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Waste management, waste resource facilities and waste conversion processes

Ayhan Demirbas *

Sirnak University, Engineering Faculty, Sirnak, Turkey

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ABSTRACT

In this study, waste management concept, waste management system, biomass and bio-waste resources, waste classification, and waste management methods have been reviewed. Waste management is the collection, transport, processing, recycling or disposal, and monitoring of waste materials. A typical waste management system comprises collection, transportation, pre-treatment, processing, and final abatement of residues. The waste management system consists of the whole set of activities related to handling, treating, disposing or recycling the waste materials. General classification of wastes is difficult. Some of the most common sources of wastes are as follows: domestic wastes, commercial wastes, ashes, animal wastes, biomedical wastes, construction wastes, industrial solid wastes, sewer, biodegradable wastes, non-biodegradable wastes, and hazardous wastes.

1. Introduction

The amount of waste has been steadily increasing due to the increasing human population and urbanization. Waste materials are generated from manufacturing processes, industries and municipal solid wastes (MSW) [1]. MSW is defined as waste durable goods, nondurable goods, containers and packaging, food scraps, yard trimmings, and miscellaneous inorganic wastes from residential, commercial, and industrial sources. Liquid waste management is consists of wastewater treatment, sewage treatment, and chemical and biochemical processing. Waste management practices differ for developed and developing nations, for urban and rural areas, and for residential and industrial, producers.

The process of extracting resources or value from waste is generally referred to as recycling, meaning to recover or reuse the material. There are a number of different methods by which waste material is recycled: the raw materials may be extracted and reprocessed, or the heat content of the waste may be converted to electricity. New methods of recycling are being developed continuously, and are described briefly below:

– Physical reprocessing.
– Biological reprocessing.
– Energy recovery.

Waste management is one of the major environmental concerns in the world. Human activities and changes in lifestyles and consumption patterns have resulted in an increase in solid waste generation rates. Waste management is also carried out to recover resources from it. Waste management can involve solid, liquid, gaseous or radioactive substances, with different methods and fields of expertise for each. Various types of waste can be collected separately. Early researcher mentioned as the waste management is one of the public infrastructures that are based on a specific type of physical infrastructure to provide the goods or services, and in this respect it resembles the electricity, natural gas, and water sector [1–5].

Education and awareness in the area of waste and waste management is increasingly important from a global perspective of resource management. The role of sustainable waste management is to reduce the amount of waste that is discharged into the environment by reducing the amount of waste generated. Waste is mostly dumped in the countryside or burned in open fires. The resulting pollutions can cause hygienically and environmentally problems. For improving such situations, concepts have to be designed. Wastes polluting the environment and threaten human health requires the public education. Educating personnel will also improve the efficiency of the waste management system and minimize its possible health and environmental risks. Improper management of wastes can lead to serious health threats as a result of fires, explosions, and contamination of air, soil, and water. Likewise, improper waste management and disposal pose threats to those living in nearby communities and can result in costly cleanups [6–11].

2. Waste management concept

Waste management is the collection, transport, processing, recycling or disposal, and monitoring of waste materials. A typical waste management system comprises collection, transportation,

* Tel.: +90 462 230 7831; fax: +90 462 248 8508.
E-mail address: ayhandemirbas@hotmail.com

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pre-treatment, processing, and final abatement of residues. The purpose of waste management is to provide sanitary living conditions to reduce the amount of matter that enters or leaves the society and encourage the reuse of matter within the society.

A waste management concept including the following goals [1]:

1. Reduction of total amount of waste by reduction and recycling of refuse.
2. Recycling and re-introduction of suitable groups of substances into production cycles as secondary raw material or energy carrier.
3. Re-introduction of biological waste into the natural cycle.
4. Best-possible reduction of residual waste quantities, which are to be disposed on "suitable" landfills.
5. Flexible concept concerning fluctuations in waste quantities and the composition of domestic waste. New developments in the field of waste management must be included into the system.

The initial situation of a developing country in the field of waste management differs compared to industrialized countries. The transfer of proven technology from one country to another can be quite inappropriate although technically viable or affordable [12]. Very important is the need to understand the local factors such as waste characteristics and seasonal variations in climate, the social aspects, cultural attitudes towards solid waste and political institutions as well as having an awareness of the more obvious resource limitations which often exist.

One goal of the teaching and training module is to deepen the knowledge of students in the field of waste management. The user will be provided with descriptions to the following topics which are important when dealing with waste management [1–11]:

– generation and composition of waste,
– physical, thermal and biological treatment,
– environmental management,
– collection and transport,
– composting and digestion,
– recycling, reducing, reusing,
– landfilling and aftercare,
– hazardous waste.

3. Waste management system

The waste management system consists of the whole set of activities related to handling, treating, disposing or recycling the waste materials. The purpose of waste management system is to make sure that the waste materials are removal from the source or location where they are generated and treated, disposed of or recycled in a safe and proper manner. The system consists of several steps as tabulated in Table 1. Modern waste management systems, which many developing country cities aspire to, are all characterized by 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., transformation of the waste materials into useful products, and (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.

Advanced waste management systems include prioritized management strategies to minimize environmental problems and preserve resources. Waste management strategies are categorized into four areas with respect to their final disposition of the waste:

Table 1
Components of waste management system.

Main components	Subparts
Production of materials	Waste sources Source separation Internal collection Production rates Waste types
Collection and transport	Collection Transport Transfer
Treatment or reprocessing	Physical reprocessing: Shredding, sorting, compacting Thermal reprocessing: Incineration, gasification Biological reprocessing: Anaerobic digestion, aerobic composting
Final disposition	Recycling Land filling

– minimization or prevention of waste generation,
– recycling of waste,
– thermal treatment with energy recovery,
– land filling.

Minimization of waste has the top priority is generally the responsibility of the waste producer.

