Modern methods of processing biowaste of poultry and livestock

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Abstract. Recycling of biowaste is accompanied by its transformation into an economic product, while at the same time contributing to the protection of the environment and bringing benefits to public health. This article provides an overview of modern technologies for processing biowaste associated with their direct use, biological, thermochemical and physical-chemical processing. Direct use technologies include land use, feed, and direct combustion. The main options for biological treatment are composting, vermicomposting, and fermentation. Physical and chemical treatment includes transesterification, compaction, and thermochemical-pyrolysis, liquefaction, gasification. Sustainable recycling of biowaste requires a sufficient amount of waste as input and market demand for the products produced. For biowaste, such markets will depend on the end-use of the product. Not all the presented methods contribute to the preservation of the environment, so the search for environmentally friendly and at the same time cost-effective technologies is currently continuing. It is aimed at combining various biowaste processing technologies into a single system that has new advantages, taking into account productivity, resource intensity and environmental friendliness. Many scientists agree that the future of waste disposal is in nature-like technologies, because nature has all the necessary recycling mechanisms.

1. Introduction

Biowaste treatment benefits public health, the environment and economy, turning waste into an economic product. This article provides a comprehensive overview of biowaste treatment technologies grouped in four categories: (1) direct use (direct use of land, direct animal feed, direct burning), (2) biological treatment (composting, vermicomposting, black fly treatment, digestion, fermentation), (3) physicochemical treatment (interesterification, compaction) and (4) thermochemical treatment (pyrolysis, liquefaction, gasification).

In this context, biowaste treatment technologies are defined as processes that transform discarded biowaste into new products with potential value. Treatment technologies of urban solid biowaste are grouped into four main categories: (1) direct use, (2) biological treatment, (3) physicochemical and (4) thermochemical treatment.
Figure 1. The main categories of solid biowaste treatment technologies

2. Materials and methods
Sustainable waste processing requires sufficient waste as input and market demand for output products. (Vergara and Tchobanoglous 2012). Such markets will depend on the proposed final use of the product for biowaste, which can be roughly arranged into three end-use groups:

**Livestock.** Products derived from biological waste can be used as animal feed. This is gaining increasing relevance, given the significant global shift towards diets with consumption enlargement of animal products. Demand for meat and milk in 2050 is expected to be 58 and 70% higher than in 2010. Growing demand for animal products requires more feed. Higher prices for traditional fodder resources such as soy and fishmeal, the risk of their absence in the future and the associated negative environmental consequences in the production of such traditional feeds lead to the emergence of innovations and alternative feeds. Protein products derived from waste products such as insects or worms are increasingly seen as a possible alternative (Makkar et al. 2014).

**Agriculture.** Biological waste, a source of carbon and plant nutrients can be processed into various types of soil modifications with benefits for both crops and soils. Soil supplements derived from biological waste (for example, compost, digestate) are perceived as low value products by many consumer groups (Gilbert 2015). However, soils are becoming more vulnerable in an intensive agricultural practice. The rapid carbon turnover (3-5 times faster than in temperate regions) and its extraction, a decrease in the capacity for storing nutrients and water, as well as a decline in erosion resistance, emphasize the need to replenish carbon and plant nutrients. This can be achieved by processing organic waste in agriculture. (Smith et al. 2015).

**Bioenergy.** Particular attention is paid to the energy contained in biomass waste. Given the growing demand for energy, 1.2 billion people (17% of the world population) do not have electricity and 2.7 billion people (38% of the world population) still rely on irrational waste wood for cooking (OECD/IEA 2015), biowaste energy products are of great interest (Lohri et al. 2016). In addition, expanding global mobility coupled with declining oil reserves in the world, is enhancing the interest in technology for upgrading biofuel products.
The direct use of biowaste on earth is an ancient form of waste management, also called land spreading, and refers to the practice of dispersing unprocessed waste in the fields. Direct land use, animal waste, and outright open burning are classified as “direct use”. The risks of this practice depend on the biological waste composition. Pollution can easily endanger human, animal, and environmental health. The distribution of manure (dropping) in the fields is usually described in the literature on land waste. This is especially topical for crops that require large amounts of organic nutrients (Dulac 2001).

