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Biochemistry of wastes recycling

Sakariyau Adio Waheeg[1,*], Ridwan Olamilekan Adesola[2], Sadiq Musa Garba[3]

[1]Department of Biochemistry, Faculty of Life Science, Federal University of Technology Minna, Bosso LGA, Niger State, Nigeria

[2]Department of Veterinary Medicine, Faculty of Veterinary Medicine, University of Ibadan, Ibadan, Oyo State, Nigeria

[3]Department of Pharmacology, and Toxicology, Faculty of Pharmaceutical Sciences, Usmanu Danfodioyo University, Sokoto, Sokoto State, Nigeria

*E-mail address: waheed.sakariyau@st.futminna.edu.ng

ABSTRACT

Waste is an unwanted byproduct of human actions that physically contains the same substance as the valuable product. Waste is produced as a result of inefficient manufacturing processes, and its constant creation results in a waste of critical resources. Recycling is the conversion of waste materials into new materials and things, and a material's recyclability is determined by its ability to regain the attributes it had in its virgin or original state. Waste is divided into broad categories depending on its environmental impact (hazardous and non-hazardous waste), physical state (solid, liquid, and gaseous waste), and source. Biological reprocessing, energy recovery, and physical reprocessing are some of the waste recycling processes available. The purpose of waste management is to create sanitary living circumstances in order to limit the quantity of garbage that enters and leaves society while also encouraging the reuse of waste. Fermentation of organic waste, anaerobic digestion, bioleaching, biosorption, and bioreduction are examples of biochemical waste recycling technologies. We review to provide adequate and concise information on the biochemistry of waste management.

***Keywords*:** biochemistry, waste recycling, waste management

1. INTRODUCTION

The majority of human actions produce waste (Brunner and Rechberger, 20114). Despite this, waste generation remains a major source of worry, as it has been since prehistoric times

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(Chandler *et al.*,1997). The rate and volume of garbage produced have both increased in recent years. As the amount of waste produced grows, so does the variety of waste produce (Vergara and Tchobanoglous, 2012). Unlike in prehistoric times, when wastes were simply an annoyance that needed to be eliminated. Because the population was tiny and a large amount of land was accessible at the time, proper management was not a serious issue. Those were the days when the ecosystem could simply absorb the amount of trash created without any damage (Tchobanoglous *et al.*, 1993). As a result of the industrial revolution, people began to migrate from rural to urban regions in the sixteenth century, resulting in a significant increase in trash output (Wilson, 2007).

This influx of people to cities resulted in a population explosion, which in turn resulted in an increase in the volume and diversity of waste generated in cities. Metals and glass began to appear in substantial amounts in municipal waste streams around this time (Williams, 2005). Littering and open dumps arose as a result of the increased number of people in cities and villages. These landfills, in turn, became breeding grounds for rats and other vermin, creating serious health dangers. Several pandemic outbreaks with large mortality tolls came from poor waste management techniques (Tchobanoglous *et al.*,1993). As a result, public officials began to dispose of waste in a controlled manner in the nineteenth century in order to protect public health (Tchobanoglous *et al.*,1993).

What is a waste, exactly? This is a critical subject in today's trash management. Waste is an unwanted result of human activity that physically contains the same substance as the valuable product (White *et al.*, 1995). Waste is also defined as any product or substance that is no longer useful to the maker (Basu, 2009). Wastes, according to Dijkema *et al.*, (2000), are materials that people would wish to dispose of even if money is required for disposal. Although waste is an inevitable byproduct of human activities, it is also the result of inefficient manufacturing processes, resulting in a loss of critical resources (Cheremisinoff, 2003). A chemical that one person considers a waste could be a valuable resource for another. As a result, a substance can only be considered garbage if its owner marks it as such (Dijkema *et al.*, 2000). Despite the subjective nature of wastes, it is critical to define exactly what a waste is. This is because a material's designation as a trash will serve as the foundation for the rules needed to protect the public and the environment where waste is processed or disposed of.

Recycling is the process of extracting resources or value from waste, which entails recovering or reusing the material. Waste material can be recycled in a variety of ways: the basic elements can be recovered and reprocessed, or the waste's heat content can be transformed to power. New methods of recycling are being developed continuously, and they are; Physical reprocessing, Biological reprocessing, and Energy recovery etc.

2. CLASSIFICATION OF WASTE

Waste comes in a variety of shapes and sizes, and its classification can be stated in a variety of ways. Physical states, physical attributes, reusable potentials, biodegradable potentials, source of production, and degree of environmental impact are all frequent factors utilized in trash classification (Demirbas, 2011; Dixon and Jones, 2005; White *et al.*, 1995). According to White *et al.* (1995), waste can be divided into three categories based on their physical states: liquid, solid, and gaseous waste. Although it is obvious that different countries have distinct categories. The most popular classes are shown in the diagram below;

Based on Physical state: Solid waste, Liquid waste, and Gaseous waste

Based on Source: Household/Domestic waste, Industrial waste, Agricultural waste, Commercial waste, Demolition and construction waste, and Mining waste

Based on Environmental impact

Hazardous waste, and Non-hazardous waste, Liquid wastes, which can be disposed of through sewer networks or lost to ground water, and hazardous wastes, which require stricter environmental restrictions due to their potential to cause environmental harm, are excluded due to the study's limited scope. Only solid waste, except hazardous solid waste, will be covered in depth.

Solid waste is defined by Tchobanoglous *et al*. (1993) as waste produced by human activity that is solid or semisolid in nature and discarded as useless items. Solid wastes, according to Beranek (1992), are a broad category of wastes created as a result of numerous activities such as agricultural, landscaping, and other operations such as home and commercial processes. Solid wastes, he claimed, are distinct from waste water and gaseous waste emissions. Solid wastes, in his opinion, are any wastes that people would typically deem suitable for disposal on land.

Municipal garbage, some biomedical waste, electronic waste, and some hazardous waste are all included in solid waste, according to Basu (2010). Solid waste can be putrescible or non-putrescible, according to Basu. Solid wastes, according to Kaseva and Gupta (1996), are waste materials generated by municipal, industrial, and agricultural activities. Solid wastes, unlike other wastes, do not dissipate easily, according to Tchobanoglous *et al.*, (1993). They argued that they will be found where they are tossed today in the future.

Sources/Types of Waste

Since solid waste consists of several types of waste, it is important to briefly examine the various forms and types of solid waste.

Municipal solid waste (MSW)

Municipal solid waste (MSW) is a significant waste stream that is also one of the most extensively researched. MSW has several ramifications, according to White et al. (1995). They stated that because garbage is a waste stream that people frequently come into contact with, legislators and local governments view its collection, treatment, and disposal as a critical service.

Municipal solid waste is defined by Kaseva & Gupta (1996) as garbage collected by city authorities, which includes household refuse, non-hazardous solids from industry, commercial, institutional, and non-pathogenic hospital waste. MSW is defined by Buah *et al.* (2007) as garbage collected for local governments from home and commercial sources.