Recycling has second priority as it results in the recovery of materials that can be used as raw materials for other purposes than the one where it was generated. When recycling began to be recognized as essential for both environmental and resource management reasons, recycling rates for household wastes in most developed countries in the 1980s were in the low single figures by percent. Modern western waste management systems have rebuilt recycling rates over the last 20 years [5].

Disposal options can be categorized environmental impacts into six levels, from low to high; namely, reduce, reuse, recycle, compost, incinerate and landfill [13].

Collection is not an ordinary job. Waste collection methods vary widely between different countries and regions. Domestic waste collection services are often provided by local government authorities, or by private industry. Some areas, especially those in less developed countries, do not have a formal waste-collection system [1].

The level and type of waste generated by a business will reflect the nature and size of its operation. To manage waste effectively businesses must understand the quantity and type of waste that occurs on site, the reasons why it is generated and find opportunities to prevent or reduce the generation of that waste. Waste streams generated on site that cannot be avoided should be

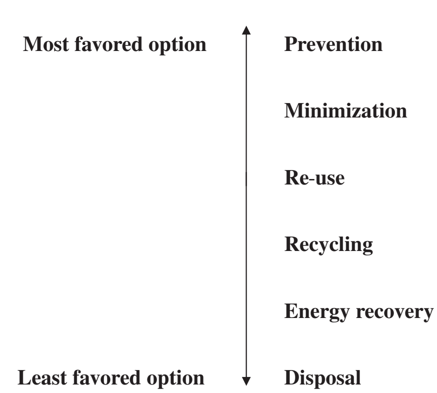

Fig. 1. Waste management hierarchy.

appropriately stored and transferred to appropriately regulated waste contractors for off-site treatment.

Large quantities of waste cannot be eliminated. However, the environmental impact can be reduced by making more sustainable use of the waste. This is known as the "waste hierarchy" [1,14]. The waste hierarchy refers to reduce, reuse and recycle, which classify waste management strategies according to their desirability in terms of waste minimization. The hierarchy of disposal options, which categorizes environmental impacts into six levels, from low to high; namely, reduce, reuse, recycle, compost, incinerate and landfill [13]. The waste hierarchy remains the cornerstone of most waste minimization strategies. The aim of the waste hierarchy is to extract the maximum practical benefits from products and to generate the minimum amount of waste. The hierarchy of best waste management practice is illustrated in Fig. 1.

4. Biomass and bio-waste resources

Typically, biomass refers to the nonfood part of plants. Various biomass resources include woody and herbaceous species, wood wastes, agricultural and industrial residues, waste paper, municipal solid waste, bio-solids, waste from food processing, animal wastes, aquatic plants and algae, and so on [7,15–19]. Major organic components of biomass can be classified as cellulose, hemicelluloses, and lignin. The major categories of biomass feedstock are listed in Table 2.

There are four major ways to use biomass energy: direct combustion, gasification, pyrolysis, and anaerobic digestion. In countryside regions of developing nations, combustion of dry agriculture waste has been the most important method for heating and cooking. Dry biomass can also be burned to produce electricity, gasified to produce methane, hydrogen, and carbon monoxide, or converted to a liquid fuel. The wet form of biomass, such as sewage sludge, cattle manure, and food industry waste, can be fermented to produce fuel and fertilizer. Because biomass can be converted directly into a liquid fuel, it could supply much of our transportation fuel needs in the future for cars, trucks, buses, airplanes, and trains. Solar and wind energy supported systems can be used in biomass conversion processes [10,20–27].

4.1. Solid wastes

Wastes from industrial and municipal sources present an attractive biomass source, as the material has already been collected and can be acquired at a negative cost due to tipping fees (i.e., sources will pay money to get rid of waste). Municipal solid waste (MSW) is defined as waste durable goods, nondurable goods, containers and packaging, food scraps, yard trimmings, and miscellaneous inorganic wastes from residential, commercial, and industrial sources. Contents of domestic solid waste are given in Table 3 [28].

Table 2
Major categories of biomass feedstock.

No.	Major category	Biomass feedstock
1	Forest products	Wood, logging residues, trees, shrubs and wood residues, sawdust, bark, etc.
2	Biorenewable wastes	Agricultural wastes, mill wood wastes, urban wood wastes, urban organic wastes
3	Energy crops	Short-rotation woody crops, herbaceous woody crops, grasses, forage crops
4	Food crops	Residue from grains and oil crops
5	Sugar crops	Sugar cane, sugar beets, molasses, sorghum
6	Landfill	Municipal solid wastes
7	Industrial organic wastes	Plastic wastes, oil wastes, leather wastes, rubber wastes, organic acid wastes, etc.
8	Algae, kelps, lichens, and mosses	Water hyacinth, mushrooms, etc.
9	Aquatic plants	Algae, water weed, water hyacinth, reed, and rushes

Table 3
Contents of domestic solid waste (wt% of total).

Component	Lower limit	Upper limit
Paper waste	33.2	50.7
Food waste	18.3	21.2
Plastic matter	7.8	11.2
Metal	7.3	10.5
Glass	8.6	10.2
Textile	2.0	2.8
Wood	1.8	2.9
Leather and rubber	0.6	1.0
Miscellaneous	1.2	1.8

4.2. Agriculture residues

Major agricultural residues include crop residue, straws and husks, olive pits and nut shells, and so on. The residue can be divided into two general categories: (1) field residue: material left in the fields or orchards after the crop has been harvested and (2) process residue: materials left after the processing of the crop into a usable resource. The field residues include stalks, stems, leaves, and seed pods. The process residues include husks, seeds, bagasse, and roots. Some agricultural residues are used as animal fodder, for soil management, and in manufacturing.

Cereal straw is the dry stalk of a cereal plant that is left behind in the field after the grain or seed has been removed during combining. After harvesting, a small amount of straw is used as feed, animal bedding, mushroom compost, or garden mulch, and the majority is burned or incorporated in the soil. Field burning has been practiced as a means of straw disposal, but now many countries are putting bans on this practice due to the pollution generated. The collection cost (raking, baling, etc.) of straw is around $25/ton. The volumetric energy density of straw is about 10–20 times less than that of coal or petroleum. Compaction technologies have been developed to produce straw pellets and wafers with a high mass density, but the cost of such compaction is high.