Poultry farming in Russia is an economically profitable production providing the population with poultry meat, eggs, and their processed products. At the same time, poultry farms are a source of dropping formation in the amount of much larger than main products (more than 25 million tons per year). One chicken gives about 250 pieces of eggs per year (16-17 kg) and releases up to 50-60 kg of droppings with an average humidity of about 70%; dropping particles contain from 30 to 80% of organic matter. Dropping is a source of toxic gases of ammonia, hydrogen sulphide, methane, and carbon monoxide polluting the atmosphere and adversely affecting the ozone layer state. It also contains medicines used to disinfect poultry houses.

The manure insertion into the soil without prior quarantine and processing is not allowed. Fresh dropping contains a significant amount of weed seeds and helminth eggs. It is a favorable environment for the development of pathogenic microorganisms. According to the World Health Organization, more than 100 species of various pathogens of animal and human diseases are able to successfully develop in this environment. For instance, the causative agent of salmonellosis remains viable up to 5 months, tuberculosis -17 months. The soil is largely seeded with microflora when such dropping is inserted which creates environmental and sanitary hazards. According to Federal Classificatory Catalog of Wastes (FCCW), fresh chicken droppings belong to the third hazard class (1), and rotted one already belongs to the fourth hazard class being a valuable organic fertilizer that contains all the necessary nutrients for plant growth and development (1).

Direct land use should focus only on clean organic waste (Gendebien et al. 2001) since non-biodegradable waste fractions or pollutants will affect soil and crop quality or threaten the health of farmers. A study conducted for the EU Commission concluded that more than 90% of the waste scattered across European lands is mainly animal manure, the remaining 10% is food waste (Gendebien et al. 2001).

Utilization of chicken manure for many farms is a complex problem and requires significant material costs and the availability of free space. The most common solution is to use the dropping as a fertilizer or to produce it. However, this resource is used only by 30%, which is explained by the lack of effective technologies for such production, since some of them lead to the loss of valuable substances, while others do not fully disinfect.

Untreated organic waste undergoes natural aerobic biodegradation with direct use of the land after it enters the field. Degradation mobilizes nutrients and increases soil organic matter. However, degradation can also cause nitrogen to compete in the soil when the microbial population exceeds the culture in using nitrogen for its own metabolism, resulting in signs of nitrogen deficiency in the crop. Smith et al. (2015) estimated that the use of untreated waste reduces the nitrogen available for crop growth by 66%. On the other hand, untreated biowaste consisting of nutrient-rich materials can lead to nutrients leaching into ground or surface water or to evaporation in the form of ammonia.

The main result of direct land-based waste application is to amend the soil with a high content of organic matter. Organic matter plays a triple role in the soil: 1) biologically acting as a source of nutrients and energy for microbes; 2) chemically buffering soil pH changes; and 3) physically affecting soil structure and related properties. According to Dulac (Dulac 2001), scattering of raw organic (manure) dropping is especially useful for degraded soils in arid areas. Nevertheless, the same studies emphasize the risk of reducing the availability of micronutrients needed for plant growth when using unstable organic material (Dulac 2001). Thus, it is necessary to introduce restrictions and controls on the export of unprocessed organic waste to land to prevent risks for the environment and
human health (EPA 2004; Dulac 2001). One of the control measures is to ensure sufficient time between the waste insertion and the subsequent planting and harvesting (Dulac 2001).

The potential benefits and risks of this practice are closely related to waste quality. Soil treatment does not remove the pathogen. Direct use of biomass studies focus on these risk aspects, evaluating the effect of specific organic residues on soil and/or crop characteristics in terms of fertility, structure, and micronutrient content (Hegberg et al. 1990; Olowolafe 2008; Walsh and McDonnell 2012). The dropping contains: nitrogen (N) – 1.6%, phosphorus (P) – 1.5%, potassium (K) – 0.8%, calcium (Ca) — 2.4%, magnesium (Mg) – 0.7%, sulfur (S) – 0.4%, and micronutrients: copper, manganese, cobalt, zinc, boron, all essential amino acids, growth regulators - auxins, many vitamins (carotene, B 12, nicotinic acid, vitamin K, vitamin E, etc.) (3) Nitrogen and phosphorus are greater by several fold in the dropping than in cattle and pig manure.

