Literature Review

2.1 Energy

Energy is defined as the ability to produce change or do work, and that work can be divided into several main tasks we easily recognize: Energy produces light, Energy produces heat, Energy produces motion, Energy produces sound, Energy produces growth and Energy powers technology [10].

2.2 Sources of Energy

The major energy sources we use today are classified into two broad groups; non-renewable and renewable [10].

2.2.1 Non-renewable sources

Non-renewable energy sources include coal, petroleum, natural gas, propane, and uranium. They are used to generate electricity, to heat our homes, to move our cars, and to manufacture products from candy bars to cell phones. These energy sources are called non-renewable because they cannot be replenished in a short period of time. Petroleum, a fossil fuel, for example, was formed hundreds of millions of years ago, before dinosaurs existed. It was formed from the remains of ancient sea life, so it cannot be made quickly. We could run out of economically recoverable non-renewable resources someday [10,11].

2.2.2 Renewable sources

They are called renewable energy sources because their supplies are replenished in a short time. Day after day, the sun shines, the wind blows, and the rivers flow. We use renewable energy sources mainly to make electricity [11] ,12]. Electricity is different from the other energy sources because it is a secondary source of energy. That means we have to use another energy source to make it. In the United States, coal is the number one fuel for generating electricity [13].

2.2.2.1 Solar energy

The Solar Energy Institute was established in 1978 for graduate education (MSc and PhD) and research on solar energy and its applications. Along with the solar energy, other renewable energy resources like wind, biomass and geothermal are also being studied [12].

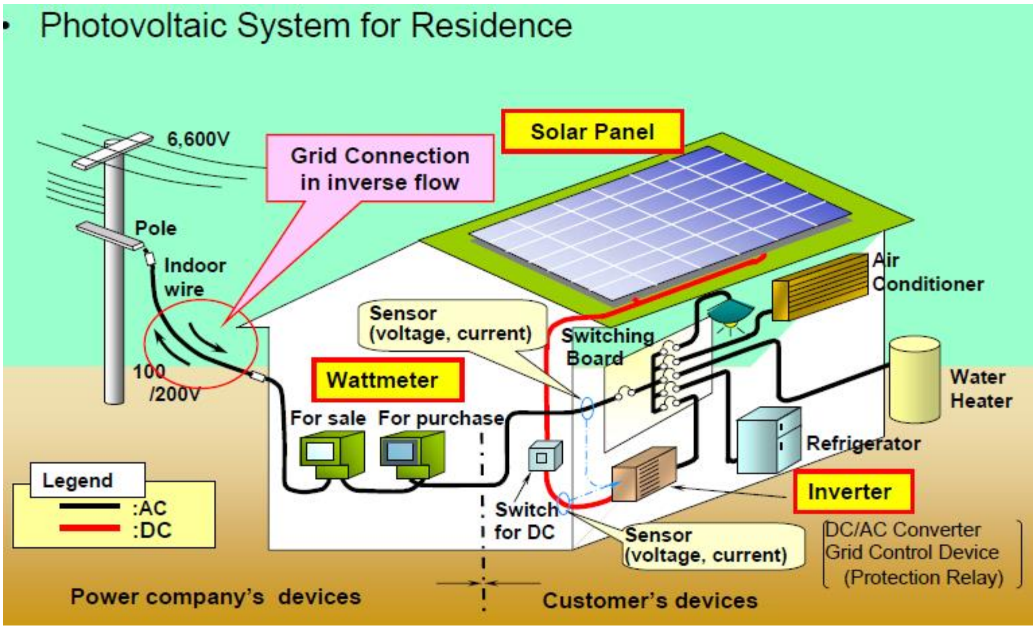

Figure 2.1 show Photovoltaic system for residence [12].

Output from solar panel is in direct current. In order to use the output for usual home appliances, direct current must be converted into alternating current through an inverter. In the system shown in the figure, solar panel is connected with the home electric circuit by way of inverter. In Japan, voltage in the home electric circuit is 100 or 200 [10].

2.2.2.2 Wind power

The power in the wind turns propeller like blades around a rotor which spins the connected generator. Power of wind is proportional to the function of the square of the blade length, and the cube of wind speed. Therefore, the longer the blade length and higher the wind speed, we can get bigger power of wind [12]. Wind has considerable potential as a global clean energy source, being both widely available, though diffuse, and producing no pollution during power generation. Wind energy has been one of humanity's primary energy sources for transporting goods, milling grain, and pumping water for several millennia [10].