Corn stover is the non-grain and above-ground part of the corn plant consisting of stalk, tassel, leaves, cob, husk, and silk. The crown and its surface roots are not considered part of the stover. Currently, about 5% stover is used for animal bedding and feed, and the remaining is plowed into the soil. Corn stover has potential for direct burning, conversion into biofuels, and fiber for pulp and paper industry as well as the particle board and oriented strand board industries [29]. On average, the dry mater weight of a corn plant is split equally between the grain and stover. Stover is the above ground portion of the corn plant, other than grain, and consists of stalk (including tassel), leaves, cob, husk, and silks [30].

Due to its widespread production, rice husk is the world's most common residue. One ton of husk is produced for four tons of rice grain produced. Rice husk is removed from the grain in the processing plants; hence, this biomass is available in the collected form. In addition, rice husk is uniform in nature and has a better flow characteristic than other forms of biomass. Hence, biofuel technologies such as gasification can use husk, as uniform fuel quality is needed for the best results. However, husk has a relatively high silica content, which can cause ash and slag problems in the boiler on the combustion.

Sugarcane has one of the best photosynthesis efficiencies as it can convert up to 2% of incident solar energy into biomass. Each ton of sugar cane (burned and cropped) produces 135 kg of sugar and 130 kg of dry bagasse. The annual production varies from year to year, with a cane crushing period of 6–7 months. Baggase has a heating value of 19.2 MJ/kg-dry basis. Most sugar mills burn bagasse to produce heat needed for cooking of cane and for the evaporation of water from the syrup. But, usually, there is a large excess of bagasse at the plant, and, traditionally, mills have resorted to inefficient burning as a method of disposal.

There are a number of plants that can convert solar energy into biomass at a high efficiency, including herbaceous woody crops, short rotation woody crops, forage crops (alfalfa, clover, switchgrass, and miscanthus grasses), sugar crops (sugar cane, sugar beet, fiber sorghum, and sweet sorghum), starch crops (corn, barley, and wheat), and oil crops (soybean, canola, palm, sunflower, safflower, rapeseed, and cotton). Woody crops (e.g., willow, poplar) and tropical grasses (e.g., napier grass, elephant grass) are receiving more attention from energy crop companies. Woody plants grow slowly and have hard external surfaces, whereas herbaceous plants grow faster with loosely bound fibers due to lower lignin content. In fact, the relative proportion of cellulose and lignin is one of the determining factors in identifying the suitability of plant species for subsequent processing as energy crops. Both woody and herbaceous plants require specific growing conditions, including soil type, soil moisture, nutrient balances, and sunlight; all of these factors determine their suitability and production rate. Sorghum consists of numerous subspecies. Many sorghum species are used for food, such as grains and syrups. Some species are used as fodder plants, either cultivated or part of a pasture.

The oil palm is a tropical tree originally found growing wild in West Africa. Later it was developed into an agricultural crop in Malaysia. Oil palm plants can produce about 4–5 tons of oil/ha/year, which is about 10 times the yield of oil from soybean. Oil palm is the highest oil-producing plant on a per acre basis.

A nonedible oil plant that is gaining prominence is Jatropha. The Jatropha curcas variety is suitable for oil production, as its seeds contain up to 37 wt% oil. It is a drought-resistant perennial and grows well in marginal/poor soil. The plant can keep producing seeds for up to 50 years. Seeds need to be harvested at maturity, and not all fruits mature at the same time.

4.3. Pulp and paper industry waste

Operations in the pulp and paper industry generate a vast amount of biomass residue, including bark, leaves, needles, branches, and sludge. The nonsludge biomass can easily be used in one of the biofuel production processes. Pulp mill sludge represents an attractive feedstock for biofuels, as currently most of the sludge is disposed in landfills where it degrades to methane gas, a more harmful greenhouse gas than carbon dioxide. By using it in biofuel production, land and water contamination from landfills can be avoided.

Another byproduct is black liquor, which contains a significant energy value due to the dissolved lignin. Currently, black liquor is combusted to produce needed energy in the paper mill, and the extra energy is used to raise electricity for export. Black liquor composition can be represented as $C_{10}H_{12.5}O_7Na_{2.4}S_{0.36}$ [31,32], and its components with energy value mainly consist of dissolved lignin degradation products along with the cellulosic and hemicellulosic hexose and pentose sugar degradation products [33].

4.4. Wood and forest waste

Forest harvesting, a major source of biomass for energy, is carried out to thin young stands, to cut old stands for timber/pulping, or to remove the stands damaged by insects, disease, or fire. The tops and branches are obtained that have little timber or pulp value but have good energy content. Forest residues normally have low density and fuel values that keep transport costs high, and so it is economical to reduce the biomass density in the forest itself. Forest management to avoid forest fires also represents an attractive source of biomass.

4.5. Algae

Due to the high light-to-biomass conversion efficiency, algae are gaining attention for fuel use. Microalgae are the fastest-growing photosynthesizing organisms, as they can complete an entire growing cycle within only a few days. In some algae, up to 50% of their mass contains oil content. Hence, production of algae oil for biodiesel is gaining attention in experimental efforts. However, due to the high cost involved in the separation of algae from water, there has not been any commercial undertaking so far. It is estimated that 40 tons of oil/ha/year can be produced using diatom algae, which is 7–31 times more than the yield from the best-performing vegetable oil plant, oil palm, and 200 times higher than the soybean plant [34–37].

Microalgae have long been recognized as potentially good sources for biofuel production because of their high oil content and rapid biomass production. The oil productivity of many microalgae exceeds the best producing oil crops. In recent years, use of microalgae as an alternative biodiesel feedstock has gained renewed interest from researchers, entrepreneurs, and the general public. Biodiesel produced from microalgae is being investigated as an alternative. The lipid and fatty acid contents of microalgae vary in accordance with culture conditions [38–46].

