Chapter 17
Valorization of Animal Waste for the Production of Sustainable Bioenergy

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Abstract The alarming rise in our dependency on fossil fuels like coal, oil, and natural gas has put these resources in a state of depletion. Due to the rapid industrialization and population growth, there is also an enormous growth in energy demand. Access to clean and green energy is crucial for the sustainable growth of human society in order to meet this steadily increasing demand. A possible alternative source for producing clean energy is biomass. One of the highly promising renewable energy options that lead to a more sustainable energy system is the use of animal waste (blood, bone, sludge, manure, lipids, and meat effluent). These wastes are rich in carbohydrates, proteins, and lipids. Animal wastes can contribute significantly to an appropriate waste management system since it does not endanger food security and minimize environmental impacts. The generation of bioenergy from animal waste is linked to reducing the generation of solid waste and its disposal on the land, specifically minimizing all risks and negative effects in all sectors during waste disposal. A sustainable bioenergy industry that improves fuel security covers the difficult issue of climatic change as well. In order to meet domestic demand and to export, intensification of animal waste conversion strategies to bioenergy (biogas, biodiesel, bio-alcohol, and bioelectricity) production is established. The energy-rich bioenergy is produced by the anaerobic digestion and fermentation processes, which also reduce pollution and global warming. In this chapter, we have explored the applications of animal waste as potential source to be used for sustainable energy production.

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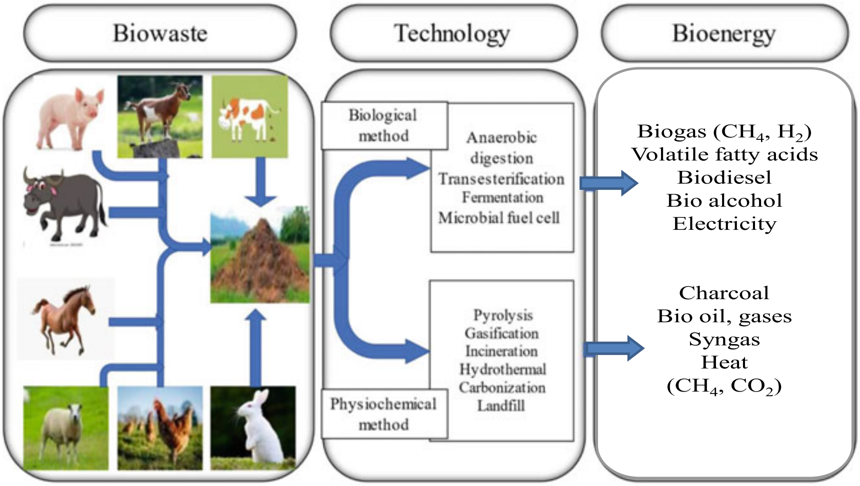
Graphical Abstract



Overall plan for producing bioenergy from various biowastes

Keywords Food waste · byproducts · Sustainable energy · Biogase

17.1 Introduction

Manure and other byproducts of meat processing are produced in massive amounts worldwide, especially on dairy and poultry farms in third-world nations (Zhu and Hiltunen 2016). The quantity of waste collected from farms typically varies depending on several factors including its type, size, age, diet, feeding, and reproductive practices (Khalil et al. 2019). For instance, estimates place the daily yields of animal manure from cattle (10–20 kg), sheep (2 kg), and chickens (0.1 kg), respectively (Kaygusuz 2002; Omrani 1996). Additionally, the above parameters can also affect the quantity of blood and rumen material. The average weight of large and small ruminants and poultry is 250 kg, 40 kg, and 1.5 kg, respectively (Abdeshahian et al. 2016; Afazeli et al. 2014). Blood and rumen usually make up about 8.4% and 12% of large ruminants (cattle and buffalo) body weight while small ruminants (goat and sheep) account for 3% and 25%, respectively. Numerous applications, including fuels, internal combustion energy generators, microturbines, fuel cells, etc., can directly utilize it. The animal waste from the meat processing industry is comprised of animal fat waste, bone, feathers, hair, meat, and skin, and these include a lot of organic stuff that generate odors and, if not treated, can serve as a medium for the growth of several pathogenic microorganisms. Its management is a significant issue for livestock producers. Animal farms frequently store it in a lagoon for future use as manure (Mathias 2014). Methane, one of the most dangerous pollutants to air than CO_2, is produced as a result of the natural decomposition process. Animal waste storage tank runoff has the potential to contaminate groundwater by penetrating the water table. Over the past decade, there has been an increase in the conversion of animal waste into biofuel, although this practice is still limited by the expense and maintenance of digesters (Gebrezgabher et al. 2010). The waste digestion capability, the amount of protein and fibrous matter, all affect the quality of animal feces. Garbage that contains between 20 and 25% solids is treated as such and is simple to stack and pick up with a loader, whereas semi-solid waste is processed as a liquid. Animal excreta makes an excellent starting point for the production of biogas since it already includes the majority of the necessary bacteria in a waste-to-energy technical process.

17.2 Effects of Animal Wastes

Wastes have a serious threat to the environment and pose a potential risk to human life. It leads to disease outbreaks, reduced life expectancy, and dangerous environments, which have an impact on both humans and animals. While some wastes might decay, those that do not produce methane gas, which greatly add to global warming and unpleasant odor. Wastes cause environmental pollution including land, water, and air pollution. Dust, smoke, and stink are the key elements of air pollution. Burning solid waste releases CO_2 and N_2O, which contribute to ozone layer depletion and the greenhouse effect (Bhat et al. 2018). Additionally, CH_4 and H_2S are released into the environment. These compounds are poisonous to living things. Polluted water is an additional undesirable impact of waste on the ecosystem. According to reports, 1400 individuals each day lose as a result of water-related illnesses and disorders (Khan et al. 2019). Water sources, such as springs, rivers, groundwater, streams, and oceans, are adversely affected by wastes by reducing pH levels and posing health risks to aquatic life and individuals who use this water. Among these contaminants, some are extremely hydrophilic and less water-soluble (Varjani et al. 2017). The use of receiving water that has been polluted by waste from one region could be permitted at another. Ineffective waste management may result in soil pollution. Wastes that are discarded carelessly breed disease-carrying vectors and are unsightly. Iron-derived metals, radioactive wastes, and other substances are dangerous to organisms and plants of soil habitat, which lowers crop yield (Mani and Kumar 2014). Mosquitoes thrive in stagnant bodies of water, clogged drains, tires where rainwater is collected, empty food containers, polythene bags, and other materials. The risks faced by the waste management force also include tissue injury, respiratory tract infections, wounds from glass, contaminated razor blades, and needles, in addition to parasitic diseases brought on by interaction with the waste on the skin (Alam and Ahmade 2013). Although workers wear safety gear including gloves and nasal masks, modern automated methods should be promoted to reduce the risk of waste treatment-related injuries to refuse workers. Langdon et al. (2019) conducted research on the risk evaluation of organic pollutants in composted solid municipal waste in Australia. Based on the potential effects on health, they can classify the risk levels in their study into low, moderate, and high priority. As a result, steps are taken to ensure that each of the waste's harmful components is disposed of safely and effectively. The study of the electronic waste impact on public health by Ayilara et al. (2020) revealed that the discharge of numerous toxic metals into the air causes air pollution and affects human health and the environment badly.