The properties of organic residues are very variable, as well as the reaction of soil and crop. Therefore, the task of assessing the crop production impact on the soil remains complicated (Gendebien et al. 2001). In general, it is recommended to avoid direct use in the land in order to avoid negative incidental effects, and instead turn on the treatment process (for example, by composting) before spreading the waste to the field. This provides a hygiene phase and the conversion of nutrients to a lighter form for plants.

Open burning is not considered an acceptable way to handle biowaste, although it is still widely practiced. Burning poses a significant threat to human health and the environment as a result of mixed waste emissions, incinerated and/or not completely burning. Open burning is primarily aimed at reducing waste and does not restore energy and nutrients.

3. Results and Discussion

An analysis of studies conducted over the past 10 years in the field of open burning shows that the focus was on estimating emissions and related environmental and health impacts (Babel and Vilaysouk 2016; Nagpure et al. 2015; Prasad Raju and Partheeban 2014; Zhang et al. 2011). Although most studies have focused on emissions of nitrogen oxides and complex organic compounds, concernment in emissions and the effects of short-lived climate pollutants has increased in the last decade. Black carbon receives significant attention as SLCP (Stohl et al. 2015) and it has been reported that the effects of black carbon from waste incineration are still insufficiently documented (Bond et al. 2013). Studies on the open burning effects help politicians obtain evidence to enforce strict rules and controls (Forbid et al. 2011; Park et al. 2013).

**Biological treatment** is understood as the controlled conversion of waste by living organisms. Biochemical processes are much slower than thermochemical conversion but require significantly less external energy (Basu 2013). Since all living organisms need water to survive, biological treatment always takes place in a humid environment. Thus, biochemical conversion processes are mainly applied to high humidity biowaste.

**Composting** involves controlled aerobic decomposition of organic matter, which leads to a relatively stable organic final product called humus. Composting is undoubtedly an ancient practice documented by the Greeks, Romans, and early civilizations in South America, China, Japan, or India (Hershey 1992). Early scientific publications on composting as a management option in agriculture date back to Sir Howard's publications around 1933. Being in India, Sir Howard was inspired by the composting use in Chinese agriculture (Diaz and de Bertoldi 2007). Therefore, he developed and documented the principles of modern composting called the Indore Process (Howard 1935).

Composting of organic matter is determined by the diversity of microorganisms and invertebrates populations, and the dynamics of populations varies greatly both in time and in space (Insam and de Bertoldi 2007). Microorganisms break down organic matter and produce carbon dioxide, water, and heat. Process control implies that the prevailing parameters, such as the composition of the organic material (carbon to nitrogen ratio), particle size, free air space, aeration, temperature, humidity or pH are controlled, directed and adjusted to achieve rapid degradation and good compost quality. Manure and dropping composting is one of the most promising and cost-effective methods. The main factor...
affecting the composting intensity is the ratio of C to N (C:N). An efficient course of the composting process is possible with a C: N ratio equal to 20-30:1. Carbon is not enough in the liquid manure (5-10:1), whereas the indicator is close to optimal in the nesting manure (19:1). The addition of carbon-containing substrates (peat, straw, sawdust, etc.) allows optimizing the composting process. Three main methods of composting are used in agriculture: on-site, focal, and layered (the most effective and widespread).

When conditions are not optimal, the process may slow down or not occur at all. Under optimal composting conditions degradation proceeds through three phases: 1) mesophilic phase that lasts several days; 2) thermophilic that lasts from several weeks to several months, and finally 3) a cooling and ripening phase that can last several months (Epstein 1997). During the thermophilic phase, the temperature can rise up to 55-70°C due to the metabolism of microorganisms which contributes to the material hygiene. The end of the composting process is achieved when the internal temperature of the stack is close to the ambient temperature and the oxygen concentration in the air cavities inside the stack remains >10-15% for several days (Cooperband 2002).