5. Waste classification

The waste products of a home include paper, containers, tin cans, aluminum cans, and food scraps, as well as sewage. The waste products of industry and commerce include paper, wood, and metal scraps, as well as agricultural waste products [47].

Generation refers to the amount of material that enters the waste stream before recovery, composting, or combustion. Recovery refers to materials removed from the waste stream for the purpose of recycling and/or composting. The energy content of MSW in the US is typically from 10.5 to 11.5 MJ/kg. The generation and recovery of MSW varies dramatically from country to country and deserves special mention. For example, recent estimates indicate MSW generation in the UK of about 30 million tons of which 90% is land filled. In comparison, Sweden land filled only 34% of their MSW generation [48].

There are various options available to convert solid waste to energy (WTE). Mainly, the following types of technologies are available: (1) sanitary landfill, (2) incineration, (3) pyrolysis, (4) gasification, (5) anaerobic digestion, and (6) other types. Sanitary landfill is the scientific dumping of municipal solid waste due to which the maturity of the waste material is achieved faster and hence gas collection starts even during the landfill procedure. Incineration technology is the controlled combustion of waste with the recovery of heat, to produce steam that in turn produces power through steam turbines. A gasification technology involves pyrolysis under limited air in the first stage, followed by higher temperature reactions of the pyrolysis products to generate low molecular weight gases with calorific value of 1000–1200 kcal/nm^3. These gases could be used in internal combustion engines for direct power generation or in boilers for steam generation to produce power. In biomethanation, the putrescible fraction of waste is digested anaerobically, in specially designed digesters. Under this active bacterial activity, the digested pulp produces the combustible gas methane and inert gas carbon dioxide. The remaining digestate

Table 4
General classification of wastes.

Classification	Waste description
Type 1	A mixture of highly combustible waste, primarily paper, cardboard, wood, boxes and combustible floor sweepings; mixtures may contain up to 10% by volume of plastic bags, coated paper, laminated paper, treated corrugated cardboard, oily rags and plastic rubber scraps. Commercial and industrial sources
Type 2	A mixture of combustible waste such as paper, cardboard, woodscrap, foliage, floor sweepings and up to 20% cafeteria waste. Commercial and industrial sources
Type 3	Rubbish and garbage. Residential sources
Type 4	Animal and vegetation waste from restaurants, cafeterias, hotels, etc. Institutional, club and commercial sources
Type 5	Human and animal remains consisting of carcasses, organs and solid tissue wastes from farms, laboratories and animal pounds
Type 6	Medical waste including sharps pathological, surgical and associated infectious waste materials
Type 7	Department store waste
Type 8	School waste with lunch programs
Type 9	Supermarket waste
Type 10	Other wastes (radiactive wastes, metallic wastes, gaseous wastes etc.)

is a good quality soil conditioner. Other technologies available are pelletization, pyro-plasma, and flash pyrolysis. All these technologies have merits and demerits [49].

The choice of technology has to be made based on the waste, quality, and local conditions. The best compromise would be to choose the technology, which (1) has lowest life cycle cost, (2) needs least land area, (3) causes practically no air and land pollution, (4) produces more power with less waste, and (5) causes maximum volume reduction [49].

General classification of wastes is difficult. Some of the most common sources of wastes are as follows. These wastes can be classified into (1) domestic wastes, (2) commercial wastes, (3) ashes, (4) animal wastes, (5) biomedical wastes, (6) construction wastes, (7) industrial solid wastes, (8) sewer, (9) biodegradable wastes, (10) non-biodegradable wastes, and (11) hazardous wastes.

Domestic wastes include the wastes generated in houses. It includes paper, plastic, glass, ceramics, polythene, textiles, vegetable waste, etc. Commercial wastes include the waste generated in commercial establishments like shops, printers, offices, go downs, etc. It includes packing materials, spoiled goods, vegetable and meat remnants, polythene, printer paper, etc. Ashes come from the burning of solid fossil fuels like coal, wood and coke. Many houses and road side eateries still use these fuels. Open burning of wastes also generates ashes.

Construction wastes generate garbage like metal rods, bricks, cement, concrete, roofing materials, etc. This type of wastes is also generated by the digging activities of the various departments like the telephone, electricity, drainage, etc. Small-scale industries generate some wastes. For example, garment factory would dump textiles of various kinds. The sewer removed from the sewerage during cleaning is often left on the roadside. This poses several health hazards to the public. The biodegradable wastes are those that can be decomposed by the natural processes and converted into the elemental form. For example, kitchen garbage, animal dung, etc. The non-biodegradable wastes are those that cannot be decomposed and remain as such in the environment. They are persistent and can cause various problems. For example, plastics, nuclear wastes, glass, etc. Hazardous wastes are potentially dangerous and can cause diseases, fire, etc. The hazardous wastes include toxic wastes. Toxic wastes are those that are poisonous in nature. Hazardous radioactive wastes react explosively with air or water; corrode other materials [50,51]. The radioactive wastes are particularly dangerous as they cause lasting damage such as change in the genetic structure of individuals (mutation). General classification of wastes is shown in Table 4.

Table 5
Selected waste treatment processes.

Waste stream		Waste disposal methods
Combustible wastes		Roaster incineration Fluid bed incineration Pyrolysis–incineration Pyrolysis–gasification Separation–composting–incineration (Wet and dry) separation-digesting-incineration Separation-digesting-pyrolysis Separation-digesting-gasification Separation-digesting-incineration in a cement plant Selective separation–incineration
Non-combustible wastes		Landfill
Partially combustible waste streams	Wood	Pyrolysis and co-incineration in a coal power plant Pyrolysis and co-incineration in a powdered coal power plant Incineration in a fluid bed furnace gasification
	Plastics	Gasification Feedstock recycling
	Organic wastes	Composting Anaerobic digestion

6. Waste management methods

Classification and assignment of different waste materials to classes cannot be easily achieved by conventional parameters [1]. Some new techniques have been proposed and developed by researchers. Nowadays not all the wastes are classified under the same classical category, requiring the same procedure of elimination. Especially in the industries in which the types of wastes are so varied it is very difficult and impractical to set up and operate a different management system for different types of wastes [7]. Thus has emerged the necessity of a, management system which would eliminate all types of wastes. Table 5 has presented a selection of promising waste treatment processes.