17.3 Protein from Animal Source

Furthermore, the meat industry consistently produces large amounts of byproducts that are unavoidable, such as wastewater that is frequently highly contaminated with chemicals and organic debris, as well as blood, skeletons, epidermis, hair, feathers, viscera, and hoofs. According to reports of Abdilova et al. (2021), Jayawardena et al. (2022), the worldwide production of meat byproducts is estimated to be at 52.6 million tons per year or 20% of total meat production. Although some metabolites are eatable and rich in nutrients including polypeptides, vitamins, essential amino acids, and minerals. Their consumption as human food for nourishment is waning and is still confined to a small number of limited regions (Baysal and Ülkü 2022). The improper disposal of meat byproducts potentially pollutes the surroundings and endanger human health by spreading encephalopathies. Its disposal is both difficult and expensive (Jayawardena et al. 2022). Due to these factors, considerable work has gone into creating procedures to effectively revalue some of these byproducts, which are highly proteinaceous, such as cartilage, blood, epidermis, and skeletons. A wide variety of products for human nutrition, bird and pet food, animal feed, and composts, as well as for the chemical, biomedical, and pharmacological uses, were developed as a result of these processes (Arvanitoyannis and Ladas 2008; Lynch et al. 2018; Shirsath and Henchion 2021; Toldrá et al. 2016, 2021).

17.3.1 Source of Collagen

The most prevalent protein in mammals and the principal component of numerous meat byproducts, such as skin, cartilage, and bones, is collagen. Collagen, which is made up of bundles of fibrillar structures, gives various bodily parts of living beings special mechanical strength and stability. Collagen-rich byproducts are instead valued for the isolation of bioactive amino acids due to collagen's poor nutritional summary and deficiency of important amino acids, which are predominantly made up of glycine, proline, and hydroxyproline (Shoulders and Raines 2009). Several purification techniques have been developed to efficiently separate this protein from many byproducts so that it is used in food applications, cosmetics, and biomedicine to benefit from its technologically functional properties. This protein can also be used in partially hydrolyzed forms, such as in gelatin (Cao et al. 2021; Gómez-Guillén et al. 2011; Jayawardena et al. 2022; Lynch et al. 2018; Toldrá et al. 2016, 2021).

Although the amount of blood produced globally is not known, this byproduct, estimated to be produced at 2.5 billion liters annually, contains enough protein to satisfy the needs of nearly 17 million people. The potential of this waste is not being fully realized because only 4% of these proteins are valued for human use. Different industrial uses of blood for value-added products include coloring agents in textiles, a spray adjuvant, and fertilizer. In addition, it is also utilized for animal and human nutritional and pharmaceutical applications. Proteins account for 35% and 8% of the quantities of red blood cells, which make up 40% of blood, and plasma, which makes up 60% of blood. Up to 60% of the protein in plasma is made up of albumin, which is the most common protein in the body. When purified, albumin is a valuable component for use in medical applications because it stabilizes vaccines, tests for antibiotic sensitivity, and Rh factor evaluations (Toldrà et al. 2019).

17.3.2 Source of Keratin

Hair, nails, hooves, and feathers are among the byproducts which are often exceptionally rich in keratin but are hardly used as food ingredients due to their poor nutritional value and limited digestibility. Keratin's filamentous structure, which is similar to collagen and is characterized by strong power and chemical strength, confers extraordinary resistance to most physical and biological mediators (Bragulla and Homberger 2009). Annually, 40 million tons of keratin-rich trash are generated, posing waste management issues due to a shortage of suitable dumping techniques (Tesfaye et al. 2017). Conventional keratin waste incineration secretes hazardous gases which are ironic in sulfur because of the high level of cysteine, whereas a high amount of disulfide cross-linking and condensed structures causes delayed biodegradation rates, increasing these slow-degrading byproducts and so posing unmanageable issue for the atmosphere and human health worldwide (Korniłłowicz-Kowalska and Bohacz 2011; Peng et al. 2020).

Due to the little digestibility of keratinous constituents, hydrolysis procedures are employed for the creation of soluble peptides or amino acids for human and animal diets, or as useable fertilizer. Pure keratin extracts possess numerous uses in biotechnology, cosmetics, dermatology, and medicine as biocompatible materials such as sponges, fibers, and microcapsules after treatment. On the other hand, the mentioned approaches to recover the protein are expensive and unproductive till now, and hence, long-term solutions to valorize these byproducts are immediately required. Various organs and glands are counted edible in various parts of the world, although their use for human ingesting is still limited (Chojnacka et al. 2011; Holkar et al. 2018; Reddy et al. 2021). They do, however, supply valuable pharmacological substances in a few circumstances, like melatonin from the pineal gland, heparin from liver, insulin from the pancreas, and estrogen and progesterone hormones from the ovaries (Nollet and Toldrá 2011).

To repurpose leftover meat parts, interpreting is used for removing fat from solid animal waste at high temperatures, resulting in edible fats like lard and tallow (Jayathilakan et al. 2012). Collagen and gelatin are isolated and extracted from the residual insoluble meal using diluted citric acid, hydrothermal treatments, and enzymes that involve high pressure and temperature; other tissue proteins, like myofibrillar proteins, are extracted using a base, salt, acid, and biological catalyst (enzymes) (Dhillon 2016; Jayathilakan et al. 2012). Process effluents not only contain significant amounts of solid waste, but they also contain sufficient amounts of blood and muscle proteins, which are possibly recovered using isoelectric precipitation after NaOH solubilization (Bethi et al. 2020; Lynch et al. 2018; Mokrejs et al. 2009).