Figure 2.2 show Propeller type of wind [11].

2.2.2.3 Waste

Solid waste can become a viable renewable resource through a range of waste management technologies [13]. In the description of the waste management process, it is necessary to clarify some concepts: waste and specially Municipal Solid Waste. The term "waste" might can be subject to different interpretations. There is a general understanding which notes that waste includes all mixed rubbish which is generated by human action in, either domestic, industrial or commercial activities. Directive from the Commission of Environment of the European Union defines waste as “any substance or object which the holder discards or intends or is required to discard” [4].

Human settlements and societies have always generated rubbish and throughout time, such generated amounts have become a problem [3]. Natural reserves of raw materials and energy sources decrease whereas extraction costs increase. This action generates serious environmental problems and social imbalances [5].

Solid wastes are those materials no longer useful to society. "Solid waste", and even "municipal solid waste", cannot be thought of as a single combustible material or fuel. Rather, each category of solid wastes contains a wide variety of heterogeneous solid fuels which burn with distinctive characteristics [6].

2.3 Medical Waste

Medical waste is defined as any solid, fluid or liquid waste including container and any intermediate product, which is generated during diagnosis, treatment or immunization of human beings or animals or in research activities or in the production or testing of biological products [14].

Waste generated from healthcare activities can be broadly categorised as general waste and hazardous waste [14,15]. The major portion of waste generated in healthcare activities is comprised of general waste that can be treated in the same way as domestic waste. However, this remains true only when proper segregation and separation of waste is practiced according to the type at the source. There are different estimates regarding the share of hazardous and non-hazardous constituents of healthcare waste [16].

A definition of hazardous waste was established for the first time in the USA at the beginning of the 1980s.It encompasses all substances that are hazardous to human health and the environment [17].

2.4 Hospital and Medical Waste

In general, hospital waste refers to all waste generated by hospitals including infections and non-infectious waste materials, hazardous wastes and chemicals, biological and non-biological that is discarded and not intended for further use. It consists of infectious and non-infectious solid waste, hazardous waste, and low-level radioactive waste [14,18].

Medical waste is often considered to be a subcategory of hospital waste and indicates ‘potentially’ infectious waste that is produced from healthcare facilities [19].

2.5 Classification of Medical Waste

Medical waste includes both non-hazardous and hazardous waste constituents. The non-hazardous waste includes wool, kitchen wastes, etc., that does not pose any special handling problem or hazard to health or the environment [15]. Non-hazardous waste is generated in the patients’ ward areas, out-patient-department (OPD), kitchens, offices, etc. [1,15]. The hazardous waste portion includes pathological, infectious sharps and chemical wastes. Hazardous wastes are normally produced in labour wards, operation theatres, laboratories, etc.

According to WHO the 10-25% hazardous fractions of total HCW are usually classified into the following waste groups, Figure 2.3