6.1. Disposal methods

An integrated approach is required in an attempt to manage such large quantities of a diverse, contaminated mixture of wastes in an energy efficient and environmentally benign manner. This would require examining critically various steps in the life of the wastes such as the raw materials for their manufacture, the manufacturing processes, design and fabrication of the finished products, possible reuse of those items, and the proper disposal of the wastes, in totality [1]. Such an integrated waste management concept comprises:

– source reduction,
– reuse,
– recycling,
– landfill and gas-to energy,
– waste to energy conversion.

Traditionally, solid wastes have been disposed in landfills. Landfill disposal is the most inexpensive waste management option.

Animal wastes are generated from the hospitals and include expired drugs, plastic syringes, surgical dressings, etc. They can be very infectious biomedical wastes are generated from the hospitals and include expired drugs, plastic syringes, surgical dressings, etc. They can be very infectious. Proper medical waste management requires special treatment of medical waste such as incineration or hazardous waste landfill facilities [52].

Many people see radioactive waste disposal as a complex, difficult and dangerous technological activity. The geological disposal of radioactive waste is one of the most safety method. Geological disposal is based on the concept of multiple barriers that work together to provide containment. The natural barrier is provided by the rocks and soils between the repository and Earth's surface.

6.2. Landfill

A landfill is not a normal environmental condition, though, nor is it intended to be. Instead, a landfill is more like a tightly sealed storage container. A landfill is designed to inhibit degradation to protect the environment from harmful contamination. Deprived of air and water, even organic wastes like paper and grass clippings degrade very slowly in a landfill [1].

Landfill leachates contain a large number of compounds, some of which can be expected to create a threat to health and nature if released into the natural environment. Landfill leachate treatment has received significant attention in recent years, especially in municipal areas [53]. The generation of MSW has increased in parallel to rapid industrialization. Approximately 16% of all discarded MSW is incinerated [54]; the remainder is disposed of in landfills. Effective management of these wastes has become a major social and environmental concern [55]. Disposal of MSW in sanitary landfills is usually associated with soil, surface water and groundwater contamination when the landfill is not properly constructed. The flow rate and composition of leachate vary from site to site, seasonally at each site and depending on the age of the landfill. Young leachate normally contains high amounts of volatile fatty acids [56]. MSW statistics and management practices including waste recovery and recycling initiatives have been evaluated [57]. The organic MSW was chemically and biologically characterized, in order to study its behavior during anaerobic digestion, and its pH, biogas production, alkalinity, and volatile fatty acid production was determined by Plaza et al. [58]. Anaerobic digestion of the organic food fraction of MSW, on its own or co-digested with primary sewage sludge, produces high quality biogas, suitable as renewable energy [59]. Typical analysis of raw landfill gas is given in Table 6 [28].

Table 6
Typical analysis of raw landfill gas.

Component	Chemical formula	Content
Methane	CH_4	40–60 (% by vol.)
Carbon dioxide	CO_2	20–40 (% by vol.)
Nitrogen	N_2	2–20 (% by vol.)
Oxygen	O_2	<1 (% by vol.)
Heavier hydrocarbons	C_nH_{2n+2}	<1 (% by vol.)
Hydrogen sulfide	H_2S	40–100 ppm
Complex organics	–	1000–2000 ppm

Decomposition in landfills occurs in a series of stages, each of which is characterized by the increase or decrease of specific bacterial populations and the formation and utilization of certain metabolic products. The first stage of decomposition, which usually lasts less than a week, is characterized by the removal of oxygen from the waste by aerobic bacteria [60]. In the second stage, which has been termed the anaerobic acid stage, a diverse population of hydrolytic and fermentative bacteria hydrolyzes polymers, such as cellulose, hemicellulose, proteins, and lipids, into soluble sugars, amino acids, long-chain carboxylic acids, and glycerol [61]. Fig. 2 shows the behavior of biogas production with time, in terms of the biogas components. Fig. 2 indicates that the economic exploitation of CH_4 is worthwhile after one year from the start of the landfill operation. The main components of landfill gas are by-products of the decomposition of organic material, usually in the form of domestic waste, by the action of naturally occurring bacteria under anaerobic conditions.

Methods developed for treatment of landfill leachates can be classified as physical, chemical and biological which are usually used in combinations in order to improve the treatment efficiency. Biological treatment methods used for the leachate treatment can be classified as aerobic, anaerobic and anoxic processes which are widely used for the removal of biodegradable compounds [62]. Biological treatment of landfill leachate usually results in low nutrient removals because of high chemical oxygen demand (COD), high ammonium-N content and the presence of toxic compounds such as heavy metals [53]. Landfill leachate obtained from the solid waste landfill area contained high COD and ammonium ions which resulted in low COD and ammonium removals by direct biological treatment [62]. Several anaerobic and aerobic treatment systems have been studied in landfill leachate [63]. Leachates contain non-biodegradable substrates which are not removed by biological treatment alone and an increase of leachate input may cause reduction in substrate removal [64]. Raw landfill leachate was subjected to pre-treatment by coagulation–flocculation and air stripping of ammonia before biological treatment. In order to improve biological treatability of the leachate, coagulation–flocculation and air stripping of ammonia were used as pre-treatment [65]. Natural zeolite and bentonite can be utilized as a novel landfill liner material [66].

6.3. Incineration

Incineration is a disposal method that involves combustion of waste material [1]. Incineration and other high temperature waste treatment systems are sometimes described as "thermal treatment". As stated by Yang et al. [67] a solid waste incinerator is a type of facility which is designed, built, and operated at specified design conditions. A typical incinerator processes wastes that have been collected as input material, and achieves its goal, i.e., treatment of waste material and as secondary benefit recovers heat energy from the combustion process.