The main product obtained by composting is a compost-resistant dark brown, soil-like material with a friable texture, dark color, and earthy smell. Compost contains important plant nutrients such as nitrogen, potassium and phosphorus, although usually not as much as animal manure or chemical fertilizers (Polprasert 2007). It also contains a number of beneficial minerals and humus-rich and microorganisms that can be used to make changes to the soil, to cover landfills, reclamation or land restoration schemes (Brinton and Evans 2001). Other products released during the composting process are leaching, water vapor, and carbon dioxide (Polprasert 2007).

The search for effective microorganisms—destructors of organic waste of poultry farms, the creation of full-fledged consortia of microorganisms and their implementation is one of the most promising combating methods with organic agricultural waste.

Vermicomposting. Biohumus is defined as the aerobic process of degradation and stabilization of organic waste by the interaction of microorganisms and earthworms under controlled conditions. Microbial communities contribute to the degradation of organic matter and high density of earthworms, and then feed on waste and cast earthworms, also called vermicompost (Ndegva et al. 2000).

Biohumus depends on the interaction between microorganisms and earthworms. The microorganisms in the waste prepare the waste for earthworms through the first stage of aerobic degradation, namely, vermicomposting, thus preceding the pre-composting phase. Moreover, microorganisms are also found in the intestines of worms, they decompose organic material into smaller particles, and also provide the earthworm with food. Earthworms, in turn, feed on waste and also contribute to microbial activity by producing microbial active fecal material, which is useful for faster decomposition of organic waste and improves the nutritional quality of the product from vermicompost (Singh et al. 2011).

Suitable types of earthworms for vermicomposting are those that are highly adaptable to various types of waste and conditions, fast nutrition and digestion, as well as rapid growth and reproduction rate. Epigeal earthworms live right below the soil surface (they avoid direct sunlight) being feeders for garbage and most suitable for vermicomposting operations. Eisenia fetida is the most commonly used species among them, except Lumbricus rubellus, Eisenia andrei, Perionyx excavatus and eudrilus eugeniae, which is popular in many countries (Kumar 2005). Most types of earthworms require moderate/mesophilic temperatures in the range of 10-35°C (Sim and Wu 2010). Worms feel most comfortable and eat most quickly in this range. The important factors affecting the process of vermicomposting are batch density, temperature, feed rate, humidity, C/N, and pH ratio.

Waste is mineralized and plant nutrients become available as the feed passes through the earthworm intestines. The grinding effect of the intestine leads to the formation of granules characteristic of vermicompost. The nitrogen content in vermicompost is usually 1-2% higher than in compost, and nutrients have been reported to be more accessible to plants (Adhikary 2012). Besides, enzymes and microorganisms from the intestine exhibit very beneficial properties for soil and plants,
and also inhibit diseases. Leaching from worm bins can also be used as liquid fertilizer, which is commonly used in small-scale systems. Another product of vermicomposting is earthworms themselves being rich in protein (65%) with all essential amino acids and can be used as animal feed (Lalander et al. 2015). They are considered good probiotic feed or used as additives in the diet of fish or poultry farms. (Adhikary 2012). Ground and swallowed earthworms have also been studied in terms of their medicinal properties and have been found to be effective in the treatment of thrombotic diseases (Christy et al. 2015) and have a favored effect on the healing process (Goodarzi et al. 2016).

Growing interest occurs from the potential increase in the waste value, not just compost. Many different systems have been designed for optimal engineering vermicomposting. Vermicomposting systems are considered less energy-intensive, more cost-effective and economically expedient in comparison with traditional processing technologies. However, the expected obstacles to vermicomposting may be the need for a large space, poor quality of raw materials, insufficient attention or knowledge of biological process requirements, and finally, limited marketing experience. The above mentioned prevents the economic feasibility of vermicompost.