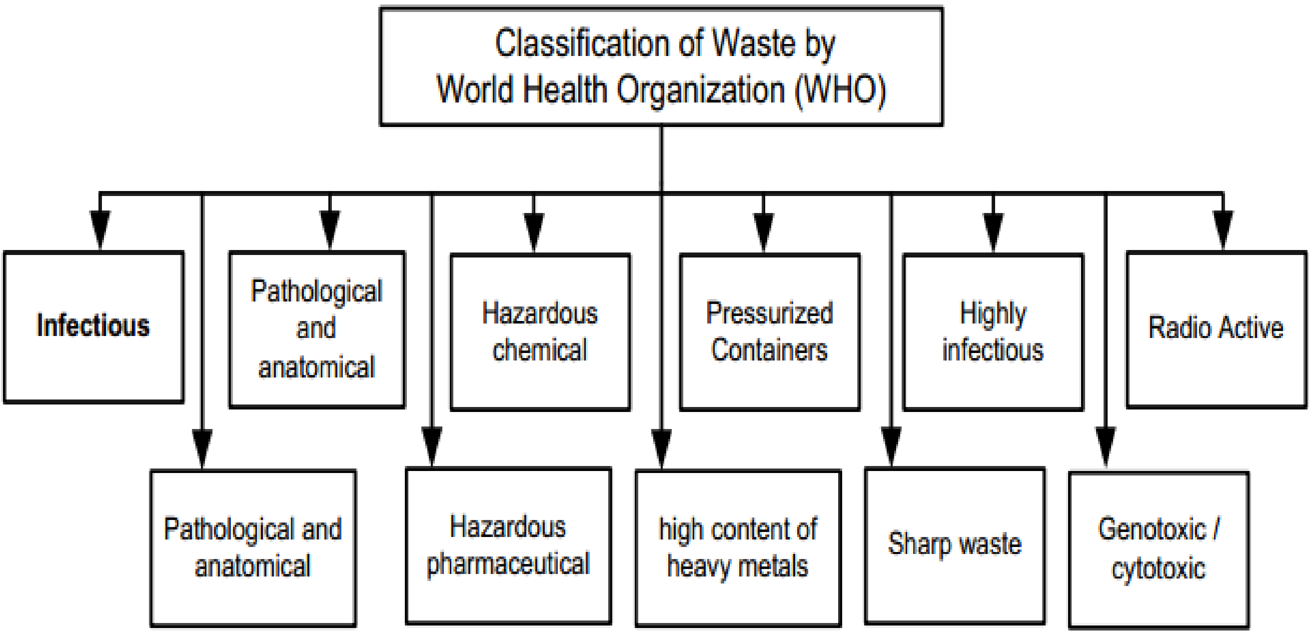

Figure 2.3: Classification of waste by WHO [1].

From the figure above

- **Infectious** All wastes suspected to contain pathogens in sufficient quantities to cause diseases to other host or person. It includes discarded materials or equipment used for the diagnosis, treatment and prevention of disease as dressings, swabs, and others. This group also includes liquid waste such as urine, blood and sputum or lung secretions [19].
- **Pathological and anatomical** waste consists of organs, tissues, body parts or fluids such as blood. Anatomical waste is a sub-group of pathological waste and consisting of recognizable human body parts [20].
- **Hazardous pharmaceutical** waste includes expired, unused, spilt and contaminated pharmaceutical products, drugs and vaccines [18].

- **Hazardous chemical** waste consisting of discarded chemicals (solid, liquid or gaseous) that are generated during disinfecting procedures or cleaning processes [17].
- **High content of heavy metals** Wastes with high contents of heavy metals are highly toxic such as cadmium or mercury from thermometers or manometer [19]. They are considered as a sub-group of chemical waste but they should be treated specifically.
- **Pressurized containers** consists of full or empty containers or aerosol cans with pressurized liquids, gas or powdered materials [20].
- **Sharp waste** Sharps are items that can cause cuts or puncture wounds, needle stick injuries for instance [21]. They are considered to be highly hazardous instrument and potentially infectious waste.
- **Highly infectious** include body fluids of patients with highly infectious diseases, microbial cultures and stocks of highly infectious agents from Medical Analysis Laboratories [22].
- **Genotoxic / cytotoxic** waste derived from drugs that are generally used in oncology or radiotherapy units that have a high hazardous mutagenic or cytotoxic effect, vomit or urine from patients treated with cytotoxic drugs or chemicals should be considered as genotoxic [22].
- **Radioactive** waste includes gas, liquids and solids contaminated with radio nuclides whose ionizing radiations have genotoxic effects [23].

The Environmental Protection Agency (EPA) lists the following categories of medical waste [1,24]