Municipal solid waste (MSW) is defined by White *et al.* (1995) as waste generated by households and businesses. They went on to say that municipal solid garbage accounts for a modest percentage of overall solid waste generated. Municipal solid trash, according to Vergara and Tchobanoglous (2012), represents the lifestyles and practices of the people who produce it. They also stated that if MSW is not adequately handled, it can have a severe influence on public health and the environment.

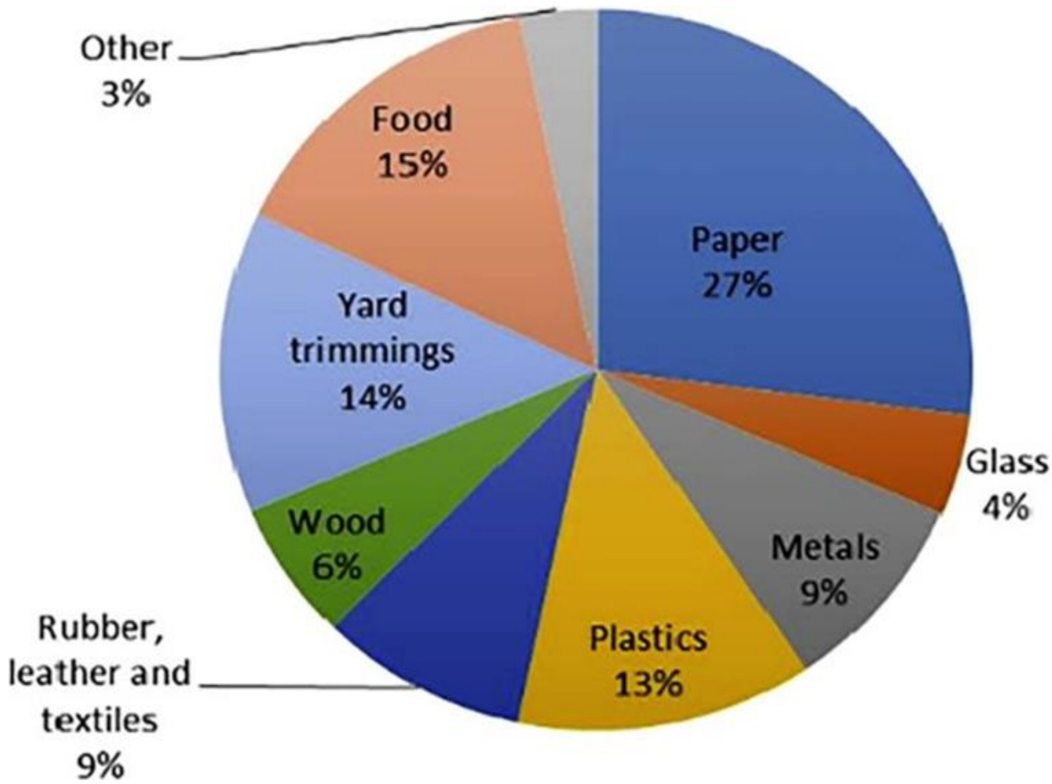

Figure 1. Composition and classification (by material) of SW (USEPA, 2013).

Industrial solid waste

Industrial wastes, according to Ngoc and Schnitzer (2009), are waste produced as a result of the processing of raw materials for the development of new goods. They suggested that these could be found in industries, mines, or mills. According to Shafigh *et al.* (2014), palm oil processing accounts for a significant portion of total solid waste in Malaysia, Indonesia, and Thailand. According to the report, Thailand's palm oil industry produces roughly 3.2 million metric tons of solid waste each year. The waste produced by the industry includes bunches, fruits shells, and palm fibre, with comparable values of 47 and 40 million tons for Malaysia and Indonesia, respectively. Ngoc and Schnitzer (2009) described the many types of wastes generated by companies, noting that some of the wastes are harmful and others are not.

Agriculture Solid waste

Agricultural solid wastes are numerous and outside the scope of this research. Agricultural wastes, on the other hand, are wastes generated by activities such as animal rearing, plant seeding, and milk production, according to Tchobanoglous (1993). Agricultural waste materials, according to Williams (2005), include animal dung, various crop wastes, and silage effluent. Agricultural wastes are generally recyclable in the energy and manufacturing industries. However, according to Seadi and Holm-Nielsen (2004), improper management of agricultural waste can result in environmental hazards, such as the overapplication of manure on land, which can pollute surface and ground water.

Food waste

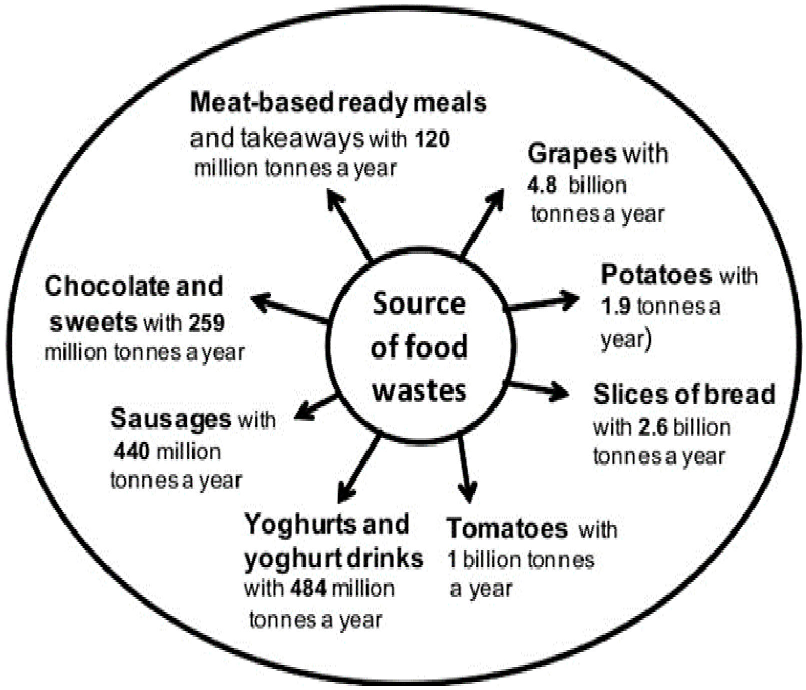

Figure 2. Source of Food wastes and their quantity (Girotto *et al.*, 2015)

Food waste is created when food is discharged, lost, deteriorated, or polluted during the preparation of food for human use. Food waste is becoming more of a concern as a result of modern lifestyles and a growing global population. It can also come from all participants in the food supply chain, including the agricultural and industrial sectors, as well as merchants and end users. When edible fractions are donated to social services, the amount of waste produced increases. Food waste from industrial processes is used to make biogas, biofuels, or biopolymers, and it is also used in the composting process for nutrient recovery and carbon fixation. Food waste can be used for energy recovery or related goods with correct management via incineration and land filling procedures.