Keratin extraction is problematic because of its resistance to disintegration via conventional solvents. Although tough extraction conditions involving strong acids and base, sodium sulfide, and reducing mediators help disturb the condensed structure of keratin and assisting dissolving, their use is limited due to the hazardous nature of such substances (Bethi et al. 2020; Vineis et al. 2019). Aqueous extraction employing catalysts, microwave-assisted extraction, reducing agents, ionic liquids, steam flash explosion, and enzymes are some other less harmful extraction techniques that have been researched (Ji et al. 2014; Plowman et al. 2014; Pourjavaheri et al. 2019; Shavandi et al. 2017; Sinkiewicz et al. 2017). By the process of high-temperature hydrolysis with base and acid or microorganism treatment, the marketable extraction of keratin results in keratin hydrolysates, afterward that are employed in hair conditioning and care products and leather bronzing (Karthikeyan et al. 2007; Shah et al. 2019).

17.3.3 Source of Gelatin

Mammalian gelatin represents more than 90% of the market share for all types of gelatin (Usman et al. 2022). Animal collagen is partially hydrolyzed to produce it. White connective tissues found in bones, muscles, and skin are primarily made up of collagen. It is a protein that is present in tissues and organs and makes up about 30% of all proteins. The primary components of collagen are found in significant amounts and include proline, glycine, and hydroxyproline amino acids. Water does not mix with gelatin, but it does with collagen. Three structural modifications are made during the conversion: (1) the breaking up of large peptide chains into smaller ones, (2) the breaking up of bonds between chains, and (3) the configuration of the peptide chain. To produce gelatin, unwanted materials like lipids and minerals must be removed because they could prevent the extraction of gelatin (Boran and Regenstein 2010).

It is primarily connective tissue protein and is widely found in mammals, birds, and fishes (Eysturskarð et al. 2009). Although pigskin is the main source of gelatin, other sources also help to provide the necessary conditions for gelatin synthesis (Boran and Regenstein 2010; Sai-Ut et al. 2012). Bovine skin (29.4%) and pork, as well as cattle bones (23.1%), all contribute to the formation of gelatin, which contains around 46% porcine (23.1%) (Gómez-Guillén et al. 2011). The alternatives to porcine gelatin have received great demand (Morrison et al. 1999). Furthermore, compared to bovine and porcine gelatin, fish gelatin also has a small market share (Choi and Regenstein 2000). However, a sizable number of scientific research are already accessible that suggest gelatin obtained from aquatic sources has superior film-forming characteristics to that of mammals (Avena-Bustillos et al. 2011). Fish gelatin was also noted to have strong sensory attribute-releasing qualities with a low melting point (Aewsiri et al. 2009). Gelatin from Halal sources thus became a crucial problem. Contrarily, gelatin generated from sources such as poultry, animals (which are regarded as Halal and slaughtered following Islamic law), and particularly marine sources, are approved as Halal and might be a viable replacement for swine gelatin (Bhat and Karim 2009).

According to the literature, 15% of edible gelatin comes from bovine hides and 80% comes from pigskins. Bovine and porcine materials, such as pig bones, pigskins, bovine bones, and hides, are the main raw materials used to manufacture gelatin on a large scale. These constituents are employed in the production of gelatin-based products on a large scale, including gelatin sheets, granules, and powder (Peters 2006). Gelatin's foaming, emulsifying, setting, and water-holding capacities are some of its further useful properties. Having it is unique gelling, stabilizing, healing, ointment, capsule, and coating properties, gelatin is also the most widely utilized biodegradable ingredient in the commercial food processing, pharmaceutical, and photography industries (Rakhmanova et al. 2018). Tons of gelatin are reportedly utilized yearly in bread goods, ice cream, meat, candy, and desserts (Djagny et al. 2001; Poppe 1992). Additionally, during cold storage, the gelatin prevents lactose sugar from recrystallizing (Jamilah and Harvinder 2002). A survey claims that the pharmaceutical business uses about 6% of all gelatin produced. It is used in the pharmaceutical business to create hard and soft capsule shells, tablets, granulation, and syrups since it acts as a natural coating material (Hidaka and Liu 2003). Gelatin is a crucial ingredient in energy drinks and plays a significant role in the synthesis of these beverages for athletes in the sports field (Phillips & Williams, 2011). After applying gelatin to a glass plate containing the sensitizing agent, it was first employed in photography in 1871. It is frequently used in the formulations of shampoo, lipstick, conditioner, cream, and fingernail products cosmetics industry.

17.4 Bioenergy Generation from Animal Wastes

17.4.1 Biogas Production via Animal Waste

One of the best choices for addressing the growing worldwide energy consumption is the conversion of waste into energy by different technologies, such as the generation of biogas. Biogas is among the alternative renewable energy resource that are utilized to replace other nonrenewable fuels in countryside regions, notably in developing nations in Asia and Africa, to conserve energy. It is a clean, effective, and sustainable source of energy. In the year 2006, biogas production was approximately 62 billion kWh in Europe, whereas Germany produced about 4300 plants producing 1600 MW of power (Rohstoffe eV 2009). The two leading Asian nations utilizing biogas technology are India and China. In the majority of emerging Asian and African nations, biogas production is mostly used for home applications (Sorathiya et al. 2014).

The production of biogas is also desired; subsequently, the solid waste product (digestate) is able to be utilized as a natural fertilizer or a substrate for growing plants in greenhouses. Anaerobic digestion (AD), often known as the production of biogas, is this process in which organic materials are broken down by microorganisms in an anoxic environment (Adekunle and Okolie 2015). This procedure often results in the creation of biogas mixes that primarily contain CH_4 (60%) and CO_2 (35–40%), with the presence of other gases like H_2, NH_3, and H_2S (dependent on the composition and source of used organic matter) (Zupančič and Grilc 2012). Approximately, 0.75–0.8 $m^3$of biogas can provide 1 unit (1 kWA) of power and a 10 kVA generator, which, if run for 8 h, may produce 80–90 units. It has been reports that the Biogas-based Power Generation Program (BPGP) is the primary strategy in India for generating biogas power, with 73 projects established with a total capacity of 461 kW (Buragohain 2012). Germany possess 7320 electricity-generating biogas plants with a combined capacity of 2997 MW, accounting for 13% of all renewable energy sources (Markard et al. 2016). Indonesia can produce 684.83 Mw of power from biogas like other Asian nations (Widodo and Hendriadi 2005). Although China has started to establish biogas-based power plants, just 3% of them were producing electricity as of 2012. They have tested biogas power units with a day-to-day capacity of 18,000–60,000 kWh based on chicken and calf waste (Fig. 17.1) (Chen et al. 2012). Many nations have already begun using biogas to generate electricity.