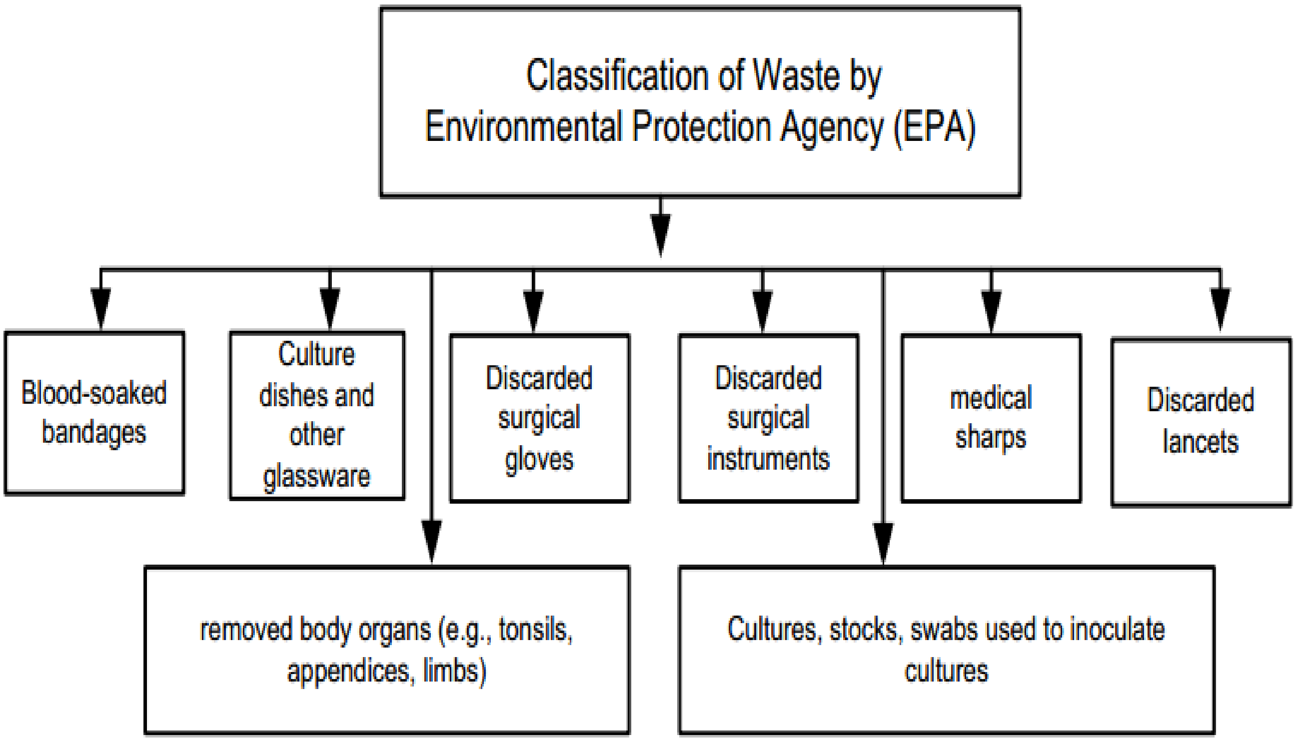

Figure 2.4: Classification of waste by EPA, USA [1,24]

2.6 Categories of Medical Waste

In accordance with World Health Organisation (WHO)'s established criteria [25], clinical/healthcare waste can be grouped under five categories for the purposes of risk assessment.

Table 2.1 show categories of medical waste [1].

Group	Explanation
A	• All human tissues • Blood and blood products • Surgical dressings, swabs and other waste from the treatment of patients that are significantly soiled with blood, pus or serous fluids.
B	• Discarded used syringe needles • Cartridges • Broken glass and other contaminated disposable sharp instruments or items
C	• Microbiological cultures and waste from pathology departments (clinical laboratories and post-mortem rooms)
D	• Expired or unutilized pharmaceuticals (other than intravenous infusion preparations, such as saline, which are non-environmentally polluting) • All cytotoxic wastes even when in diluted form
E	• It contains items which usually present low level of risk, and are also produced in greater numbers in community and home settings • Items used to dispose of urine, faces and other bodily secretions or excretions assessed as not falling within Group A • This includes used disposable bed pans or bed pan liners, incontinence pads, stoma bags and urine containers • As clinical waste only if they originate from patients infected with risky etiologic agents they will be treated in the same way as Group A wastes.

2.7 Source of medical waste

All types of health care facilities, laboratory, clinics, nursing homes and medical, dental and veterinary hospitals generate a waste stream varied in its composition. Health care wastes are generated from different sources [25].

2.7.1 Major sources

Major sources comes from big facilities like

a) Hospitals, e.g. general hospital, district hospital.

b) Healthcare establishments, e.g. emergency medical care services, healthcare centres and dispensaries, obstetric and maternity clinics, outpatient clinics, dialysis centres, first-aid posts and sick bays, long-term healthcare establishments and hospices, transfusion centres, military medical services.

c) Related laboratories and research centres, e.g. medical and biomedical laboratories, biotechnology laboratories and institutions, medical research centres.

d) Mortuary and autopsy centres.

e) Animal research and testing facilities.

f) Blood banks and blood-collection services.

g) Nursing homes for the elderly.