Waste Management System

The waste management system encompasses all actions involving the handling, treatment, disposal, or recycling of waste materials. The goal of a waste management system is to ensure that waste materials are removed from the source or area where they are generated, and that they are safely handled, disposed of, or repurposed. Many developing nation towns seek to have modern waste management systems with high recycling rates of clean, source separated materials. The waste management system consists of four main parts:

a) generation e.g. waste- production
b) collection e.g. collection systems and transport of waste materials
c) treatment e.g. a transformation of the waste materials into useful products

d) final disposing e.g., the use of recyclable products or the placement of on-recyclable materials in landfills. Each of these steps is again comprised of several subparts.

Table 1. Components of waste and their recycling potentials

Waste components	Recycling Potentials
Plastics and aluminum	-Plastics can be recycled into fleece jackets -Aluminum can be shredded to produce molten aluminum
Kitchen waste and Nylon	-Kitchen wastes can be recycled into compost. -Nylon bags can be recycled into original products.
Vegetable stem and Basket	-Vegetable stems and garbage can be used as composts -Basket can serve as fuel for cooking.
Leather and Saw dust	-Leather can be recycled into original products. -Sawdust from wood can be used to produce plywood
Fridges, Computers, Television and Phones	-These machines parts can be separately collected and send to recycling plants for dismantling and recycle into related products

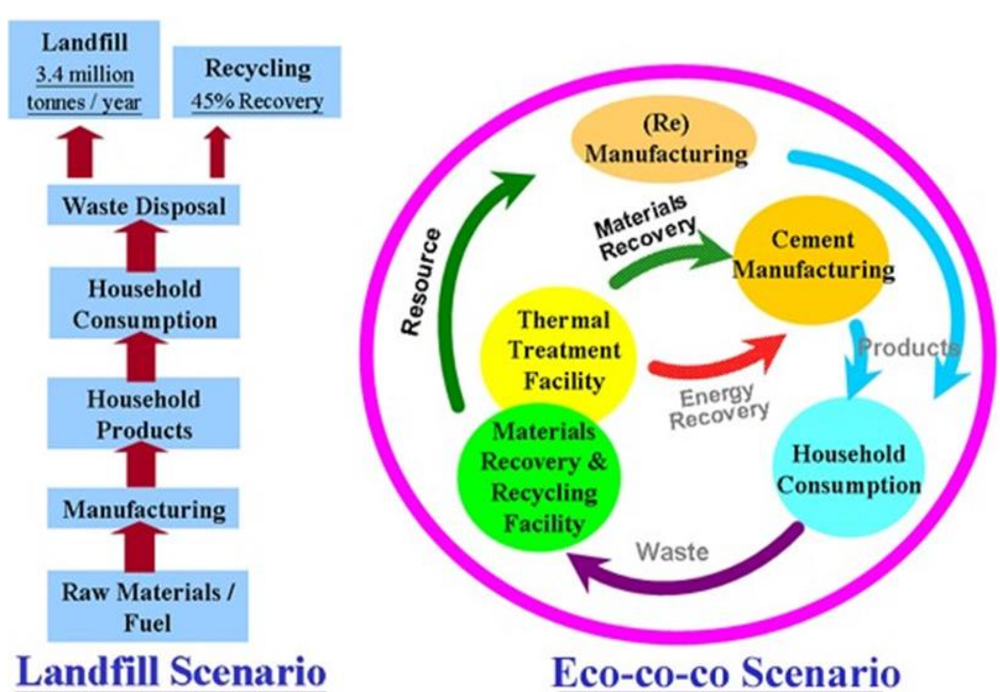

Figure 3. Waste management cycle (Siddique et al., 2008)

Prioritized waste management solutions are included in advanced waste management systems to reduce environmental problems and preserve resources. When it comes to the eventual disposition of trash, waste management solutions are divided into four categories:

Minimization or prevention of waste generation, recycling of waste, thermal treatment with energy recovery, and land-filling.

Large amounts of garbage are impossible to eradicate. However, by making more sustainable use of garbage, the environmental impact can be lessened. This is referred to as the "trash hierarchy" (Kan, 2009; Batayneh *et al.*, 2007). Reduce, reuse, and recycle are the three levels of the waste hierarchy, which classify waste management solutions based on their waste minimization effectiveness. Reduce, reuse, recycle, compost, incinerate, and landfill are the six degrees of disposal alternatives that categorize environmental impacts from low to high (Siddique *et al.*, 2008). Most waste minimization solutions still use the waste hierarchy as their foundation. The goal of the waste hierarchy is to get the most practical value out of things while producing the least amount of garbage.

Waste Management Methods

Conventional parameters cannot easily classify and assign different waste products to distinct classifications (Kan, 2009). Researchers have proposed and developed some novel strategies. Nowadays, not all trash is classified in the same traditional category, necessitating the same elimination technique. It is extremely difficult and impracticable to set up and operate separate waste management systems for different types of waste, especially in businesses where waste types are so diverse (Cardak, 2009). As a result, the need for a waste management system that can handle all sorts of trash has arisen.

Disposal method

In order to manage such large quantities of a diverse contaminated mixture of wastes in an energy efficient and environmentally friendly manner, an integrated approach is required. This would necessitate a comprehensive examination of various stages in the life cycle of wastes, including the raw materials used in their manufacture, manufacturing processes, design and fabrication of finished products, possible reuse of those items, and proper waste disposal (Kan, 2009). An integrated waste management strategy would include: source reduction, reuse, recycling, landfill and gas-to-energy, and waste-to-energy conversion.

Solid garbage has traditionally been disposed of in landfills. The most cost-effective waste management solution is landfill disposal. Expired medications, plastic syringes, surgical dressings, and other animal wastes are generated in hospitals. Biomedical wastes, which include expired medications, plastic syringes, surgical bandages, and other potentially infectious items, are generated by hospitals. They can be quite contagious. Medical waste requires particular treatment, such as cremation and hazardous waste land fill sites, for proper management (Altin *et al.*, 2003).

Landfill method

A landfill, on the other hand, is not intended to be a typical environmental condition. A landfill, on the other hand, is more like a securely sealed storage container. To safeguard the environment from dangerous contamination, a landfill is designed to prevent degradation. Even organic wastes like paper and grass clippings decay slowly at a landfill when they are deprived of oxygen and water (Kan, 2009). Landfill leachates contain a wide range of substances, some of which could pose a health and environmental risk if released into the environment. In recent years, landfill leachate treatment has gotten a lot of attention, especially in city areas (Uygur, 2004). MSW production has expanded in tandem with rising industrialization. EPA (1994) estimates that about 16% of all waste MSW is burned, with the rest ending up in landfills. Effective waste management has become a serious social and environmental issue (Erses *et al.*, 2003). When municipal solid waste (MSW) is disposed of in sanitary landfills, contamination of the soil, surface water, and ground water is common. The flow rate and composition of leachate differ from site to site, seasonally at each site, and based on the landfill's age. The amount of volatile fatty acids in young leachate is usually quite high (Timur *et al.*, 1999).

