y.; He, W.; Liu, J.; Wang, X.; Qu, Y.; Ren, N. A horizontal plug flow and stackable pilot microbial fuel cell for municipal wastewater treatment. *Bioresour. Technol.* **2014**, *156*, 132–138. [CrossRef] [PubMed]
289. Lee, Y.; Oa, S.W. High speed municipal sewage treatment in microbial fuel cell integrated with anaerobic membrane filtration system. *Water Sci. Technol.* **2014**, *69*, 2548–2553. [CrossRef]
290. Akgul, V.; Cirik, K.; Duyar, A.; Koroglu, E.O. The effect of olive oil mill and molasses wastewater as a co-substrate during simultaneous textile wastewater treatment and energy generation. *Int. J. Glob. Warm.* **2021**, *23*, 30–42. [CrossRef]
291. Shah, H.; Patel, H.; Patel, K. Generation of bioelectricity using salt bridged two chambered mediator-less microbial fuel cell. *Adv. Environ. Biol.* **2016**, *10*, 53–59.
292. Xie, B.; Gong, W.; Ding, A.; Yu, H.; Qu, F.; Tang, X.; Yan, Z.; Li, G.; Liang, H. Microbial community composition and electricity generation in cattle manure slurry treatment using microbial fuel cells: Effects of inoculum addition. *Environ. Sci. Pollut. Res. Int.* **2017**, *24*, 23226–23235. [CrossRef]
293. Rojas Flores, S.; Naveda, R.N.; Paredes, E.A.; Orbegoso, J.A.; Céspedes, T.C.; Salvatierra, A.R.; Rodríguez, M.S. Agricultural wastes for electricity generation using microbial fuel cells. *Open Biotechnol. J.* **2020**, *14*, 52–58. [CrossRef]
294. Memon, A.R.; Aftab, A.; Shaikh, G.Y. Parametric effect during power generation from sewage sludge using prototype mfc. *Mehran Univ. Res. J. Eng. Technol.* **2015**, *34*, 116–120.
295. Parkash, A. Bio-electricity generation from different biomass using microbial fuel cell. *MOJ Proteom. Bioinform* **2016**, *3*, 124–127. [CrossRef]
296. Zhang, X.; Porcu, L.; Andresen, J.M. Sustainable energy from dairy farm waste using a microbial fuel cell (mfc). *World Renew. Energy Congr. 2011 Swed.* **2011**, *57*, 247–250.
297. Siddique, M.; Jatoi, A.S.; Soomro, S.A.; Mengal, A.N.; Ayat, M.; Mandokhail, S.J.; Khan, A. Effective utilization of cow dung with distillery waste water as substrate in microbial fuel cell for electricity generation. *J. Appl. Emerg. Sci.* **2019**, *8*, 138–145.
298. Vijay, A.; Vaishnava, M.; Chhabra, M. Microbial fuel cell assisted nitrate nitrogen removal using cow manure and soil. *Environ. Sci. Pollut. Res. Int.* **2016**, *23*, 7744–7756. [CrossRef]
299. Javed, M.M.; Nisar, M.A.; Ahmad, M.U. Effect of nacl and ph on bioelectricity production from vegetable waste extract supplemented with cane molasses in dual chamber microbial fuel cell. *Pak. J. Zool* **2021**, *54*, 247–254. [CrossRef]
300. Erenler, A.S. Comparison of usage potential of bulgur wastewater in microbial fuel cell technology with other industrial wastes. *Int. J. Math. Eng. Nat. Sci.* **2019**, *3*, 1–14.
301. Aderiye, I.J.B.; Adebule, P.A.; Odunayo, A.R. Electricity potentials and chemical components generation from kitchen waste, palm kernel waste, and cow dung in microbial fuel cells (mfcs). *Int. J. Eng. Sci. Comput.* **2019**, *9*, 21291–21296.
302. Gadhave, P.; Sasane, R.; Wagh, G.; Bhatt, N.; Sutar, P. Electricity generation from dairy farm wastes in a dual-chamber microbial fuel cell using aluminium electrodes. *Int. J. Recent Technol. Eng.* **2020**, *8*, 3345–3449. [CrossRef]
303. Saha, T.C.; Protity, A.T.; Zohora, F.T.; Shaha, M.; Ahmed, I.; Barua, E.; Salimullah, M.; Abu, H. Microbial fuel cell (mfc) application for generation of electricity from dumping rubbish and identification of potential electrogenic bacteria. *Adv. Ind. Biotechnol.* **2019**, *2*, 010.