The production of algal biomass is achieved by thermo-chemical transformation procedures from livestock waste (Cantrell et al. 2008) and anaerobic digestion (Vijay

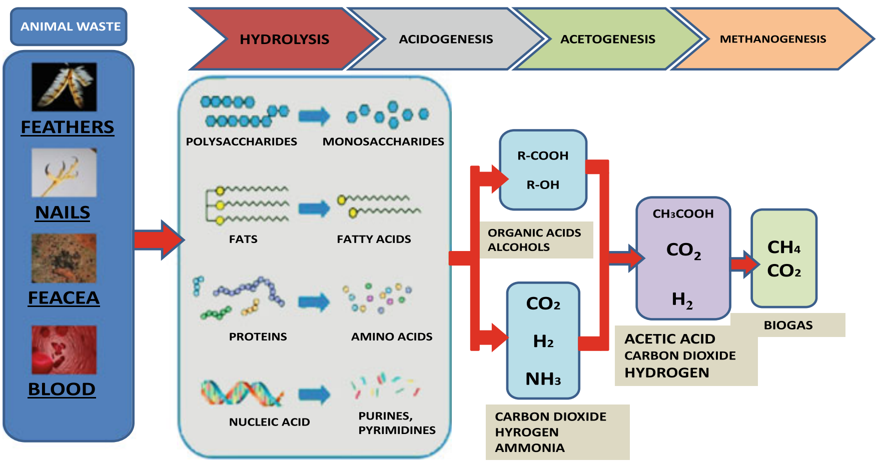


Fig. 17.1 Biogas production process

Table 17.1 Biogas generation from different animal wastes

Substrate	Biogas l/Kg	Methane l/Kg
Anaerobic digestion		
Cattle slaughterhouse waste	–	641
Animal waste	0.45	–
Chicken manure	1.08	–
Cattle manure	12.1	184
Swine slurry	–	394
Poultry slaughterhouse waste	–	595
Chicken droppings	4.6	438
Anaerobic co-digestion		
Cattle excreta	1.1	179
Cattle manure	2.4	620
Sheep dung	–	199

2011), both of which require carbon dioxide as a primary constituent of the produced gases. In addition to producing algal biomass and intracellular oil, algae possibly use carbon dioxide 10 times more effectively than land plants (Miao and Wu 2006). The growth of algae offers several advantages, including quick biomass production rates of about 50 metric tons per acre per annum (Demirbaş 2001), a high accumulation of fatty acids and hydrocarbons, and the potential to contribute to waste treatment. Bio-oil is one of the many products with added value that are made from these algal products. Therefore, it is a very potential non-crop-based raw material for the manufacturing of biofuel. In a pond nourished with biogas slurry that included 200 gm^3 of total nitrogen and 2.5 gm^3 of total dissolved phosphorus, 6.83 gm^3 of algal biomass productivity per day was noted (Table 17.1; Fig. 17.1) (Chen et al. 2012).

17.4.2 Biodiesel from Animal Fat Waste (AFW)

Three long-chain fatty acids and glycerol combine to form the triacylglycerol (TAG) that constitutes AFW. Due to their high viscosity, these fats cannot be used as motor fuel directly. Pretreatment is essential because AFW contains free fatty acids from the leather industry, meat processing industry, and slaughterhouses that affect the transesterification process (Adewale et al. 2015). Similar to the technique used to make biodiesel from fat from other feedstocks, transesterification is used to process the derived fat further. Numerous research organizations have provided evidence of the successful production of biodiesel from a variety of animal fats, including beef tallow, pig lard, chicken, fish, and sheep (Alptekin et al. 2014; Mata et al. 2014). Kwon et al. (2012) recorded a unique technique for producing biodiesel from animal fat utilizing charcoal, and CO_2 at ambient pressure achieves a biodiesel conversion efficiency of 98.5% in one minute at 350–500 °C. Free fatty acids (FFAs) affect biodiesel production and transesterification, therefore, Shi et al. (2013) designed an integrated catalytic process to convert chicken fat into biodiesel. Using a membrane catalytic reactor, biodiesel is created from the free fatty acids in chicken fat via esterification with methanol, and the resulting oil is then put through transesterification with sodium methoxide. Animal cells require additional pretreatment because of their high levels of protein and phosphoacylglycerols, therefore, using animal flesh as feedstock has certain drawbacks as well.

17.4.3 Bioelectricity from Animal Waste

Microbial fuel cells (MFCs) are anaerobic bioreactors where microorganisms consume organic waste carbon to transform chemical energy into electrical energy (Chen et al. 2018; Santoro et al. 2017). Additionally, MFCs are utilized to generate power from biowaste as a raw material. An MFC's cathode and anode (electrodes) are separated from one another by a membrane or salt bridge. When microbes decompose organic matter for growth and reproduction, a range of intermediates is produced that undergo several oxidation and reduction reactions and produce electrons and protons (Pant et al. 2016; Roy et al. 2016). Under anaerobic conditions, microbes might provide a redox mediator with electrons, and the redox mediator might subsequently oxidize the electrons to transmit them to electrodes (Ucar et al. 2017). Following its passage through an external circuit, an electron is transmitted to an electrode and diffuses through the solution to the cathodic chamber, where it combines with oxygen to synthesize water (Angelaalincy et al. 2018). The anodic chamber's potential drops as the substrate is being oxidized, and this causes a potential difference between electrodes, which produces current (Rahimnejad et al. 2015) (Fig. 17.2).

The two primary MFC designs for electricity production are single-chamber and double-chamber. A single-chamber MFC contains the waste as well as the electrodes

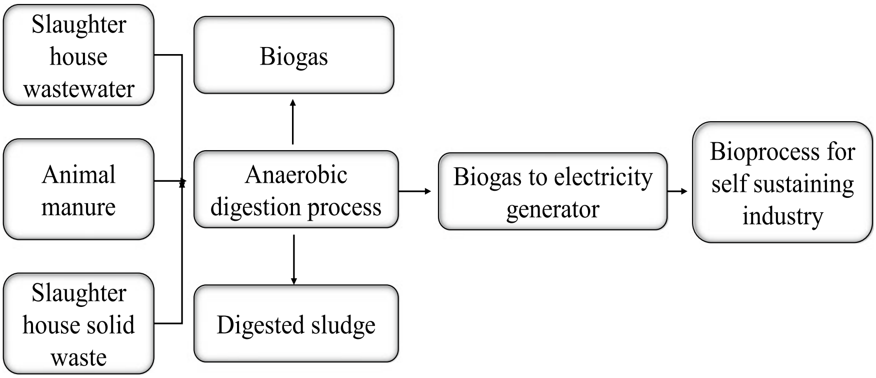


Fig. 17.2 BioElectricity generation from animal waste

Fig. 17.3 Sawdust layer on compost

in one chamber. Independent anodic and cathodic chambers make up a double-chamber MFC. Water is present in the cathodic chamber, while wastewater is present in the anodic chamber. A salt bridge connects the chambers, and a multimeter is used to gage the current. The substrate and microorganisms utilized in the MFC affect the current generated (Luo et al. 2017; Oyiwona et al. 2018; Pandey et al. 2016). MFCs heavily rely on the electron transfer mechanism, which comes in two primary flavors: direct electron transfer (DET) and mediated electron transfer (MET) (Islam, 2016; Sayed et al. 2015). While MET is carried out using an agent that can transport electrons, DET is carried out using nanowires or transmembrane-associated proteins (Fig. 17.3) (TerAvest et al. 2014).