Incineration method

Incineration is a waste disposal procedure that involves the burning of garbage (Kan, 2009). "Thermal treatment" is a term used to describe incinerators and other high-temperature waste treatment facilities. A solid waste incinerator, according to Yang *et al*., (2007), is a facility that is designed, built, and operated under specific design conditions. A typical incinerator treats garbage that has been collected as input material, meets its purpose of waste treatment, and recovers heat energy from the combustion process as a secondary benefit.

Individuals and industry carry out incineration on a local and large scale, respectively. Solid, liquid, and gaseous waste are all disposed of in it. It is accepted as a viable technique of disposing of certain hazardous wastes (such as biological medical waste). Due to concerns such as the release of gaseous pollutants, incineration is a contentious technique of waste disposal. Solid residues, such as bottom ash and air pollution control residues, are produced by solid waste incineration. In addition to a high concentration of inorganic compounds, incineration leftovers contain a high concentration of carbon compounds resulting from incomplete combustion, unburned organic matter, and carbon compounds generated during the incineration process (Ecke *et al*., 2008). Furthermore, the cremation of fossil carbon produces minimal CO2 emissions.

Biogas method

Anaerobic digestion (AD) is the process of converting organic matter directly into biogas, which is a mixture of mostly methane and carbon dioxide with small amounts of other gases like hydrogen sulfide. Methane is the primary component of biogas, which is utilized for cooking and heating in many households. The biodigester, also known as a biogas plant, is a physical structure that is used to create an anaerobic environment that promotes different chemical and microbiological processes that result in the decomposition of input slurries and the creation of biogas—mostly methane (Balat, 2008). After proper gas purification, biogas can be utilized as a fuel for engines, gas turbines, fuel cells, boilers, industrial heaters, and other activities, as well as for chemical manufacture. Treatment or stabilization of biodegradable materials prior to landfilling can be achieved using a combination of anaerobic digestion and aerobic composting.

Effects of Wastes in Environment

Waste has an adverse effect on the environment, posing a serious threat to human life. These negative consequences affect both humans and animals, and they can result in disease outbreaks, reduced life expectancy, and a dangerous environment. Some wastes may decay, but those that do not will emit methane gas, which contributes greatly to the greenhouse effect. The effects of garbage on the environment and human health will be discussed later. Pollution of the air, water, and land occurs as a result of waste. Odour, smoke, and dust are all examples of air pollution. When solid wastes are burned, greenhouse gases such carbon dioxide and nitrous oxide are emitted, causing the ozone layer to deplete and the greenhouse effect to occur (Bhat *et al.*, 2018). Methane and hydrogen sulphide are also discharged into the atmosphere. These compounds are dangerous to people's health.

Water pollution is another negative impact of trash on the ecosystem. It is estimated that 1400 people die every day as a result of water and water-related problems/diseases (Khan *et al.*,2019). Wastes that find their way into water bodies such as rivers, streams, and oceans can disrupt the ecosystem by lowering the pH and causing toxicity to aquatic life and humans who use the water. Some of these contaminants are extremely lipophilic and less soluble in water (Verjani *et al*., 2017). Toxic metals have been found in water bodies, according to reports (Holanda et al., 2020; Sahay et al., 2019). Water that has been contaminated by waste from one location could be used as receiving water in another. Improper waste management can also lead to soil pollution. Waste deposited carelessly is unattractive to the eye and breeds disease vectors. Iron, radioactive wastes, and other metals are hazardous to soil creatures and plants, lowering crop output (Mani *et al.*, 2014).

Inadequately managed wastes hold disease vectors, resulting in human ailments. Mosquitoes breed in stagnant water bodies, clogged drainages, rain-collecting tyres, empty food cans, and plastics, among other places. Tissue damage, respiratory infection, injuries from glass, razor blades, and needles, as well as parasite infections induced by physical contact with garbage, are all risks that refuse workers encounter (Alam *et al.*, 2013). Despite the use of protective equipment such as gloves and nose masks by workers, advanced automated methods should be encouraged to protect refuse workers from waste treatment-related injuries.

3. IMPORTANCE OF GOOD WASTE MANAGEMENT

Income generation opportunities

There are numerous advantages to waste recycling. One of them is the possibility for establishing livelihoods, particularly in low-income countries' cities. The income gap between the rich and the poor is rising in many countries, and unemployment is becoming more of an issue. Recycling provides income-generating opportunities for a large number of city people, particularly when done by the informal sector and co-operatives. Paying jobs are produced in the operations of collecting, picking, sorting, processing, transporting, and trading recyclable materials, as well as in the creation of useful things from these recovered resources, starting with materials that some perceive to have no value. These advantages are in addition to the environmental advantages of fewer wastes to dispose of and lower demand for non-renewable raw resources, which must often be imported from overseas using scarce foreign currency.

Climate change

The rising global concern about climate change has drawn attention to the methane released when solid waste decomposes in the absence of oxygen. More than twenty times the amount of carbon dioxide has the same greenhouse effect (trapping heat in the earth's atmosphere) as methane (which is the gas normally linked to global warming). Collecting this methane and burning it (to produce carbon dioxide) or putting it to good use is thus a good strategy to reduce the global warming impact of trash disposal. As a result, payments of carbon credits are occasionally made to landfills that collect and burn (or use) the methane gas they produce.

The demand for raw resources is reduced as a result of the reduction, reuse, or recycling of materials in the waste stream, which reduces the carbon dioxide produced by the extraction, processing, and transportation of these raw materials. As a result, RRR has a lower impact on global temperatures.

Concept of Recycling

Figure 4. The three chasing arrows of the international recycling logo (Villalba *et al.*, 2002)

The process of transforming waste resources into new materials and things is known as recycling. This notion frequently includes the recovery of energy from waste materials. The ability of a material to reclaim the qualities it had in its virgin or original condition determines its recyclability (Villalba *et al.*, 2002). It's a greener alternative to "traditional" garbage disposal that saves resources and reduces greenhouse gas emissions. Recycling reduces energy consumption, air pollution (from incineration), and water pollution by preventing the waste of potentially valuable materials and minimizing the use of fresh raw resources (from land filling). Recycling is the third component of the "Reduce, Reuse, and Recycle" waste hierarchy and is an important part of modern waste reduction (Lienig *et al.*,2017;). By substituting raw material inputs and moving waste outputs out of the economic system, recycling tries to achieve environmental sustainability (Geissdoerfer *et al.*, 2017). Some ISO standards exist for plastics waste recycling and environmental management control of recycling practices. Glass, paper, cardboard, metal, plastic, tyres, textiles, batteries, and electronics are all recyclable materials. Composting or other biodegradable waste reuse, such as food or garden waste, is also a type of recycling. Materials to be recycled are either given to a household recycling center or collected from curbside bins, where they are sorted, cleaned, and reprocessed into new materials that will be used to make new products.