Incineration is carried out both on a small scale by individuals and on a large scale by industry. It is used to dispose of solid, liquid and gaseous waste. It is recognized as a practical method of disposing of certain hazardous waste materials (such as biological medical waste). Incineration is a controversial method of waste disposal, due to issues such as emission of gaseous pollutants. Solid waste incineration generates solid residues, such as bottom ash and air pollution control residues. Besides a high content of inorganic compounds, incineration residues also contain abundant carbon compounds deriving from incomplete combustion, unburned organic matter and carbon compounds formed during the incineration

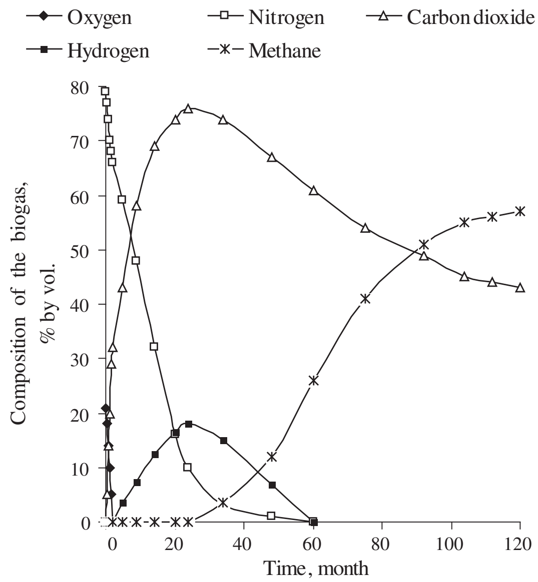

Fig. 2. Production of biogas components with time in landfill.

process [68]. In addition, the incineration of fossil carbon results in minor emissions of CO_2.

6.4. Biogas

Anaerobic digestion (AD) is the conversion of organic material directly to a gas, termed biogas, a mixture of mainly methane and carbon dioxide with small quantities of other gases such as hydrogen sulfide. Methane is the major component of the biogas used in many homes for cooking and heating. The biogas has a chemical composition close to that of natural gas, the biodigester, or a biogas plant, is a physical structure used to provide an anaerobic condition which stimulates various chemical and microbiological reactions resulting in the decomposition of input slurries and the production of biogas—mainly methane [69].

Biogas can be used after appropriate gas cleanup as a fuel for engines, gas turbines, fuel cells, boilers, industrial heaters, other processes, or for the manufacturing of chemicals. Before landfilling, treatment or stabilization of biodegradable materials can be accomplished by a combination of anaerobic digestion followed by aerobic composting.

The same types of anaerobic bacteria that produced natural gas also produce methane today. Anaerobic bacteria are some of the oldest forms of life on earth. They evolved before the photosynthesis of green plants released large quantities of oxygen into the atmosphere. Anaerobic bacteria break down or digest organic material in the absence of oxygen and produce biogas as a waste product.

The anaerobic digestion process occurs in the following four basic steps: (1) hydrolysis, (2) acidogenesis, (3) acetogenesis, and (4) methanogenesis. The AD is a bacterial fermentation process that is sometimes employed in wastewater treatment for sludge degradation and stabilization. This is also the principal process occurring in the decomposition of food wastes and other biomass in landfills. The AD operates without free oxygen and results in a fuel gas called biogas, containing mostly CH_4 and CO_2 but frequently carrying other substances such as moisture, hydrogen sulfide (H_2S), and particulate matter that are generally removed prior to use of the biogas. The AD is a biochemical process for converting biogenic solid waste into a stable, humus-like product. Aerobic conversion uses air or oxygen to support the metabolism of the aerobic microorganisms degrading the substrate. Aerobic conversion includes composting and activated sludge wastewater treatment processes. Composting produces useful materials, such as mulch, soil additives and amendments, and fertilizers.

Digestion is a term usually applied to anaerobic mixed bacterial culture systems employed in many wastewater treatment facilities for sludge degradation and stabilization. Anaerobic digestion is also becoming more widely used in on-farm animal manure management systems, and is the principal process occurring in landfills that creates landfill gas (LFG). Anaerobic digestion operates without free oxygen and results in a fuel gas called biogas containing mostly methane (CH_4) and carbon dioxide (CO_2), but frequently carrying impurities such as moisture, hydrogen sulfide (H_2S), and particulate matter.

The AD is known to occur over a wide temperature range from 10 to 71 °C. Anaerobic digestion requires attention to the nutritional needs and the maintenance of reasonable temperatures for the facultative and methanogenic bacteria degrading the waste substrates. The carbon/nitrogen (C/N) ratio of the feedstock is especially important. Biogas can be used after appropriate gas cleanup as a fuel for engines, gas turbines, fuel cells, boilers, industrial heaters, other processes, and the manufacturing of chemicals. Anaerobic digestion is also being explored as a route for direct conversion to hydrogen.

For anaerobic systems, methane gas is an important product. Depending on the type and nature of the biological components, different yields can be obtained for different biodegradable wastes. For pure cellulose, for example, the biogas product is 50% methane and 50% carbon dioxide. Mixed waste feedstocks yield biogas with methane concentrations of 40–60% (by volume). Fats and oils can yield biogas with 70% methane content.

Under anaerobic conditions, various pathways exist for pyruvate metabolism which serve to reoxidize the reduced hydrogen carriers formed during glycolysis. The ultimate acceptor builds up as a waste product in the culture medium. The end products of the pathways are: (1) CO_2, ATP, and acetate; (2) CO_2 and ethanol; (3) H_2 and CO_2; (4) CO_2 and 2,3-butylene glycol; (5) CO_2, H_2, acetone, ATP, and butanol; (6) succinate; and (7) lactate. The pathway that occurs depends on the microorganism cultivated and the culture.

7. Conclusion

Waste and recycling management plans should be developed for any construction project prior to the start of work in order to sustain environmental, economic, and social development principles.