2.7.2 Minor sources

Minor sources comes from small facilities and researches like:

a) Small healthcare establishments, e.g. physician's office, dental clinics, and acupuncturists.

b) Specialized healthcare establishments and institutions with low waste generation, e.g. convalescent nursing homes, psychiatric hospitals, institutions for disabled persons.

c) Non-health activities involving intravenous or subcutaneous interventions, e.g. cosmetic piercing and tattoo parlours.

d) Funeral services.

e) Ambulance services.

f) Home treatment.

2.8 Medical Waste Management

Medical waste can be infectious and hazardous, and it is highly likely that patients, healthcare staff in a hospital, waste handlers, and the community be exposed to the infectious medical waste [26].

Improper management of medical waste raises concern over the health risk posed by its infectious character, the potential safety hazards posed by needles and other sharps, and the aesthetic degradation of exposed environments [21,27].

It can be the cause of various infections, toxic effect, injuries and risks polluting the environment [28]. It is important to point out that the term 'medical waste' has often been used interchangeably with other terms such as 'hospital waste' and 'infectious waste' around the world [28]. To create safe, responsible and customized programs to collect and dispose of medical waste, it is important to prepare and implement the medical waste policies [28,29]. In addition, public awareness is very important and need to find the sources such as media which can effectively influence the healthcare sector to adopt the proper medical waste management procedures [29].

2.8.1 Colour Coding and Type of Container

Schedule II of Biomedical waste (Management and Handling) Rules, 1998 summarizes colour coding and type of container that must be used while handling specific category of medical waste. This ensures source segregation and ease of multi-treatment and disposal of different categories of waste. This provides secure of health for waste handlers, workers in disposal unit and to the whole environment. Colour coding of containers may be based on characteristics of bio-medical waste as follows table of Colour coding and Type of Containers for disposal of Medical Wastes [30].

Table 2.2 show how colour coding work

Colour Coding and Type of Container	**Category of wastes**
Yellow colour Plastic bag	Human anatomical waste, Animal waste, Microbiology, Biotechnology waste and Soiled waste.
Red colour Disinfected container/ plastic bag.	Microbiology, Biotechnology waste, Soiled waste and Solid waste.
Blue/white translucent coded plastic bag/puncture proof container.	Waste sharps and Solid waste
Black colour plastic bag	Discarded medicines, cytotoxic drugs, Incineration Ash and chemical waste.

Figure 2.5 Colour coding applied in Hospitals.

2.8.2 Segregation, Packaging, Transportation Procedure of Medical Waste

Waste shall not be mixed with other wastes [32]. Biomedical waste shall be segregated into containers/bags at the point of generation as per biomedical waste rules and these containers shall be labeled as biohazard, cytotoxic and handle with care, etc. No untreated bio-medical waste shall be kept stored beyond a period of 48 hours [33].

Transportation of biomedical waste containers/bags shall also be labeled with sender's name and address, receiver's name and address and their telephone numbers [32,34]. As per the Motor Vehicle Act 1998, untreated biomedical waste shall be transported only is such vehicle as may be authorized for the purpose by the competent authority as specified by the government [35].

As per the second amendment of biomedical waste rules in 2000, the guidelines for common medical waste treatment facility, for transportation vehicle are

- Separate cabins shall be provided for driver/staff and the biomedical waste containers.
- The base of the waste cabin shall be leak proof to avoid pilferage of liquid during transportation.
- The waste cabin may be designed for storing waste containers in tiers.
- The waste cabin shall be so designed that it is easy to wash and disinfect.
- The inner surface of the waste cabin shall be made of smooth surface to minimize water retention.
- The waste cabin shall have provisions for sufficient openings in and/or sides so that waste containers can be easily loaded and unloaded [36].

2.9 Medical Waste Management policies in some Countries

The best available technologies are used for the development of alternatives for the proper disposal of medical waste with minimal risks to human health and the environment is investigated in this chapter to illustrate a comparison between what is happening in the developed countries and developing countries as a way to find a gap between the culture and technological method that are used in various countries [37].