Recycling Industrial Waste

Figure 5. Reverse vending waste machine (Layton, 2009)

E-waste recycling

According to the Environmental Protection Agency, e-waste accounts for 20–50 million metric tons of global waste per year. It is also the EU's fastest-growing waste stream (Kinver, 2007). Many recyclers do not properly recycle e-waste. The Basel Convention was established to stop the flow of hazardous goods into poorer nations when the cargo barge Khian Sea dropped 14,000 metric tons of toxic a shinHaiti. The e-Stewards accreditation was designed to ensure that recyclers are held to the highest environmental standards and to assist consumers in identifying responsible recyclers. This works in tandem with other important legislation to prevent harmful substances from entering rivers and the atmosphere, such as the EU's Waste Electrical and Electronic Equipment Directive and the United States' National Computer Recycling Act. Television sets, monitors, telephones, and computers are routinely examined and repaired during the recycling process. If they are broken, they can be disassembled for pieces that are still valuable if labor is inexpensive enough.

Plastic recycling

Plastic recycling is the act of reclaiming scrap or waste plastic and repurposing it into useable items that are often quite different from what they were in the first place. For example, melting down soft drink bottles and casting them as plastic chairs and tables could be an example (Layton, 2009). The same piece of plastic can only be recycled 2–3 times before its quality deteriorates to the point where it can no longer be used for various forms of plastic.

Waste plastic pyrolysis to fuel oil

Another method includes using a far less accurate thermal depolymerization process to convert various polymers into petroleum. Almost any polymer or a mixture of polymers might be used in this method, including thermoset materials like vulcanized rubber tires and biopolymers found in feathers and other agricultural waste. The compounds produced, like natural petroleum, can be used as fuels or feedstock. Plastic pyrolysis is a process that converts petroleum-based waste streams like plastics into high-quality fuels and carbons.

4. BIOCHEMICAL METHODS OF WASTE RECYCLING

Solid-state fermentation of organic waste

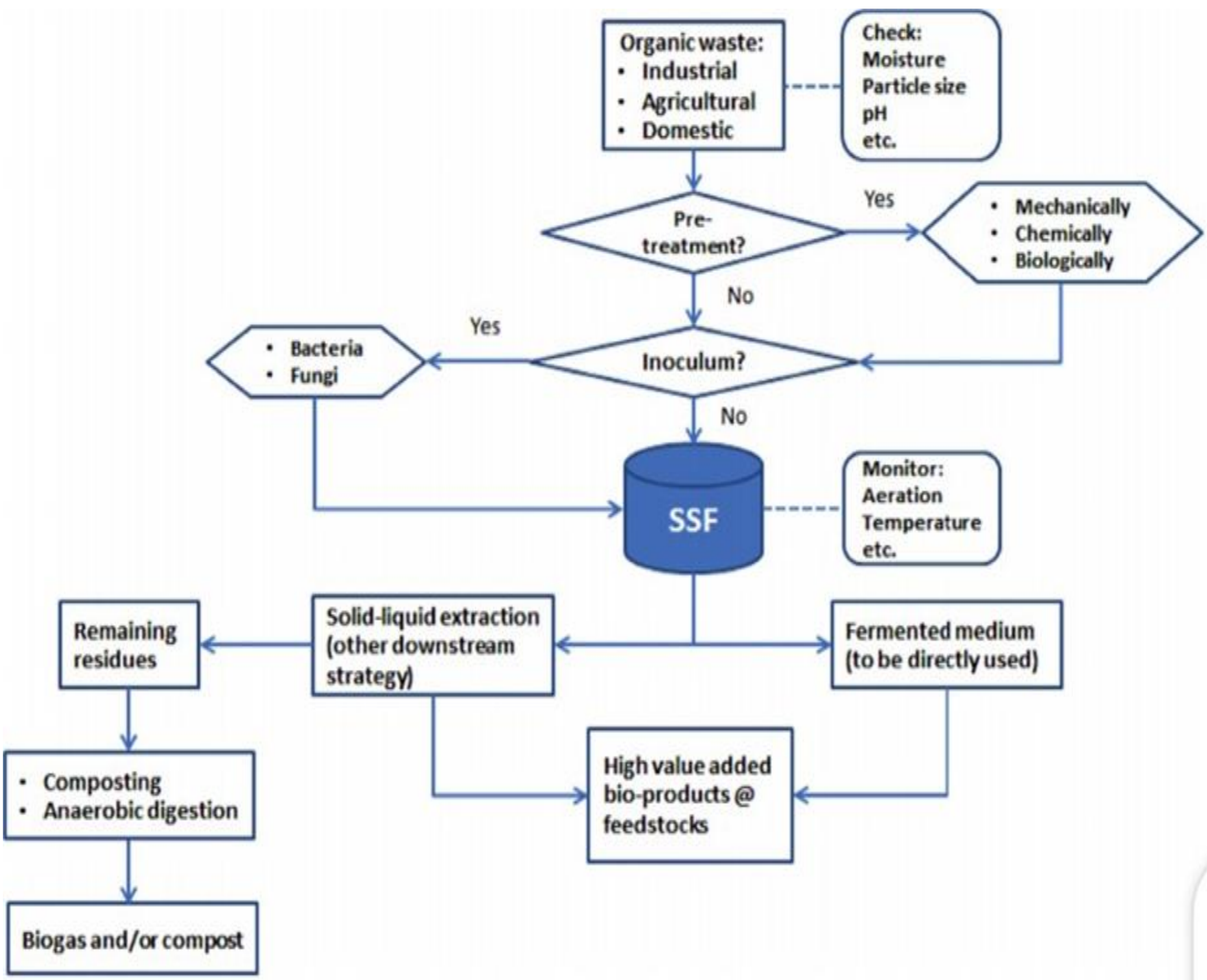

Figure 6. Bioproducts produced from Solid State Fermentation (SSF) (Yazid *et al.*, 2016)

Agricultural trash, home food waste, human and animal wastes, and other organic solid wastes make up the majority of organic solid wastes. Normally, they are used as animal feed, burnt, or disposed of in landfills (Mussatto *et al.*,2012). Nonetheless, incineration is an expensive disposal approach that pollutes the air. On the other side, microbes generally break down and digest organic waste in landfills, resulting in leachate, which contaminates ground water. Furthermore, the decomposition of these organic wastes in such condition's releases methane, which is 25 times more destructive than carbon dioxide as a greenhouse gas (Sanhez *et al*.,2015). Organic solid wastes, on the other hand, contain compounds high in proteins, minerals, and sugars that could be employed as substrates or raw materials in other processes. Because microorganisms require primarily carbon, nutrition, and moisture for cultivation and development. As a result, organic waste could be an excellent choice for providing the necessary nutrients and circumstances for these bacteria to proliferate and grow. Microorganisms will play a key role in decomposing organic wastes into their constituents and converting them into high-value-added products in this regard. Microorganisms growing on solid and moist surfaces that act as nutrition sources for microbial development in the absence or near absence of water carry out this important SSF process (Holker *et al.,* 2005).