**Black soldier fly (BSF)** processing is a new technology in the organic waste treatment. It includes the conversion of biowaste into protein and insect oil. Originally from America, the transport of goods contributed to the widespread of the black soldier fly, Hermetia illucens L. (Diptera: Stratiomyidae). Its appetite for the decomposition of organic matter was discovered in the early 20th century. Around the mid-twentieth century, Furman et al. (1959) scientifically verified that the presence of BSF larvae could inhibit the reproduction of the Muscadomestica housefly in poultry farms. The authors also found a massive manure reduction in which BSF larvae were present in large numbers.

For disposal, BSF larvae can feed on food waste (Diener et al. 2011; Leong et al. 2015; Nguyen et al. 2015; Parra Paz et al. 2015), animal manure (Li et al. 2011b; Myers et al. 2008; Sheppard et al. 1994; Yu et al. 2011), human excrement (Banks et al. 2014; Lalander et al. 2013), and fish waste (St-Hilaire et al. 2007). The importance of a certain level of moisture in the feedstock was demonstrated by Furman et al. (1959), where wetting chicken droppings led to a significant reduction in waste. Although BSF larvae can survive in liquid media, a large number of them appear to develop only in wet or semi-solid conditions (Newton et al. 1995). High cellulose wastes, such as wood and dry leaves, are not suitable for composting larvae and can be added as a structure-forming agent. Ideally, wet and dry materials are mixed and combined to produce suitable larvae feed.

The growth rate of BSF larvae, and therefore, the rate of waste reduction and bioconversion depends on several factors such as temperature and the feedstock humidity. Temperatures between 25 and 32°C are most suitable for all stages of BSF life (Tomberlin et al. 2009; Tomberlin and Sheppard 2002). The space requirement for BSF processing depends on operational parameters such as larva density and feeding rate. Determining these parameters requires a compromise between high waste reduction (high larval density and low feeding rate) and high biomass production (low larval density and high feeding rate) (Parra Paz et al. 2015). Reported feeding rates range from 1.9 kg/m² and a day (Diener et al. 2009) to 9.8 kg/m² and a day (Parra Paz et al. 2015).

The main products resulting from BSF technology are larvae and residue. The protein content and amino acid profile of fat-free insect flour is similar to fishmeal and, therefore, can replace it in animal feed. Grown larvae are suitable as a (partial) substitute for fishmeal in animal feed, and experiments have shown good results when feeding fish, chickens or pigs (Makkar et al. 2014; Stamer 2015). Other feasible products to be studied are the production of biodiesel from larvae or the use of chitin and oil (Li et al. 2011a). On the other hand, the residue still contains valuable nutrients and can be used as a soil modification. However, due to the short processing time, the sediment must go through a ripening phase to prevent oxygen depletion in the soil which prevents seed germination or inhibits the growth of roots and plants (Brinton and Evans 2001).

The identification and management of risks associated with pathogens and a toxic substance in the recycling of waste into the food chain (for example, heavy metals, pesticides or pharmaceuticals) is crucial. Although BSF activity accelerates the decline of Salmonella spp., further processing of both the residue and the larvae is required as other pathogens such as Enterococcus spp., bacteriophages
and helminth eggs are not reduced (Lalander et al. 2013). Moreover, the heavy metals being in the feed stock are able to accumulate in larvae and prepupahrequiring precautions, ideally avoiding the use of contaminated organic waste as feed stock (Diener et al. 2015).

The emphasis on growing a colony of flies is especially vital when running a biowaste business. A complex specializing in growing larvae-packer and processing collected products serves several decentralized and reliable settings for biowaste treatment. In other words, small-scale biowaste producers receive the larva from a centralized BSF object facility and convert their organic waste into insect protein. Fattened larvae are then directly sold to poultry and fish farmers or sent back to BSF centralized enterprises for further treatment. Separation and centralization can facilitate the growth of a scattered network of organic waste processors using BSF technology, thereby reducing transportation costs and emissions from waste treatment.

Anaerobic digestion (AD), also called biomethanization or biomethanation, is a reliable, well-established engineering process for the biochemical decomposition of both liquid and solid organic matters by various bacterial activities in an oxygen-free environment. The process occurs naturally in many anoxic environments such as stream flows, soils, animal intestines, and landfills (Vögeli et al. 2014). The use of AD biowaste dates back thousands of years when biogas was used in Assyrian bathhouses to heat water (Suriaavanshi et al. 2010). Historically, AD was mainly associated with wastewater treatment from aerobic sediment and animal manure (Esposito et al. 2012).