There have been reports of many bacterial species producing electricity in an MFC, including *Aeromonas, E. coli, S. cerevisiae, C. albicans, Clostridium, K. pneumonia, and Shewanella* (Bhatia et al. 2018). The effectiveness of MFCs has been observed to be increased by some electron mediators, including potassium ferricyanide ($K_3Fe(CN)_6$) and natural redox (Sund et al. 2007). Exogenous mediators are used to enhance an MFC's performance; however, they are poisonous, may prevent microbial development, and raise costs. To address this issue, Islam et al. (2018) explored a method by using palm oil mill effluent as a raw material to co-culture both *L. starkeyi* and *K. pneumonia* bacteria in an anodic chamber. In contrast to a pure culture, an electron shuttle mediator was developed by *K. pneumonia* (2, 6 di-tert-butyl benzoquinone) that improved *L. starkeyi* performance by six times. Due to its limited ability to produce current, an MFC remains an impractical method for producing bioelectricity. Additionally, because mesophilic bacteria catalyze the majority of processes, this method requires a lower temperature.

17.5 Compost

Compost, a carbon-rich fertilizer used to enrich soils, is made from organic materials such as livestock manures and other organic components. A properly composted manure has a humus-like odor. Pathogens and weed seeds are eliminated from it by the heating process during the compost formation. Composting is a useful method for properly recycling deceased animals, but it can also leave behind feathers, teeth, and bone fragments that are removed mechanically if necessary. By composting dead birds according to a certain technique, the poultry sector in the United States has discovered a solution to dispose of that waste (Morrow and Ferket 1993). Due to the poultry sector's success in this region, the US pig business is becoming increasingly interested in starting to compost its mortalities (Kashmanian and Rynk 1995). Pig carcasses are composted over a concrete floor in containers made of treated wood, concrete, or hay bales (McCaskey et al. 1996). The corpses are laid on top of a layer of sawdust that is one foot thick, which is then one foot thick on all sides. Layers are added until the bin is full. When dealing with huge sows, the carcasses can either be composted whole or dismembered (Morrow et al. 1995).

The compost is churned manually or automatically after three months, and then, the process is finished after another three months (Imbeah 1998). The compost is not turned constantly when static-pile composting is utilized. Within 24 h of death, animal corpses are placed in a compost pile and covered with a significant amount of solid manure or dirt. Composting technique is carried out to prevent unpleasant smells, flies, and other animals (Morrow and Ferket 2001). On the other hand, this technique should not be done with deceased animals which are previously infected with neurological disorders such as cow-made disease, anthrax, and other ailments that are isolated in restrain (Belay et al. 2002). In India, pile composting is the most used method. The NADEP method is another composting technique that has been shown to provide more significant nutrients than the traditional method (Yadav 2012). In Japan, composting is primarily used for livestock waste. Composting was used to treat about 50% and 25%, respectively, of the solid waste produced by pigs and cattle. Additionally, in Japan, liquid composting was applied to 2.1% and 6.9% of the waste from pigs and cattle, respectively (Haga 1999). In Japan, there are primarily five different types of composting systems in use: piles, boxes, rotary kilns, closed vertical types, and open elongated types with turning devices. The open elongated and pile type are primarily used for large ruminants. In affluent nations, since a lot of water is used to collect pig feces, making composting is a challenging procedure. The manure's composting qualities will be improved via solids separation. It has been effective to compost separated pig manure containing 79% moisture (Lo et al. 1993). Composting high-moisture manure was proposed to be done with low-moisture bulking materials such as straw, sawdust, peat, peanut shells, and rice hulls (Georgacakis et al. 1996).

17.6 Conclusion and Future Perspectives

According to estimates, the millions of tons of animal waste produced worldwide have the potential to harm the environment by emitting CO_2. As a result, the conversion of animal waste can reduce greenhouse gas emissions, which in turn helps to prevent global warming and climatic change, and control environmental pollution. The use of animal waste does come with some challenges that call for additional research to develop trustworthy, widely used, and efficient conversion procedures. These challenges are brought on by high-moisture content, complicated combinations of changeable compositions, and poor waste management. It was discovered that anaerobic digestion was the most developed technology for processing manure into renewable energy. However, the overall growth of this technology in rural parts of developing countries was hampered by problems such as high capital costs, poor working conditions, manure transportation, and digestate management (Khoshnevisan et al. 2021). Literature indicated that to address the aforementioned issues and manage liquid and solid livestock wastes following the objectives of the circular bioeconomy and sustainable development principles, biorefinery is the best option. The implementation of biological treatments is fairly easy and requires little upfront investment. Their drawbacks include a lengthy (15–30 day) processing period and a tendency for bacterial inhibition when exposed to pollutants found in food waste. Additionally, these treatment procedures could need a pretreatment. Biological treatments are very easy to adopt and need little upfront investment. They do, however, have drawbacks, such as a lengthy (15–30 day) processing period and a propensity to restrict bacterial growth when exposed to toxins found in waste. Additionally, pretreatments are necessary for various procedures. The bacteria used in anaerobic digestion are extremely sensitive to pH, temperature, and salts. Hazardous chemicals formed during the reactions, mandating policies concerning control measures, and process condition optimization (Pham et al. 2015). Without any additional cleaning, biogas is often utilized to generate heat and, ultimately, electricity. Biogas must be upgraded if it is to be utilized for other purposes, such as fuel for cars and fuel cells. The conversion methods that can transform biogas into high-value compounds are focused on by many researchers. These chemicals could be produced by converting methane (from biogas) into syngas, which could then be utilized as a raw material to produce other chemicals with a high value-added. Future study is required to ensure the successful application of animal manure management from a technological, ecological, agricultural, commercial, and interpersonal safety point of view.