Anaerobic digestion

Anaerobic digestion (AD) is the process of converting organic matter directly into biogas, which is a mixture of mostly methane and carbon dioxide with small amounts of other gases like hydrogen sulfide. Methane is the primary component of biogas, which is utilized for cooking and heating in many households. The biodigester, or abiogas plant, is a physical structure used to provide an anaerobic condition that stimulates various chemical and microbiological reactions resulting in the decomposition of input slurries and the production of biogas—mostly methane—the biogas has a chemical composition similar to that of natural gas (Balat, 2008). After proper gas purification, biogas can be utilized as a fuel for engines, gas turbines, fuel cells, boilers, industrial heaters, and other activities, as well as for chemical manufacture. Treatment or stabilization of biodegradable materials prior to land filling can be achieved using a combination of anaerobic digestion and aerobic composting. Methane is created today by the same anaerobic microorganisms that produced natural gas. Anaerobic bacteria are among the most ancient forms of life on the planet. They developed before green plants' photosynthesis discharged vast amounts of oxygen into the atmosphere. In the absence of oxygen, anaerobic bacteria break down or digest organic matter, producing biogas as a waste product.

Chemical recycling

Chemical recycling is not yet fully developed, which is why only a few companies are working on it. This process requires a significant amount of investment and experienced employees. Numerous ways are now being investigated; for example, substantial research is being conducted to determine the best conditions for gasification and pyrolysis, and the processes that have reached commercial maturity are glycolysis and methanolysis (Francis, 2016; Achilias *et al.*,2007; Karayannidis *et al*., 2002). Some reagents, such as water (hydrolysis), acids (acidolysis), glycols (glycolysis), or alcohols, can cleave PET (polyethylene terephthalate) (alcoholysis). Different results are obtained depending on the reagent used. Hydrolysis is a recycling process that involves a reaction of PET with water in an acid, alkaline, or neutral environment, resulting in total depolymerization of the PET into its monomers. The disadvantages of the hydrolysis process are indicated by the high temperatures (between 200 and 250 °C), by pressures (between 1.4 and 2 MPa) and by the long time needed to complete depolymerization.

Biosorption

The ability of biomass or certain biomolecules to bind and concentrate chosen ions or other molecules from aqueous solutions is known as biosorption (Volesky, 2007). It is a passive process that is unaffected by metabolic activity. As a result, no nutrients are required, and activities can be carried out in highly toxic settings. Biosorption has mostly been used to remove harmful metals such as arsenic, chromate, cadmium, and uranium from polluted waterways (Volesky and Holan, 1995). Metal-containing solutions, such as industrial waste waters, leachates, and mine waters, have a pH of ten, a complex composition with competing elements, and toxic chemicals or organic compounds that alter biosorptive characteristics. Therefore, major challenges of biosorptive approaches are stability of materials, selectivity, effectivity, and cost efficiency. Different approaches use the metal binding motifs of natural proteins, e.g. metallothioneins, as biosorptive component. Metallothioneins (MT) are cysteine-rich proteins that bind different metals such as Cd, Hg, Cu and Pb. MTs from different natural sources have been expressed in *E. coli* and *Pseudomonasputida* and used as biosorbent, mainly for removal of heavy metals (Chen *et al.,* 1999) and (Mejare and Bulow, 2001).

Bioreduction

Platinum, palladium, rhodium, and ruthenium are platinum group metals that are widely utilized in medicine, electronics, optical devices, and catalysis (Yong *et al*., 2003). It is frequently employed as a catalyst, for example, in vehicle catalytic converters or in chemical syntheses. Although palladium and other precious metals have a high technical recyclability, large amounts of Pd are emitted during the manufacturing, consumption, and recycling processes. Pd effective recycling procedures that avoid secondary waste streams of harmful chemicals, as well as efficient recovery of Pd from industrial waste waters, are required to minimize Pd loss and enable a circular economy. The use of Pd (II) reducing microorganisms is an appealing strategy that combines the removal of Pd from waste streams, hence minimizing Pd loss, with the bio-reduction of nanocatalysts and non-toxic biological deposition of Pd-nanoparticles on biomass (De Corte *et al.,* 2012). The catalysts themselves can be employed to degrade a variety of resistant contaminants or to create chemical syntheses (Lloyd *et al.,*1998; Yates *et al*.,2013).

Biowaste for Fertilizers Production

Chemical fertilizers mostly containing nitrogen, phosphorus, and potassium (NPK) have had substantial environmental repercussions throughout the years, as these fertilizers have been sprayed widely across many regions around the world (Savci *et al*., 2019). This necessitates the conversion of various types of biomass waste into organic fertilizers, such as animal manure, sewage sludge waste, and food waste. Animal-based organic waste (manure), compost (plant sources and food waste), and urban garbage (sewage sludge and domestic waste) are the three types of organic waste that can be used as agricultural fertilizers (Uysal *et al.,* 2011).

Animal manures

Manures are organic in nature and contain beneficial nutrients such as nitrogen and phosphorus, which can be utilized as fertilizers to generate high yielding and high-quality crop products. The control of these cattle excrements is crucial since they may have negative long-term consequences on soil aggregation (Guo *et al.*, 2019). The nutrients from the excretions will concentrate on the soil's surface, where they will be flushed into water streams by rainfall or surface runoff, causing algae to proliferate and eutrophication (Lee *et al.*, 2013). Aside from that, cattle excretions are a significant source of GHG pollution, diseases, and stink. As a result, a suitable manure management technique, such as energy fertilizer conversion, is required to create minimal environmental effects while permitting the efficient recycling of plant nutrients (Lee *et al.*,2013; Sharara *et al.*,2018). The advantages of using manure as an organic fertilizer, as well as issues for long-term use of these manures, must be considered. Animal waste combined with chemical fertilizer, such as nitrogen fertilizer, yielded no meaningful results, possibly because the activity of the livestock manure was reduced in the presence of nitrogen fertilizer (Esmailpour *et al.*, 2013). After a three-month growth stage, using efficient microorganisms or biofertilizers for rice growth on farm yard additions was also found to be superior to NPK enriched soils.

Food waste composting

Composting is a long-term method of turning organic and biodegradable food waste into a stable form of organic matter and fertilizers that can be utilized as soil amendments in agriculture (Wolka *et al.*,2015). The type of raw materials utilized, the composting process, the circumstances of decomposition, and the addition of nutrients during composting all influence the content and quality of compost. Converting food and municipal solid waste to compost and using it to improve crop production and soil fertility will help with soil organic matter management and carbon footprint reduction (Razza *et al*.,2018). Nonetheless, there are a few obstacles to overcome in the composting process:

1) The process is lengthy and could take up to three to four months for a small-scale operation
2) there may be acidification of soil and odor emissions during composting
3) there are possibilities of heavy metals contamination;
4) the economic prospects of a composting facility is uncertain (Li *et al.*, 2019). Hence, more effective and efficient methods of composting need to be developed to make the management of food waste through composting a promising direction for sustainability.