2.9.1 Czech Republic

The waste management strategy of the Czech Republic is dealt with in two basic documents: State Environmental Policy and Implementation Plan and national waste management plan revised periodically and accompanied by regional waste management implementation [38]. The first national management plan had to be prepared by the end of 2002. The act lays down the content of this plan, an obligatory part of which will be submitted to the government and subsequently published in the Collection of Acts [38].

2.9.2 Poland

The Polish national waste management strategy and implementation plans are elaborated in two documents: Strategy for Balanced Development in Poland from now to 2025 and the Second Ecological Policy of the State. In that waste management is covered in the Second Ecological Policy of the State in the chapter on waste management [39]. The following issues are set as a priority:

- To complete adjustments of Polish legislation to EU standards and to prepare a waste Management strategy regarding national, regional and local limits for land filling as a short-term priority.
- To minimise waste production and increase reuse of waste.

- To implement waste management plans and create a collection system as the medium-term priority.
- To reduce the amount of biodegradable-waste landfills, to achieve the successful removal of old landfills as a long-term priority.
- There are no sub-national waste management plans available. Specific legislative instruments provide for municipal waste, hazardous and non-hazardous waste and wastewater treatment sludge [40].

2.10 Characteristics of Medical Waste

Hospital wastes include different kinds of wastes such as infectious, radioactive, chemical, heavy metals and regular municipal wastes [41]. Medical waste can be categorized based on the risk of causing injury and/or infection during handling and disposal. Wastes targeted for precautions during handling and disposal include sharps (needles or scalpel blades), pathological wastes (anatomical body parts, microbiology cultures and blood samples) and infectious wastes (items contaminated with body fluids and discharges such as dressing, catheters and I.V. lines) [42]. Other wastes generated in healthcare settings include radioactive wastes, mercury containing instruments and polyvinyl chloride (PVC) plastics. These are among the most environmentally sensitive by-products of healthcare. WHO (1999, 2001, 2004) stated that 85% of hospital wastes are actually non-hazardous, around 10% are infectious and around 5% are non-infectious but hazardous wastes. In the USA, about 15% of hospital waste is regulated as infectious waste. In India this could range from 15% to 35% depending on the total amount of waste generated [43,44].

2.11 Impact of Infectious Agents on human health and environment

Hospital wastes, because of their infectious nature, are one of the most dangerous causes of pollution [45]. Hospital waste is potentially dangerous, since it may possess pathogenic agents. Some of the pathogenic organisms are dangerous, because they may be resistant to treatment and possess high pathogenicity. Inadequate waste management will cause environmental pollution, unpleasant smell, growth and multiplication of insects, rodents and worms and may lead to the transmission of diseases like typhoid, cholera, hepatitis and AIDS through injuries from syringes and needles contaminated with human blood [46]. The inefficient handling of biomedical waste is more likely to cause problems such as blood borne pathogens to the groups at highest risk, namely; healthcare staff, scavengers, and municipal workers (from needle sticks for example, if the biomedical wastes are handled and disposed together with domestic wastes). There is particular concern about infection with human immunodeficiency virus (HIV) and hepatitis viruses B and C, for which there is strong evidence of transmission via healthcare waste [47]. Transporting of mixed hospital waste to the waste dumping sites causes soil and groundwater pollution, and consequently health hazards for live species. Hence, collection and disposal of waste in the proper manner is of great importance as it can decrease directly and indirectly health risks to people, and damage to flora, fauna, and the environment [48].

2.12 Quantity of Medical Waste Generation

Examines the existing hospital waste strategy in Greece with a bed capacity of 400-600.Infectious waste production was estimated by weighing the incinerated waste as 880kg/day [49]. It was concluded that inappropriate segregation practices were the dominant problem, which led to increased quantities of generated infectious waste and hence higher costs for their disposal [50].

Assess the amount of healthcare risk waste generated by health establishments in Saudi Arabia. A healthcare waste management questionnaire was applied in 27 hospitals, and 16 primary health centres and clinics. They stated that the mean hospital waste rate of generation was 1.13 ± 0.96 kg/bed/day. The mean primary healthcare centres and clinics healthcare risk waste rate of generation was 0.08±0.08 kg/visitor/day. The estimated mean amount of all healthcare risk waste generated in the Kingdom of Saudi Arabia is 25,207 tons/year. A program is being established to formulate standards for healthcare waste management [51].