References

Abdeshahian P, Lim JS, Ho WS, Hashim H, Lee CT (2016) Potential of biogas production from farm animal waste in Malaysia. Renew Sustain Energy Rev 60:714–723

Abdilova G, Rebezov M, Nesterenko A, Safronov S, Knysh I, Ivanova I, Mikolaychik I, Morozova L (2021) Characteristics of meat by-products: nutritional and biological value. Int J Modern Agric 10(2):3895–3904

Adekunle KF, Okolie JA (2015) A review of biochemical process of anaerobic digestion. Adv Biosci Biotechnol 6(03):205

Adewale P, Dumont M-J, Ngadi M (2015) Recent trends of biodiesel production from animal fat wastes and associated production techniques. Renew Sustain Energy Rev 45:574–588

Aewsiri T, Benjakul S, Visessanguan W, Eun J-B, Wierenga PA, Gruppen H (2009) Antioxidative activity and emulsifying properties of cuttlefish skin gelatin modified by oxidised phenolic compounds. Food Chem 117(1):160–168

Afazeli H, Jafari A, Rafiee S, Nosrati M (2014) An investigation of biogas production potential from livestock and slaughterhouse wastes. Renew Sustain Energy Rev 34:380–386

Alam P, Ahmade K (2013) Impact of solid waste on health and the environment. Int J Sustain Dev Green Econ (IJSDGE) 2(1):165–168

Alptekin E, Canakci M, Sanli H (2014) Biodiesel production from vegetable oil and waste animal fats in a pilot plant. Waste Manage 34(11):2146–2154

Angelaalincy MJ, Navanietha Krishnaraj R, Shakambari G, Ashokkumar B, Kathiresan S, Varalakshmi P (2018) Biofilm engineering approaches for improving the performance of microbial fuel cells and bioelectrochemical systems. Front Energy Res 6:63

Arvanitoyannis IS, Ladas D (2008) Meat waste treatment methods and potential uses. Int J Food Sci Technol 43(3):543–559

Avena-Bustillos R, Chiou B-S, Olsen C, Bechtel P, Olson D, McHugh T (2011) Gelation, oxygen permeability, and mechanical properties of mammalian and fish gelatin films. J Food Sci 76(7):E519–E524

Ayilara MS, Olanrewaju OS, Babalola OO, Odeyemi O (2020) Waste management through composting: challenges and potentials. Sustainability 12(11):4456

Baysal SS, Ülkü MA (2022) Food loss and waste: a sustainable supply chain perspective. In: Disruptive technologies and eco-innovation for sustainable development, pp 90–108

Belay A, Claassens A, Wehner F (2002) Effect of direct nitrogen and potassium and residual phosphorus fertilizers on soil chemical properties, microbial components and maize yield under long-term crop rotation. Biol Fertil Soils 35(6):420–427

Bethi C, Narayan B, Martin A, Kudre TG (2020) Recovery, physicochemical and functional characteristics of proteins from different meat processing wastewater streams. Environ Sci Pollut Res 27(20):25119–25131

Bhat R, Karim A (2009) Ultraviolet irradiation improves gel strength of fish gelatin. Food Chem 113(4):1160–1164

Bhat RA, Dar SA, Dar DA, Dar GH (2018) Municipal solid waste generation and current scenario of its management in India. Int J Adv Res Sci Eng 7(02):419–431

Bhatia SK, Joo H-S, Yang Y-H (2018) Biowaste-to-bioenergy using biological methods–a mini-review. Energy Convers Manage 177:640–660

Boran G, Regenstein JM (2010) Fish gelatin. Adv Food Nutr Res 60:119–143

Bragulla HH, Homberger DG (2009) Structure and functions of keratin proteins in simple, stratified, keratinized and cornified epithelia. J Anat 214(4):516–559

Buragohain T (2012) Impact of solar energy in rural development in India. Int J Environ Sci Dev 3(4):334

Cantrell KB, Ducey T, Ro KS, Hunt PG (2008) Livestock waste-to-bioenergy generation opportunities. Biores Technol 99(17):7941–7953

Cao C, Xiao Z, Ge C, Wu Y (2021) Animal by-products collagen and derived peptide, as important components of innovative sustainable food systems—A comprehensive review. Crit Rev Food Sci Nutrit, pp 1–25

Chen R, Li R, Deitz L, Liu Y, Stevenson RJ, Liao W (2012) Freshwater algal cultivation with animal waste for nutrient removal and biomass production. Biomass Bioenerg 39:128–138

Chen S, Patil SA, Schröder U (2018) A high-performance rotating graphite fiber brush air-cathode for microbial fuel cells. Appl Energy 211:1089–1094

Choi SS, Regenstein J (2000) Physicochemical and sensory characteristics of fish gelatin. J Food Sci 65(2):194–199

Chojnacka K, Górecka H, Michalak I, Górecki H (2011) A review: valorization of keratinous materials. Waste Biomass Valorization 2(3):317–321

Demirbaş A (2001) Biomass resource facilities and biomass conversion processing for fuels and chemicals. Energy Convers Manage 42(11):1357–1378

Dhillon GS (2016) Protein byproducts: transformation from environmental burden into value-added products. Academic Press

Djagny KB, Wang Z, Xu S (2001) Gelatin: a valuable protein for food and pharmaceutical industries. Crit Rev Food Sci Nutr 41(6):481–492

Eysturskarð J, Haug IJ, Elharfaoui N, Djabourov M, Draget KI (2009) Structural and mechanical properties of fish gelatin as a function of extraction conditions. Food Hydrocolloids 23(7):1702–1711

Gebrezgabher SA, Meuwissen MP, Prins BA, Lansink AGO (2010) Economic analysis of anaerobic digestion—A case of Green power biogas plant in The Netherlands. NJAS Wageningen J Life Sci 57(2):109–115

Georgacakis D, Tsavdaris A, Bakouli J, Symeonidis S (1996) Composting solid swine manure and lignite mixtures with selected plant residues. Biores Technol 56(2–3):195–200

Gómez-Guillén MC, Giménez B, López-Caballero MA, Montero MP (2011) Functional and bioactive properties of collagen and gelatin from alternative sources: a review. Food Hydrocolloids 25(8):1813–1827

Haga K (1999) Development of composting technology in animal waste treatment-review. Asian Australas J Anim Sci 12(4):604–606

Hidaka S, Liu S (2003) Effects of gelatins on calcium phosphate precipitation: a possible application for distinguishing bovine bone gelatin from porcine skin gelatin. J Food Compos Anal 16(4):477–483

Holkar CR, Jain SS, Jadhav AJ, Pinjari DV (2018) Valorization of keratin based waste. Process Saf Environ Prot 115:85–98