5. CONCLUSION

One of the most significant environmental issues is waste. Inadequate waste management disrupts the environment, resulting in pollution of the air, water, and soil, posing a serious hazard to human health. According to certain research, the local population has low birth weight, congenital abnormalities, and a few types of cancer. The properties of wastes are greatly influenced by poor bin collecting techniques, collection, transfer, and/or transport systems. The disposal of plastic garbage is a serious global environmental issue. Plastics, which are fundamentally hydrocarbons, have calorific values ranging between 30 and 40 MJ/kg. To lessen their environmental impact, they can be burned, cremated, or destroyed utilizing enzymes from microbes. Effective planning ahead of time will prevent indiscriminate disposal and other hazardous behaviors, preventing the construction of open dumps and breeding grounds for rats and other vermin, both of which are health hazards.

References

[1] Brunner, P.H. & Rechberger, H. (2014). Waste to energy—key element for sustainable waste management. *Waste Management,* 37: 3-12

[2] Sakai, S., Sawell, S. E., Chandler, A. J., Eighmy, T. T., Kosson, D. S., Vehlow, J., ... & Hjelmar, O. (1996). World terends in municipal solid waste management. *Waste Management*, 16(5-6), 341-350

[3] Vergara, S.E. & Tchobanoglous, G. (2012). Municipal Solid Waste and the Environment: A Global Perspective. *Environmentand Resources,* 37(37): 277-309

[4] Tchobanoglous, G., Theisen, H. & Vigil, S. (1993). Integrated Solid Waste Management: Engineering Principles and ManagementIssues. *Water Science & Technology Library,* 8(1): 63-90

[5] Wilson, D.C. (2007). Development drivers for waste management. *Waste Management & Research the Journal of the InternationalSolid Wastes & Public Cleansing Association Iswa*, 25(3): 198-207

[6] Wilson, D.C., Araba, A.O., Chinwah, K. & Cheeseman, C.R. (2009). Building recycling rates through the informal sector. *Waste Management,* 29: 629–635

[7] Williams, P. T., Cunliffe, A., & Jones, N. (2005). Recovery of value-added products from the pyrolytic recycling of glass-fibre-reinforced composite plastic waste. *Journal of the Energy Institute*, 78(2), 51-61

[8] White, P.R., Franke, M. & Hindle, P. (1995). Integrated Solid Waste Management: A Life cycle Inventory. Berlin: Springer, 12-15.

[9] Basu, R. (2009). Solid Waste Management- A Model Study. *Sies Journal of Management,* 6: 20-24

[10] Dijkema, G.P.J., Reuter, M.A. & Verhoef, E.V. (2000). A new paradigm for waste management. *Waste Management,* 20: 633–668

[11] Cheremisinoff, N.P. (2003). Hand book of solid waste managementand waste minimizatio technologies[electronicresource]. Oxford: Butter worth-Heinemann.

[12] Demirbas, A. (2011). Waste management,waste resource facilities and waste conversion processes. *Energy Conversion & Management,* 52(2): 1280-1287

[13] Dixon, N. & Jones, D.R.V. (2005). Engineering properties of municipalsolid waste. *Geotextiles & Geomembranes,* 23(3): 205-233

[14] Beranek, W. (1992). Solid Waste Management and Economic Development. *Economic Development Review*, 10: 49

[15] Kaseva, M.E. & Gupta, S.K. (1996). Recycling—an environmentally, friendly and incomegenerating activity towards sustainable solid waste management. Casestudy—Dares Salaam City, Tanzania. *Resources Conservation & Recycling*, 17(4): 299-309

[16] Buah, W.K., Cunliffe, A.M. & Williams, P.T. (2007). Characterization of Products from the Pyrolysis of Municipal Solid Waste. *Process Safety & Environmental Protection*, 85(5): 450-457

[17] Ngoc, U.N. & Schnitzer, H. (2009). Sustainable solutions for solid waste managementin Southeast Asian countries. *Waste Management*, 29(6): 1982-1995

[18] Shafigh, P., Mahmud, H.B., Jumaat, M.Z. & Zargar, M. (2014). Agriculturalwastes as aggregate inconcrete mixtures—Areview. *Construction & Building Materials*, 53(3): 110-117

[19] Seadi, T.A. & Holm-Nielsen, J.B. (2004). Agriculturalwastes. InI. Twardowska,H.E.A. Antonius, A.F. Kettrup, &W.J. Lacy (Eds.), Waste Management Series, Solid Waste: Assessment, Monitoringand Remediation, 207-215.

[20] Girotto, F. (2015). Food waste generation and industrial uses: A review. *Waste Management*, 45: 32-41

[21] Siddique, R., Khatib, J. & Kaur, I. (2008). Use of recycled plastic inconcrete: a review. *Waste Management*, 28: 1835–1852

[22] Kan, A. (2009). General characteristics of waste management:a review. *Energy Education and Science Technology Part A*, 23: 55–69

[23] Batayneh, M., Marie, I. & Asi, I. (2007). Use of selected waste materials inconcrete mixes. *Waste Management*, 27: 1870–1876

[24] Cardak, O. (2009). The determination of the knowledge level of science students on energy flow through a word association test. *Energy Education and Science Technology Part B*, 1: 139–155

[25] Altin, S., Altin, A., Elevli, B. & Cerit, O. (2003). Determination of hospital waste compositionand disposal methods: a case study. *Polish Journal of Environmental Studies*, 12: 251–255

[26] Uygur, K.F. (2004). Biological nutrient removal from pre-treated landfill leachate in a sequencing batch reactor. *Journal of Environmental Management*, 71: 9–14

[27] Erses, A.S. & Onay, T.T. (2003). Insitu heavy metal attenuation in landfills under methanogenic conditions. *Journal of Hazardous Materials B*, 99: 159–175

[28] Yang, W., Nam, H. & Choi, S. (2007). Improvementof operating conditions in waste incineratorsusing engineering tools. *Waste Management*, 27: 604–613

[29] Ecke, H. & Svensson, M. (2008). Mobility of organic carbon from incineration residues. *Waste Management*, 28: 1301–1309

[30] Balat, M. (2008). Progress in biogas production processes. *Energy Education and Science Technology*, 22: 15–36

[31] Bhat, R.A., Dar, S.A., Dar, D.A. & Dar, G. (2018). Municipal Solid Waste Generation and current Scenario of its Management in India. *International Journal of Advanced Resources and Science Engineering,* 7: 419–431

[32] Khan, S.A., Suleman, M. & Asad, M. (2019). Assessment of pollution load in marble waste water in Khairabad, District Nowshera, Khyber Pukhtunkhwa, Pakistan. *International Journal of Economic and Environmental Geology,* 8: 35–39