A wide range of AD feedstocks includes sewage sludge, animal manure, food industry waste (slaughterhouse waste), crop residues (algae), and the organic solid waste fraction (Romero-Guisa et al. 2016).

Anaerobic biodegradation of complex organic substances to CH$_4$ and CO$_2$ consists of a number of microbial processes: hydrolysis, acidogenesis, acetogenesis, and methanogenesis of Mata-Alvarez (2003). Key AD operational parameters (for example, temperature, pH, humidity, substrate, C/N ratio, loading speed, holding time, inoculation, mixing), and their effect on process stability, yield and biogas quality are described in Khalid et al. (2011) and Jain et al. (2015). One of the problems with AD conversion is to avoid acidification and inhibition of methanogenic bacteria. For instance, a large amount and a high proportion of readily biodegradable organic matter in the feed can lead to a decrease in pH in the reactor and an increase in the production of volatile fatty acids which enhances and suppresses the activity of methanogenic bacteria (Bouallagui et al. 2009).

AD processes can be classified by reactor temperature (mesophilic, therophilic), solids content (low and high solids concentration), feed mode (batch and continuous feeding) or number of technological steps (single-stage and multi-stage) (Hartmann and Ahring 2006; Kothari et al. 2014; Mao et al. 2015; Vögeli et al. 2014).

The main AD products are biogas and digestate. Biogas is formed by converting the organic carbon of the feed stock to its most reduced form (methane, CH$_4$), and the most oxidized state (carbon dioxide, CO$_2$). In addition to CH$_4$ (55-60%) and CO$_2$ (35-40%), biogas also contains several other gaseous “impurities” such as hydrogen sulphide, nitrogen, oxygen, and hydrogen (Cecchi et al. 2003). Biogas with a CH$_4$ content above 45% is highly flammable (Deublein and Steinhasuer 2009). The biogas yield from individual substrates varies significantly depending on the raw material origin, organic matter content, and the substrate composition. Fats provide the highest biogas yield but require a long storage time by reason of their poor accessibility to microorganisms. Carbohydrates and proteins demonstrate higher conversion rates but lower gas yields (Weiland 2010). Direct biogas burning in furnaces is the easiest way to use biogas energy. Moreover, biogas can be used in lamps or converted to electricity in gas generators.

The resulting suspension (digestate) is rich in nitrogen and, depending on the feedstock nature and adequate dilution for specific crops, may be used in agriculture as a nutrient fertilizer and/or organic additive (Groot and Bogdanski 2013; Möller and Müller 2012). The AD process is partially able to inactivate weed seeds, bacteria (for example, salmonella, coliform bacillus, Listeria), viruses, fungi and parasites, which is of great importance if digestate is used as a fertilizer.
Unsuitable technology choice, poor design and construction of reactors, poor exploitation, lack of service responsibilities for operators, absence of markets for biogas and digested organic sediment are the reasons for the failure of the manure processing technology and MSW (municipal solid waste) (Templton2011; Parawira 2009).

**Fermentation.** Fermentation is a key technological step in the production of bioethanol (ethyl alcohol, CH$_3$CH$_2$OH or EtOH), the leading biofuel in the world market (Mussatto et al. 2010). Mixtures of bioethanol and gasoline are promoted as environmentally friendly fuels that reduce automobile exhaust emissions (Balat and Balat 2009). Currently, about 820 million cars and light trucks operate with bioethanol (Sarris and Papanikolaou 2016). Bioethanol can be obtained from several sources of biomass based on sugar, starch and lignocellulose using various conversion technologies. It is mainly produced from corn raw materials (starch) and from sugarcane (sucrose). The United States (corn) and Brazil (reed) are the two main ethanol producing countries accounting for 57 and 27% of world production (Gupta and Verma 2015).