Imbeah M (1998) Composting piggery waste: a review. Biores Technol 63(3):197–203

Islam MA, Ethiraj B, Cheng CK, Yousuf A, Thiruvenkadam S, Prasad R, Rahman Khan MM (2018) Enhanced current generation using mutualistic interaction of yeast-bacterial coculture in dual chamber microbial fuel cell. Ind Eng Chem Res 57(3):813–821

Islam K (2016) Municipal solid waste to energy generation in Bangladesh: possible scenarios to generate renewable electricity in Dhaka and Chittagong city. J Renew Energy

Jamilah B, Harvinder K (2002) Properties of gelatins from skins of fish—black tilapia (Oreochromis mossambicus) and red tilapia (Oreochromis nilotica). Food Chem 77(1):81–84

Jayathilakan K, Sultana K, Radhakrishna K, Bawa A (2012) Utilization of byproducts and waste materials from meat, poultry and fish processing industries: a review. J Food Sci Technol 49(3):278–293

Jayawardena R, Morton JD, Brennan CS, Bhat ZF, Bekhit AE-DA (2022) Meat co-products. In: Alternative proteins. CRC Press, pp 329–359

Ji Y, Chen J, Lv J, Li Z, Xing L, Ding S (2014) Extraction of keratin with ionic liquids from poultry feather. Sep Purif Technol 132:577–583

Karthikeyan R, Balaji S, Sehgal P (2007) Industrial applications of keratins–a review

Kashmanian RM, Rynk RF (1995) Agricultural composting in the United States. Compost Sci Utilization 3(3):84–88

Kaygusuz K (2002) Renewable and sustainable energy use in Turkey: a review. Renew Sustain Energy Rev 6(4):339–366

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

KhanSA, Suleman M, Asad M (2019) Assessment of pollution load in marble waste water in Khairabad, District Nowshera, Khyber Pukhtunkhwa, Pakistan. Int J Econ Environ Geol, pp 35–39

Khoshnevisan B, Duan N, Tsapekos P, Awasthi MK, Liu Z, Mohammadi A, Angelidaki I, Tsang DC, Zhang Z, Pan J, Ma L (2021) A critical review on livestock manure biorefinery technologies: sustainability, challenges, and future perspectives. Renew Sustain Energy Rev 135:110033

Korniłłowicz-Kowalska T, Bohacz J (2011) Biodegradation of keratin waste: theory and practical aspects. Waste Manage 31(8):1689–1701

Kwon EE, Seo J, Yi H (2012) Transforming animal fats into biodiesel using charcoal and CO_2. Green Chem 14(6):1799–1804

Langdon KA, Chandra A, Bowles K, Symons A, Pablo F, Osborne K (2019) A preliminary ecological and human health risk assessment for organic contaminants in composted municipal solid waste generated in New South Wales, Australia. Waste Manage 100:199–207

Lo K, Lau A, Liao P (1993) Composting of separated solid swine wastes. J Agric Eng Res 54(4):307–317

Luo H, Xu G, Lu Y, Liu G, Zhang R, Li X, Zheng X, Yu M (2017) Electricity generation in a microbial fuel cell using yogurt wastewater under alkaline conditions. RSC Adv 7(52):32826–32832

Lynch SA, Mullen AM, O'Neill E, Drummond L, Álvarez C (2018) Opportunities and perspectives for utilisation of co-products in the meat industry. Meat Sci 144:62–73

Mani D, Kumar C (2014) Biotechnological advances in bioremediation of heavy metals contaminated ecosystems: an overview with special reference to phytoremediation. Int J Environ Sci Technol 11(3):843–872

Markard J, Wirth S, Truffer B (2016) Institutional dynamics and technology legitimacy–A framework and a case study on biogas technology. Res Policy 45(1):330–344

Mata TM, Mendes AM, Caetano NS, Martins AA (2014) Properties and sustainability of biodiesel from animal fats and fish oil. Chem Eng Trans 38:175–180

Mathias JFCM (2014) Manure as a resource: livestock waste management from anaerobic digestion, opportunities and challenges for Brazil. Int Food Agribusiness Manage Rev 17(1030-2016-83037):87–110

McCaskey T, Little J, Krotz R, Lino S, Hannah T (1996) On-farm composting feasible for disposal of swine carcasses. Highlights of agricultural research (USA)

Miao X, Wu Q (2006) Biodiesel production from heterotrophic microalgal oil. Biores Technol 97(6):841–846

Mokrejs P, Langmaier F, Mladek M, Janacova D, Kolomaznik K, Vasek V (2009) Extraction of collagen and gelatine from meat industry by-products for food and non food uses. Waste Manage Res 27(1):31–37

Morrison N, Clark R, Chen Y, Talashek T, Sworn G (1999) Gelatin alternatives for the food industry. In: Physical chemistry and industrial application of gellan gum. Springer, pp 127–131

Morrow WM, Ferket PR (1993) The disposal of dead pigs: a review. Swine Health Prod Official J Am Assoc Swine Practitioners (USA)

Morrow W, Ferket P (2001) Alternative methods for the disposal of swine carcasses. North Carolina State University Animal Science Facts

Morrow WM, O'Quinn P, Barker J, Erickson G, Post K, McCaw M (1995) Composting as a suitable technique for managing swine mortalities. Swine Health Prod Official J Am Assoc Swine Practitioners (USA)

Nollet LM, Toldrá F (2011) Handbook of analysis of edible animal by-products. CRC Press

Omrani G (1996) Basics biogas production from urban and rural waste. University of Tehran Publication, Iran

Oyiwona GE, Ogbonna JC, Anyanwu CU, Okabe S (2018) Electricity generation potential of poultry droppings wastewater in microbial fuel cell using rice husk charcoal electrodes. Bioresources Bioprocess 5(1):1–6

Pandey P, Shinde VN, Deopurkar RL, Kale SP, Patil SA, Pant D (2016) Recent advances in the use of different substrates in microbial fuel cells toward wastewater treatment and simultaneous energy recovery. Appl Energy 168:706–723

Pant D, Van Bogaert G, Alvarez-Gallego Y, Diels L, Vanbroekhoven K (2016) Evaluation of bioelectrogenic potential of four industrial effluents as substrate for low cost microbial fuel cells operation. Environ Eng Manage J (EEMJ) 15(8)

Peng Z, Mao X, Zhang J, Du G, Chen J (2020) Biotransformation of keratin waste to amino acids and active peptides based on cell-free catalysis. Biotechnol Biofuels 13(1):1–12