Solid wastes comprise garbage, paper, plastics, metals, wood and synthetic materials. All living organisms have to produce some kind of waste and it has to be collected to be taken elsewhere. Many cities and towns deals with solid waste by creating a landfill; some use incinerators to burn the trash. The best way to get rid of solid waste is use a method called composting. In the process of composting, solid waste collectors use natural biological progression to swiftly decompose garbage. Solid waste is a necessary in life. Hazardous waste is the most deadly because it can harm or kill animals, humans, plants, and environments.

Unsuitable waste management practices result in the loss of resources and energy, which could be recycled and produced from a large part of the solid waste. Solid waste knowledge is hard won and too easily lost [70].

The following issues have been reviewed in this study:

- Waste management concept.
- Waste management system.

– Biomass and bio-waste resources.
– Waste classification.
– Waste management methods.

References

[1] Kan A. General characteristics of waste management: a review. Energy Educ Sci Technol Part A 2009;23:55–69.
[2] Dijkema GPJ, Reuter MA, Verhoef EV. A new paradigm for waste management. Waste Manage 2000;20:633–8.
[3] Demirbas A. Energy concept and energy education. Energy Educ Sci Technol Part B 2009;1:85–101.
[4] Kurnaz MA, Calik M. A thematic review of 'energy' teaching studies: focuses, needs, methods, general knowledge claims and implications. Energy Educ Sci Technol Part B 2009;1:1–26.
[5] Wilson DC, Araba AO, Chinwah K, Cheeseman CR. Building recycling rates through the informal sector. Waste Manage 2009;29:629–35.
[6] Demirbas A. Concept of energy conversion in engineering education. Energy Educ Sci Technol Part B 2009;1:183–97.
[7] Cardak O. The determination of the knowledge level of science students on energy flow through a word association test. Energy Educ Sci Technol Part B 2009;1:139–55.
[8] Demirbas A. Social, economic, environmental and policy aspects of biofuels. Energy Educ Sci Technol Part B 2009;1:75–109.
[9] Kecebas A, Alkan MA. Educational and consciousness-raising movements for renewable energy in Turkey. Energy Educ Sci Technol Part B 2009;1:157–70.
[10] Saidur R. Energy, economics and environmental analysis for chillers in office buildings. Energy Educ Sci Technol Part A 2010;25:1–16.
[11] Tatli ZH. Computer based education: online learning and teaching facilities. Energy Educ Sci Technol Part B 2009;1:172–81.
[12] Campbell DJV. Waste management needs in developing countries. In: Proceedings of the Sardinia conference 1993, Environmental Safety Center, Building 7.12, AEA Technology, Harwell, Oxfordshire, UK; 1993.
[13] Siddique R, Khatib J, Kaur I. Use of recycled plastic in concrete: a review. Waste Manage 2008;28:1835–52.
[14] Batayneh M, Marie I, Asi I. Use of selected waste materials in concrete mixes. Waste Manage 2007;27:1870–6.
[15] Demirbas B. Biomass business and operating. Energy Educ Sci Technol Part A 2010;26:37–47.
[16] Demirbas A. Biorefineries: current activities and future developments. Energy Convers Manage 2009;50:2782–801.
[17] Balat H. Prospects of biofuels for a sustainable energy future: a critical assessment. Energy Educ Sci Technol Part A 2010;24:85–111.
[18] Demirbas MF. Bio-oils from corn stover via supercritical water liquefaction. Energy Educ Sci Technol Part A 2009;23:97–104.
[19] Yenikaya C, Yaman H, Atar N, Erdogan Y, Colak F. Biomass resources and decolorization of acidic dyes from aqueous solutions by biomass biosorption. Energy Educ Sci Technol Part A 2009;24:1–13.
[20] Rajamohan P, Rajasekhar RVJ, Shanmugan S, Ramanathan K. Energy and economic evaluation of fixed focus type solar parabolic concentrator for community cooking applications. Energy Educ Sci Technol Part A 2010;26: 49–59.
[21] Saidur R, Lai YK. Parasitic energy savings in engines using nanolubricants. Energy Educ Sci Technol Part A 2010;26:61–74.
[22] Ralegaonkar RV, Gupta R. Application of passive solar architecture for intelligent building construction: a review. Energy Educ Sci Technol Part A 2010;26:75–85.
[23] Bugutekin A, Yilmaz M, Kentli A, Isikan MO. A mathematical model for condensation of bubbles injected through an orifice into subcooled water. Energy Educ Sci Technol Part A 2010;24:151–71.
[24] Kecebas A, Kayfeci M. Effect on optimum insulation thickness, cost and saving of storage design temperature in cold storage in Turkey. Energy Educ Sci Technol Part A 2010;25:117–27.
[25] Cerci Y. Experimental investigation of capacitor effects on performance parameters planning for household refrigerator and energy systems. Energy Educ Sci Technol Part A 2009;24:15–24.
[26] Bolukbasi A, Comakli K, Sahin S. Domestic energy savings: investigation of optimum insulation thicknesses for the external wall of rural houses in Turkey. Energy Educ Sci Technol Part A 2009;24:25–37.
[27] Mahlia TMI, Saidur R, Husnawan M, Masjuki HH, Kalam MA. An approach to estimate the life-cycle cost of energy efficiency improvement of room air conditioners. Energy Educ Sci Technol Part A 2010;26:1–11.
[28] Demirbas A. Energy priorities and new energy strategies. Energy Edu Sci Technol 2006;16:53–109.
[29] Savoie P, Descoteaux S. Artificial drying of corn stover in mid-size bales. Can Biosys Eng 2004;46:225–6.
[30] Demirbas A. Conversion of corn stover to chemicals and fuels. Energy Sources Part A 2008;30:788–96.