304. Mise, S.R.; Mane, V.V. Treatment of blended wastewater using single chamber and double chambered mfc. *Int. J. Eng. Sci. Invent.* **2017**, *6*, 54–59.
305. Singh, P.; Srivastava, A.; Srivastava, N. Electricity optimization in microbial fuel cell of distillery wastewater, vermicompost and escherichia coli. *J. Sci. Ind. Res.* **2020**, *79*, 736–739.
306. Salar-Garcia, M.J.; Obata, O.; Kurt, H.; Chandran, K.; Greenman, J.; Ieropoulos, I.A. Impact of inoculum type on the microbial community and power performance of urine-fed microbial fuel cells. *Microorganisms* **2020**, *8*, 1921. [CrossRef] [PubMed]
307. Pendyala, B.; Chaganti, S.R.; Lalman, J.A.; Heath, D.D. Optimizing the performance of microbial fuel cells fed a combination of different synthetic organic fractions in municipal solid waste. *Waste Manag.* **2016**, *49*, 73–82. [CrossRef]
308. Sheikh, R.; Karmaker, S.; Solayman, M.; Mayna, J. Bioelectricity from anaerobic co-digestion of organic solid wastes and sewage sludge using microbial fuel cells (mfcs). *J. Sustain. Bioenergy Syst.* **2018**, *8*, 95–106. [CrossRef]

309. Kucbel, M.; Raclavska, H.; Ruzickova, J.; Svedova, B.; Sassmanova, V.; Drozdova, J.; Raclavsky, K.; Juchelkova, D. Properties of composts from household food waste produced in automatic composters. *J. Environ. Manag.* **2019**, *236*, 657–666. [CrossRef] [PubMed]
310. Yadav, M.; Goswami, P.; Paritosh, K.; Kumar, M.; Pareek, N.; Vivekanand, V. Seafood waste: A source for preparation of commercially employable chitin/chitosan materials. *Bioresour. Bioprocess.* **2019**, *6*, 8. [CrossRef]
311. Slavov, A.K. General characteristics and treatment possibilities of dairy wastewater—A review. *Food Technol. Biotechnol.* **2017**, *55*, 14–28. [CrossRef] [PubMed]
312. Qin, R. The characteristics of beer industrial wastewater and its influence on the environment. *IOP Conf. Ser. Earth Environ. Sci.* **2018**, *170*, 32068. [CrossRef]
313. Natural Resources Conservation Service. Chapter 4: Agricultural Waste Characteristics. In *Agricultural Waste Management Field Handbook Part 651*; United States Department of Agriculture: Washington, DC, USA, 2008; 210–VI–AWMFH.
314. Tuprakay, S.R.; Suksabye, P.; Menchai, P.; Tuprakay, S. The physical and chemical properties of solid waste from water tourism. *Case Study Taling Chan Float. Mark. Bangk. Thailand* **2014**, *1*, 103–111.