Peters D (2006) Raw materials. In: White biotechnology, pp 1–30

Pham TP, Kaushik R, Parshetti GK, Mahmood R, Balasubramanian R (2015) Food waste-to-energy conversion technologies: current status and future directions. Waste Manag 38:399–408. https://doi.org/10.1016/j.wasman.2014.12.004. Epub 2014 Dec 30. PMID: 25555663

Phillips GO, Williams PA (2011) Handbook of food proteins. Elsevier

Plowman JE, Clerens S, Lee E, Harland DP, Dyer JM, Deb-Choudhury S (2014) Ionic liquid-assisted extraction of wool keratin proteins as an aid to MS identification. Anal Methods 6(18):7305–7311

Poppe J (1992) Gelatin. In: Thickening and gelling agents for food. Springer, pp 98–123

Pourjavaheri F, Pour SO, Jones OA, Smooker PM, Brkljača R, Sherkat F, Blanch EW, Gupta A, Shanks RA (2019) Extraction of keratin from waste chicken feathers using sodium sulfide and l-cysteine. Process Biochem 82:205–214

Rahimnejad M, Adhami A, Darvari S, Zirepour A, Oh S-E (2015) Microbial fuel cell as new technology for bioelectricity generation: a review. Alex Eng J 54(3):745–756

Rakhmanova A, Khan Z, Sharif R, Lv X (2018) Meeting the requirements of halal gelatin: a mini review. MOJ Food Proc Technol 6:477–482

Reddy CC, Khilji IA, Gupta A, Bhuyar P, Mahmood S, AL-Japairai KAS, Chua GK (2021) Valorization of keratin waste biomass and its potential applications. J Water Process Eng 40:101707

Rohstoffe eV FFN (2009). Biogas-Messprogramm II–61 Biogasanlagen im Vergleich (1st edn). Fachagentur Nachwachsende Rohstoffe eV (Ed) Gülzo

Roy S, Schievano A, Pant D (2016) Electro-stimulated microbial factory for value added product synthesis. Biores Technol 213:129–139

Sai-Ut S, Jongjareonrak A, Rawdkuen S (2012) Re-extraction, recovery, and characteristics of skin gelatin from farmed giant catfish. Food Bioprocess Technol 5(4):1197–1205

Santoro C, Arbizzani C, Erable B, Ieropoulos I (2017) Microbial fuel cells: from fundamentals to applications. A review. J Power Sources 356:225–244

Sayed ET, Barakat NA, Abdelkareem MA, Fouad H, Nakagawa N (2015) Yeast extract as an effective and safe mediator for the baker's-yeast-based microbial fuel cell. Ind Eng Chem Res 54(12):3116–3122

Shah A, Tyagi S, Bharagava RN, Belhaj D, Kumar A, Saxena G, Saratale GD, Mulla SI (2019) Keratin production and its applications: current and future perspective. In: Keratin as a protein biopolymer, pp 19–34

Shavandi A, Silva TH, Bekhit AA, Bekhit AE-DA (2017) Keratin: dissolution, extraction and biomedical application. Biomater Sci 5(9):1699–1735

Shi W, Li J, He B, Yan F, Cui Z, Wu K, Lin L, Qian X, Cheng Y (2013) Biodiesel production from waste chicken fat with low free fatty acids by an integrated catalytic process of composite membrane and sodium methoxide. Bioresour Technol 139:316–322

Shirsath AP, Henchion MM (2021) Bovine and ovine meat co-products valorisation opportunities: a systematic literature review. Trends Food Sci Technol 118:57–70

Shoulders MD, Raines RT (2009) Collagen structure and stability. Annu Rev Biochem 78:929

Sinkiewicz I, Śliwińska A, Staroszczyk H, Kołodziejska I (2017) Alternative methods of preparation of soluble keratin from chicken feathers. Waste Biomass Valorization 8(4):1043–1048

Sorathiya L, Fulsoundar A, Tyagi K, Patel M, Singh R (2014) Eco-friendly and modern methods of livestock waste recycling for enhancing farm profitability. Int J Recycl Organic Waste Agric 3(1):1–7

Sund CJ, McMasters S, Crittenden SR, Harrell LE, Sumner JJ (2007) Effect of electron mediators on current generation and fermentation in a microbial fuel cell. Appl Microbiol Biotechnol 76(3):561–568

TerAvest MA, Rosenbaum MA, Kotloski NJ, Gralnick JA, Angenent LT (2014) Oxygen allows Shewanella oneidensis MR-1 to overcome mediator washout in a continuously fed bioelectrochemical system. Biotechnol Bioeng 111(4):692–699

Tesfaye T, Sithole B, Ramjugernath D (2017) Valorisation of chicken feathers: a review on recycling and recovery route—current status and future prospects. Clean Technol Environ Policy 19(10):2363–2378

Toldrá F, Mora L, Reig M (2016) New insights into meat by-product utilization. Meat Sci 120:54–59

Toldrá F, Reig M, Mora L (2021) Management of meat by-and co-products for an improved meat processing sustainability. Meat Sci 181:108608

Toldrà M, Lynch SA, Couture R, Álvarez C (2019) Blood proteins as functional ingredients. In: Sustainable meat production and processing. Elsevier, pp 85–101

Ucar D, Zhang Y, Angelidaki I (2017) An overview of electron acceptors in microbial fuel cells. Front Microbiol 8:643

Usman M, Sahar A, Inam-Ur-Raheem M, Rahman UU, Sameen A, Aadil RM (2022) Gelatin extraction from fish waste and potential applications in food sector. Int J Food Sci Technol 57(1):154–163

Varjani SJ, Gnansounou E, Pandey A (2017) Comprehensive review on toxicity of persistent organic pollutants from petroleum refinery waste and their degradation by microorganisms. Chemosphere 188:280–291

Vijay V (2011) Biogas enrichment and bottling technology for vehicular use. Paper presented at the Biogas forum

Vineis C, Varesano A, Varchi G, Aluigi A (2019). Extraction and characterization of keratin from different biomasses. In: Keratin as a protein biopolymer. Springer, pp 35–76

Widodo TW, Hendriadi A (2005) Development of biogas processing for small scale cattle farm in Indonesia. Paper presented at the conference proceeding: international seminar on biogas technology for poverty reduction and sustainable development. Beijing

Yadav R (2012) Innovative application of scientific fact for nutrient recovery from waste water streams for sustainable agriculture and protection of environment: a review. Hydrol Curr Res 3(5)

Zhu L-D, Hiltunen E (2016) Application of livestock waste compost to cultivate microalgae for bioproducts production: a feasible framework. Renew Sustain Energy Rev 54:1285–1290

Zupančič GD, Grilc V (2012) Anaerobic treatment and biogas production from organic waste. Manage Organic Waste 2