[33] Varjani, S.J., 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

[34] Holanda, R. & Johnson, D.B. (2020). Removal of zinc from circum-neutral pH mine-impacted waters using a novel "hybrid" low pH sulfidogenic bioreactor. *Frontier Environmental Science*, 8: 22

[35] Sahay, S., Iqbal, S., Inam, A., Gupta, M. & Inam, A. (2019). Waste water irrigation in the regulation of soil properties, growth determinants, and heavy metal accumulation in different Brassica species. *Environmental Monitoring Assessment,* 191: 107

[36] Mani, D. & Kumar, C. (2014). Biotechnological advances in bioremediation of heavy metals contaminated ecosystems: An overview with special reference to phytoremediation. *International Journal of Environmental Science and Technology,* 11: 843–872

[37] Alam, P. & Ahmade, K. (2013). Impact of Solid W aste on Health and The Environment. *International Journal of Sustainable and Developmental Green Economic*, 2: 165–168

[38] Villalba, G., Segarra, M., Fernandez, A. I., Chimenos, J. M., & Espiell, F. (2002). A proposal for quantifying the recyclability of materials. *Resources, Conservation and Recycling,* 37(1), 39-53

[39] Lienig, J. & Bruemmer, H. (2017). Recycling Requirements and Design for Environmental Compliance. Fundamentals of Electronic Systems Design, Springer, 193–218

[40] Geissdoerfer, M., Savaget, P., Bocken, M.P. & Hultink, E.J. (2017). The Circular Economy–A new sustainability paradigm? *Journal of Cleaner Production,* 143: 757–768

[41] Layton, J. (2009). Eco"- plastic: recycled plastic. Science. Retrieved 9 June 2014.

[42] Starovoytova, D. (2018). Solid Waste Management (SWM) at a University Campus (Part 1/10): Comprehensive-review on legal framework and background to waste management, at a global context. *Journal of Environment and Earth Science,* 8(4), 2225-0948

[43] Mazzon, M., Cavani, L., Margon, A., Sorrenti, G., Ciavatta, C. & Marzadori, C. (2018). Changes in soil phenol oxidase activities due to long-term application of compost and mineral Nina walnut orchard. *Geoderma,* 316: 70–77

[44] Hölker, U. & Lenz, J. (2005). Solid-state fermentation--are there any biotechnological advantages? *Current Opinion in Microbiology,* 8: 301–306

[45] Francis, R. (2016). Recycling of Polymers: Methods, Characterization and Applications; John Wiley & Sons: Hoboken, NJ, USA, 2016.

[46] Achilias, D.S., Roupakias, C., Megalokonomos, P., Lappas, A.A. & Antonakou, E.V. (2007). Chemical recycling of plastic wastes made from polyethylene (LDPE and HDPE) and polypropylene (PP). *Journal of Hazardous Materials*, 149: 536–542

[47] Karayannidis, G.P. & Achilias, D.S. (2007). Chemical Recycling of Poly(ethylene terephthalate). *Macromolecules and Material Engineering,* 292: 128–146

[48] Volesky, B. & Holan, Z.R. (1995). Biosorption of Heavy Metals. *Biotechnology Program*, 11(3): 235-250

[49] Chen, W., Bruhlmann, F., Richins, R.D. & Mulchandani, A. (1999). Engineering of improved microbes and enzymes for bioremediation. *Current Opinion in Biotechnology*, 10(2): 137-141

[50] Mejare, M. & Bulow, L. (2001). Metal binding proteins and peptides in bioremediation and phytoremediation of heavy metals. *Trends in Biotechnology,* 19(2): 67-73

[51] Yong, P., Rowson, N.A., Farr, J.P., Harris, I.R. & Macaskie, L.E. (2002). Bioreduction and biocrystallization of palladium by Desulfovibrio desulfuricans NCIMB8307. *Biotechnology and Bioengineering,* 80: 369-379

[52] DeCorte, S., Bechstein, S., Lokanathan, A.R., Kjems, J., Boon, N. & Meyer, R.L. (2013). Comparison of bacterial cells and amine- functionalized abiotic surfaces as support for Pd nanoparticle synthesis. *Colloid Surface B,* 102: 898-904

[53] Lloyd, J.R., Yong, P. & Macaskie, L.E. (1998). Enzymatic recovery of elemental palladium by using sulfate-reducing bacteria. *Applied Environmental Microbiology,* 64: 4607- 4609

[54] Yates, M.D., Cusick, R.D. & Logan, B.E. (2013). Extracellular palladium nanoparticle production using Geobactersulfur reducens. *ACS Sustainable Chemical Engineering,* 1(9): 1165-1171

[55] Guo, Z., Zhang, J., Fan, J., Yang, X., Yi, Y., Han, X., Wang, D., Zhu, P. & Peng, X. (2019). Does animal manure application improve soil aggregation? Insights from nine long-term fertilization experiments. *Science Total Environment,* 660: 1029–1037

[56] Lee, Y. & Oa, S.W . (2013). Nutrient transport characteristics of livestock manure in a farm land. *International Journal of Recycling Organic Waste Agriculture,* 2: 1.

[57] Sharara, M. & Sadaka, S. (2018). Opportunities and Barriers to Bioenergy Conversion Techniques and Their Potential Implementation on Swine Manure. *Energies*, 11: 957.

[58] Esmailpour, A., Hassanzadehdelouei, M. & Madani, A. (2013). Impact of Livestock Manure, Nitrogen and Biofertilizer (Azotobacter) on Yield and Yield Components Wheat (Triticum aestivum L.). *Agronomic Resources on Mold,* 46: 5–15

[59] Wolka, K. & Melaku, B. (2015). Exploring selected plant nutrient in compost prepared from food waste and cattle manure and its effect on soil properties and maize yield at Wondo Genet, Ethiopia. *Environmental System Resources,* 4: 1–7

[60] Razza, F., D'Avino, L., L'Abate, G. & Lazzeri, L. (2018). The role of compost in bio-waste management and circular economy. In Designing Sustainable Technologies, Products and Policies; Springer: Berlin, Germany, 133–143

[61] Li, Y., Jin, Y., Borrion, A. & Li, H. (2019). Current status of food waste generation and management in China. *Bioresources Technology,* 273:654–665

[62] Chew, K. W., Chia, S. R., Yen, H. W., Nomanbhay, S., Ho, Y. C., & Show, P. L. (2019). Transformation of biomass waste into sustainable organic fertilizers. *Sustainability*, 11(8), 2266

[63] Uysal, M., & Yilmaz, K. (2011). Effect of mineral admixtures on properties of self-compacting concrete. *Cement and Concrete Composites,* 33(7), 771-776

[64] Yazid, N. A., Barrena, R., & Sánchez, A. (2016). Assessment of protease activity in hydrolysed extracts from SSF of hair waste by and indigenous consortium of microorganisms. *Waste Management*, 49, 420-426