[31] Salmenoja K. Black-liquor gasification: theoretical and experimental studies. Biores Technol 1993;46:167–71.
[32] Backman R, Frederick WJ, Hupa M. Basic studies on black-liquor pyrolysis and char gasification. Biores Technol 1993;46:153–8.
[33] Demirbas A. Pyrolysis and steam gasification processes of black liquor. Energy Convers Manage 2002;43:877–84.
[34] Sheehan J, Dunahay T, Benemann J, Roessler P. A look back at the US Department of Energy's aquatic species program—biodiesel from algae. National Renewable Energy Laboratory (NREL) Report: NREL/TP-580-24190. Golden, CO.; 1998.
[35] Demirbas A. Production of biodiesel from algae oils. Energy Sources Part A 2009;31:163–8.
[36] Ozkurt I. Qualifying of safflower and algae for energy. Energy Educ Sci Thecnol Part A 2009;23:145–51.
[37] Demirbas MF. Microalgae as a feedstock for biodiesel. Energy Educ Sci Technol Part A 2010;25:31–43.
[38] Demirbas AH. Inexpensive oil and fats feedstocks for production of biodiesel. Energy Educ Sci Technol Part A 2009;23:1–13.
[39] Chisti Y. Biodiesel from microalgae beats bioethanol. Trends Biotechnol 2008;26:126–31.
[40] Demirbas A. Progress and recent trends in biofuels. Prog Energy Combust Sci 2007;33:1–18.
[41] Demirbas AH. Biofuels for future transportation necessity. Energy Educ Sci Technol Part A 2010;26:13–23.
[42] Demirbas A. Progress and recent trends in biodiesel fuels. Energy Convers Manage 2009;50:14–34.
[43] Keskin A, Emiroglu AO. Catalytic reduction techniques for post-combustion diesel engine exhaust emissions. Energy Educ Sci Technol Part A 2010;25: 87–103.
[44] Demirbas A. Biodiesel from waste cooking oil via base-catalytic and supercritical methanol transesterification. Energy Convers Manage 2009;50: 923–7.
[45] Demirbas A. Biofuels securing the planet's future energy needs. Energy Convers Manage 2009;50:2239–49.
[46] Demirbas A. Biofuels sources, biofuel policy, biofuel economy and global biofuel projections. Energy Convers Manage 2008;49:2106–16.
[47] Dorf RC. Energy resources and policy. California: Addison-Wesley Publishing Company; 1977.
[48] Ekmann JM, Winslow JC, Smouse SM, Ramezan M. International survey of cofiring coal with biomass and other wastes. Fuel Proc Technol 1998;54:171–88.
[49] Kumar S. Technology options for municipal solid waste-to-energy project. TERI Inform Monit Environ Sci 2000;5:1–11.
[50] Demirbas A, Balat M. Wastes to energy. Future Energy Sources 2010;2:1–63.
[51] Caglar A. Valorization of tea wastes by pyrolysis. Energy Educ Sci Thecnol Part A 2009;23:135–44.
[52] Altin S, Altin A, Elevli B, Cerit O. Determination of hospital waste composition and disposal methods: a case study. Polish J Environ Stud 2003;12:251–5.
[53] Uygur Kargi F. Biological nutrient removal from pre-treated landfill leachate in a sequencing batch reactor. J Environ Manage 2004;71:9–14.
[54] EPA. Characterization of potential of municipal solid waste (MSW) components. Municipal solid waste in the United States: 1992 Update. EPA/ 530-R-94-042, NTS #PB 95-147690. Solid waste and emergency response (5305), Washington. DC: US Environmental Protection Agency (EPA); 1994.
[55] Erses AS, Onay TT. In situ heavy metal attenuation in landfills under methanogenic conditions. J Hazard Mater B 2003;99:159–75.
[56] Timur H, Ozturk I. Anaerobic sequencing batch reactor treatment of landfill leachate. Water Res 1999;33:3225–30.
[57] Metin E, Erozturk A, Neyim C. Solid waste management practices and review of recovery and recycling operations in Turkey. Waste manage 2003;23:425–32.
[58] Plaza G, Robredo P, Pacheco O, Toledo AS. Anaerobic treatment of municipal solid waste. Water Sci Technol 1996;33:169–75.
[59] Kiely G, Tayfur G, Dolan C, Tanji K. Physical and mathematical modelling of anaerobic digestion of organic wastes. Water Res 1997;31:534–40.
[60] Augenstein D, Pacey J. Landfill methane models. In: Proceedings from the technical sessions of SWANA's 29th annual international solid waste exposition, SWANA, Silver Spring, MD, 1991.
[61] Micales JA, Skog KE. The Decomposition of forest products in landfills. Int Biodeterior Biodegr 1997;39:145–58.
[62] Kargi F, Pamukoglu MY. Adsorbent supplemented biological treatment of pre-treated landfill leachate by fed-batch operation. Biores Technol 2004;94: 285–91.
[63] Ozturk I, Altinbas M, Koyuncu I, Arikan O, Gomec-Yangin C. Advanced physico-chemical treatment experiences on young municipal landfill leachates. Waste Manage 2003;23:441–6.
[64] Cecen F, Erdincler A, Kilic E. Effect of powdered activated carbon addition on sludge dewaterability and substrate removal in landfill leachate treatment. Adv Environ Res 2003;7:707–13.
[65] Kargi F, Pamukoglu MY. Repeated fed-batch biological treatment of pre-treated landfill leachate by powdered activated carbon addition. Enzyme Microb Technol 2004;34:422–8.
[66] Kayabali K. Engineering aspects of a novel landfill liner material: bentonite-amended natural zeolite. Eng Geology 1997;46:105–14.
[67] Yang W, Nam H, Choi S. Improvement of operating conditions in waste incinerators using engineering tools. Waste Manage 2007;27:604–13.
[68] Ecke H, Svensson M. Mobility of organic carbon from incineration residues. Waste Manage 2008;28:1301–9.
[69] Balat M. Progress in biogas production processes. Energy Educ Sci Technol 2008;22:15–36.
[70] Milke M. The world's great solid waste management libraries. Waste Manage 2008;28:937–8.