315. Gomes, C.C.; Lopes, M.d.L.C. Characterisation of municipal solid waste physical properties and their evolution with age. *Proc. Inst. Civ. Eng.-Geotech. Eng.* **2012**, *165*, 23–34. [CrossRef]
316. Santoro, C.; Arbizzani, C.; Erable, B.; Ieropoulos, I. Microbial fuel cells: From fundamentals to applications. A review. *J. Power Sources* **2017**, *356*, 225–244. [CrossRef] [PubMed]
317. Gajda, I.; Greenman, J.; Ieropoulos, I.A. Recent advancements in real-world microbial fuel cell applications. *Curr. Opin. Electrochem.* **2018**, *11*, 78–83. [CrossRef]
318. Petrovic, P.; Hossain, E. Development of a novel technological readiness assessment tool for fuel cell technology. *IEEE Access* **2020**, *8*, 132237–132252. [CrossRef]
319. Zhuang, L.; Zheng, Y.; Zhou, S.; Yuan, Y.; Yuan, H.; Chen, Y. Scalable microbial fuel cell (mfc) stack for continuous real wastewater treatment. *Bioresour. Technol.* **2012**, *106*, 82–88. [CrossRef]
320. Sudirjo, E.; de Jager, P.; Buisman, C.J.N.; Strik, D. Performance and long distance data acquisition via lora technology of a tubular plant microbial fuel cell located in a paddy field in west kalimantan, indonesia. *Sensors* **2019**, *19*, 4647. [CrossRef] [PubMed]
321. Ge, Z.; Wu, L.; Zhang, F.; He, Z. Energy extraction from a large-scale microbial fuel cell system treating municipal wastewater. *J. Power Sources* **2015**, *297*, 260–264. [CrossRef]
322. Zhuang, L.; Zhou, S. Substrate cross-conduction effect on the performance of serially connected microbial fuel cell stack. *Electrochem. Commun.* **2009**, *11*, 937–940. [CrossRef]
323. Camacho, J.V.; Vico, M.D.C.M.; Andrés, M.; Rodrigo, R.; Morales, F.J.F.; Cañizares, P.C. Energy production from wastewater using horizontal and vertical subsurface flow constructed wetlands. *Environ. Eng. Manag. J.* **2014**, *13*, 2517–2523. [CrossRef]
324. An, J.; Li, N.; Wan, L.; Zhou, L.; Du, Q.; Li, T.; Wang, X. Electric field induced salt precipitation into activated carbon air-cathode causes power decay in microbial fuel cells. *Water Res.* **2017**, *123*, 369–377. [CrossRef]
325. Kataki, S.; Chatterjee, S.; Vairale, M.G.; Sharma, S.; Dwivedi, S.K.; Gupta, D.K. Constructed wetland, an eco-technology for wastewater treatment: A review on various aspects of microbial fuel cell integration, low temperature strategies and life cycle impact of the technology. *Renew. Sustain. Energy Rev.* **2021**, *148*, 111261. [CrossRef]
326. Elhenawy, S.; Khraisheh, M.; AlMomani, F.; Al-Ghouti, M.; Hassan, M.K. From waste to watts: Updates on key applications of microbial fuel cells in wastewater treatment and energy production. *Sustainability* **2022**, *14*, 955. [CrossRef]
327. Joshi, S.J.; Sen, R.; Sharma, A.; Salam, P.A. *Status and Future Challenges for Nonconventional Energy Sources*; Springer: Berlin/Heidelberg, Germany, 2022; Volume 2.
328. Kretzschmar, J.; Riedl, S.; Brown, R.K.; Schröder, U.; Harnisch, F. Elatrine: Lessons learned from the development of a low-tech mfc based on cardboard electrodes for the treatment of human feces. *J. Electrochem. Soc.* **2016**, *164*, H3065–H3072. [CrossRef]
329. Ieropoulos, I.A.; Stinchcombe, A.; Gajda, I.; Forbes, S.; Merino-Jimenez, I.; Pasternak, G.; Sanchez-Herranz, D.; Greenman, J. Pee power urinal—Microbial fuel cell technology field trials in the context of sanitation. *Environ. Sci. Water Res. Technol.* **2016**, *2*, 336–343. [CrossRef]
330. Walter, X.A.; Merino-Jiménez, I.; Greenman, J.; Ieropoulos, I. Pee power® urinal ii—Urinal scale-up with microbial fuel cell scale-down for improved lighting. *J. Power Sources* **2018**, *392*, 150–158. [CrossRef] [PubMed]
331. Wang, H.; Park, J.-D.; Ren, Z.J. Practical energy harvesting for microbial fuel cells: A review. *Environ. Sci. Technol.* **2015**, *49*, 3267–3277. [CrossRef] [PubMed]
332. Santoro, C.; Soavi, F.; Serov, A.; Arbizzani, C.; Atanassov, P. Self-powered supercapacitive microbial fuel cell: The ultimate way of boosting and harvesting power. *Biosens. Bioelectron.* **2016**, *78*, 229–235. [CrossRef]
333. Li, H.; Tian, Y.; Zuo, W.; Zhang, J.; Pan, X.; Li, L.; Su, X. Electricity generation from food wastes and characteristics of organic matters in microbial fuel cell. *Bioresour. Technol.* **2016**, *205*, 104–110. [CrossRef]