Bioethanol production is carried out in three stages with additional preliminary processing if lignocellulosic raw materials are used: (0) pretreatment (delignification) to make cellulose and hemicellulose more accessible for subsequent stages, (1) acid or enzymatic hydrolysis (saccharification) to break down polysaccharides to simple sugars, (2) fermentation of sugars (hexose and pentose) to ethanol using microorganisms, mainly yeast, (3) separation and concentration of ethanol obtained by distillation-rectification-dehydration (Vohra et al. 2014). The conversion can be performed as a batch process, fed-batch or a continuous process; however, the fed-batch process is most commonly used (Fodor and Kleméš 2012). Anaerobic fermentation takes place at a temperature of 25-30°C and lasts from 6 to 72 hours, depending on the composition of the hydrolyzate, cell density, physiological activity, and yeast type. The process of thermochemical gasification and fermentation is another relatively new technological way of conversion (Balat and Balat 2009).

**Thermochemical conversion processes** use heat to induce chemical reactions as a means of extracting and creating energy carriers in the form of products. These processes differ in temperature, heating rate and required oxygen level. The processes of thermochemical conversion are faster than biochemical but require significant energy costs.

**Pyrolysis** entails the biomass decomposition under the action of heat at 450-550°C in the absence of oxygen (λ=0), resulting in the formation of solid, liquid, and gaseous products. There are two main types of dry pyrolysis methods, named according to their heating rate: slow pyrolysis, where the main product is a solid called char, and fast pyrolysis with bio-oil as the main product. There are also other subtypes of pyrolysis such as intermediate, subitaneous, ultra, and vacuum pyrolysis, which differ in residence time, heating rate, temperature, and main manufactured products (Mohan et al.2006; Vamvuka2011). The disadvantages are low efficiency, the need for preliminary drying of the dropping intended for nesting manure, lack of domestic (RF) production of the corresponding large-capacity equipment. The resulting pyrolysis mass is more toxic than the dropping and needs to be buried.

**Hydrothermal liquefaction** (HTL) also known as direct liquefaction, involves treating biomass in a hot, highly compressed aqueous environment for sufficient time to break down the solid biopolymer structure into predominantly liquid components called bio-oil or bio-raw materials (Elliott 2011; Elliott et al. 2015; Peterson et al. 2008). Thermal depolymerization allows receiving solid, liquid and gaseous fuels, chemicals and fertilizers from organic and hydrocarbon poultry waste. The first stage of processing takes place at temperatures of 250-350°C, the second one is at 500-700°C.

TDP installation for the production of oils similar to diesel fuel was demonstrated for the first time in the USA, as well as the possibility of using chicken dropping in solid oxide fuel cells (SOFC) to produce hydrogen and electricity.

**Gasification** is a thermal treatment that converts a carbon-containing material into a gas (producer gas or synthesis gas) that can be used as fuel or for the production of value-added chemicals. The main difference between the two closely related thermochemical processes of gasification and combustion is that gasification packs energy into chemical bonds in gas by adding hydrogen (H$_2$) and removing carbon (C) from the feed stock. While combustion oxidizes the H$_2$ and C feedstocks to water and
carbon dioxide, thus breaking these bonds to release energy (Basu 2010). Recently, interruptions in oil supplies and high oil prices in the 1970s have played a significant role in renewing interest in biomass gasification. Waste gasification has long been used in Japan where the lack of landfill and policies to prevent combustion and emission of dioxins.

4. Conclusion

Modern technologies for the utilization of agricultural biowaste do not fully contribute to the preservation of the environment and production. At the present stage, industry needs environmentally friendly and cost-effective technology.

The use of biotechnological methods makes it possible to turn organic waste into valuable raw materials for obtaining feed, combustible materials, fertilizers, and substrates for the chemical and microbiological industry. The combination of various biowaste treatment technologies into a single system can serve as an example for the transition from linear to cyclical design thinking with diverse and ambitious advantages.

It is necessary to develop and study new ideas and technologies and take into account process performance indicators, resource intensity, and ecological safety when assessing their competitiveness. Many scientists agree that the future of waste management is based on nature-friendly technologies because all the necessary processing mechanisms already exist in nature.

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