Review of Dental wastes are regulated under medical waste control regulations in most countries. Even though the quantity of hazardous wastes in dental solid wastes is a small proportion, there is still cross infection risk and potential danger for environment associated with mismanaged wastes. They examined the composition of solid wastes coming from eight clinics of the dental school of a University hospital in Turkey [52]. The composition of waste changes from one clinic to the other as expected. However, one can deduce from the data obtained that rubber gloves constitute close to the half of the total solid waste in almost all the clinics. Other major component is paper forming approximately 30% of the solid waste [53]. In general, total waste coming from the clinics is related with the number of procedures conducted on patients at the clinics. Only a small fraction of the waste is hazardous indicating that at Hacettepe University School of Dentistry, hazardous waste collection rules are obeyed in most of the times [54].

Most of studies reported that US hospitals generate between 2 to 4 lb. of infectious waste per patient per day, or about 15% of the total hospital waste stream [54]. Regardless of the definition used, all hospitals can benefit by reducing the amount of material entering the infectious waste stream through better waste segregation and management of its disposal [54,55].

2.13 Waste Treatments Technologies

The hierarchy of waste management and the concept of sustainable waste management have led to the development of alternative waste treatment and disposal options rather than the traditional reliance on the options of landfill and incineration. Alternatives which have a minimal environmental impact, with a view to recycling or energy recovery with low pollution, have received particular attention [56].

Among current technologies, incineration has been found to be widely, the most important advantage of incineration is that it significantly reduces the volume of material, destroys pathogens and hazardous organics, and renders the waste unrecognizable materials in the form of ash. Additionally, incineration is predicted to be more popular in the future [55]. Medical waste incineration plant refers not just to the mass burn, but also to any type of thermal treatment systems for discarded materials that waste resources and generate pollutants [56,57].

Waste materials are composed of complex chemical compounds, medical waste contains variable materials which are composed of large, complex polymereric, organic molecular chains such as cellulose, hemicellulose and lignin [57].

2.13.1 Combustion of medical waste

This process is simply burning the waste in air and produce hot gases. It converts the chemical energy stored in waste to heat, mechanical or electrical energy through process equipment like stoves, furnaces, boilers, turbo-generators, steam turbines, etc. it is possible to burn any kind of waste but in practice it is feasible for moisture <50%. The scale of combustion plant ranges from domestic level heating to a large industrial plant [58].

2.13.2 Gasification of medical waste

It is a process of partial combustion of waste to produce synthesis gas and char. The gas composition depends on the operating conditions and design of reactor as it generates few hydrocarbons also [59]. Broadly gasification is a thermo-chemical conversion of carbon based material into combustible gaseous product by gasification agents through series of heterogeneous reactions. The heterogeneous reactions are:

Partial Oxidation: $C + 1/2O_2 \leftrightarrow CO$ $\Delta H = -268$ MJ/kg mol

Complete Oxidation: $C + O_2 \leftrightarrow CO_2$ $\Delta H = -406$ MJ/kg mol

Water gas reaction: $C + H_2O \leftrightarrow CO + H_2$ $\Delta H = +118$ MJ/kg mol

Water gas shift: $CO + H_2O \leftrightarrow CO_2 + H_2$ $\Delta H = -42$ MJ/kg mol

Methanation: $CO + 3H_2 \leftrightarrow CH_4 + H_2O$ $\Delta H = -88$ MJ/kg mol

All the reactions are in equilibrium and proceed depending on the temperature, pressure and concentration of reacting species. Three product gas qualities can be produced from gasification by varying the gasifying agent, method of operation and operating conditions. The main gasifying agent is air, but oxygen/steam gasification and hydrogenation are also used [60].

2.13.3 Incineration of medical waste

Incineration is a process where complete combustion takes place in the presence of fuel and air. The fuel provides heat energy to attain incineration temperature and air provides oxygen for combustion. Incineration is effective when the waste is combustible, which is reduced to exhaust gaseous products and the incombustible waste is reduced to ash [59,60].

Figure 2.6 show incinerators with two chambers [24].

2.13.3.1 Standards for Incineration

- All incinerator's combustion efficiency (CE) shall be at least 99%
- The temperature of the primary chamber shall be 800 ± 50ºC
- The secondary chamber gas residence time shall be at least 1 sec at 1050 ± 50 ºC
- Minimum stack height shall be 30m above ground.
- Volatile organic compounds in ash shall not be more than 0.01% [8].

2.13.4 Autoclave of medical waste

Steam autoclaving is an appropriate method for treating microbiology laboratory waste, human blood and body fluid waste (if applicable), waste sharps, and non- anatomical animal wastes. Personnel who operate steam autoclaves must be thoroughly trained in the use of the equipment [61].

Assesses the possibility of the external heating of autoclaves based on results of calculations of the stress state of the monolithic and multilayer versions of these vessels. The variation of mechanical properties of the material as a function of temperature, temperature gradient, internal pressure, and tightness of fit of the layers in the multilayer wall are taken into account in the analyses [24].

2.13.4.1 Standards for Autoclaving

The autoclave should be dedicated for the purpose of disinfecting and treating bio-medical waste shall be subjected to temperature, pressure and residence time as per medical waste (Management and Handling) rules [61,62].

2.13.5 Shredders of Medical Waste

Shredders are used to destroy plastic and paper waste to prevent their reuse. The function of a shredder is to mutilate the already-disinfected waste [63]. The shredder is usually used in combination with an autoclave or a microwave [61,63]. It could be used in individual institutions or in common treatment-and-disposal facilities. This also reduces the bulk of waste making transportation easy. The waste is fed into a hopper leading to a set of revolving blades/shafts which cut the waste into small pieces [64]. These pass through a mesh and are collected at the bottom. Larger particles retained on the mesh are once again passed through the cutters. The problems with shredders are mainly due to the shafts or blades which undergo wear and tear and need periodic replacement [65]. The shredder should be cleaned every month or when particles accumulate between the blades. A shredder occupies around 1.5 sq. m and consumes about 15 kW of power [65].

Figure 2.7 Shredders for medical waste [66].

2.13.6 Pyrolysis of Medical Waste

Pyrolysis is the thermal degradation of organic waste in the absence of oxygen to produce a carbonaceous char, oil and combustible gases [26,66]. How much of each product is produced is dependent on the process conditions, particularly temperature and heating rate [65,66].

Waste materials are composed of complex chemical compounds, for example, municipal solid waste contains paper and cardboard which are composed of large, complex polymereric, organic molecular chains such as cellulose, hemicellulose and lignin. Similarly, wastes such as forestry wastes and biomass are also mainly composed of cellulose, hemicellulose and lignin polymeric molecules [27,64]. Plastics are also composed of large polymer chains. The process of thermal degradation or pyrolysis of such materials, in the absence of oxygen, results in the long polymer chains breaking to produce shorter molecular weight chains and molecules. These shorter molecules result in the formation of the oils and gases characteristic of pyrolysis of waste [8,67].

In China pyrolysis of certain medical waste materials was studied using thermogravimetric analyser coupled with Fourier transform infrared spectroscopy (TG-FTIR) [65]. Pyrolysis characteristics of three common materials were discussed. From TG and DTG curves, pyrolysis of these three materials occurred in single, two and three stages respectively. Evolved volatile products from all these three materials included 2-butanone, benzaldehyde, formic acid, acetic acid, hydrocarbon, carbon dioxide, carbon monoxide, and water; whereas no sulphur dioxide, ammonia and hydrogen cyanide was detected. The TG-FTIR approach is potential to provide valuable inputs for predictive modeling of medical waste pyrolysis [26].

2.13.6.1 Significance of the Pyrolysis

Pyrolysis is the thermal degradation of organic waste in the absence of oxygen to produce a carbonaceous char, oil and combustible gases [68]. Characterises the main differences between pyrolysis, gasification and incineration. The key difference is the amount of oxygen supplied to the thermal reactor. For pyrolysis there is an absence of oxygen, and for gasification there is a limited supply of oxygen, such that complete combustion does not take place, instead the combustible gases; carbon monoxide and hydrogen are produced [27,68].

Relatively low temperatures are used for pyrolysis, in the range 350–800 °C [69]. The application of pyrolysis to waste materials is a relatively recent development. In particular, the production of oils from the pyrolysis of waste has been investigated, with the aim of using the oils directly in fuel applications or, after upgrading, to produce refined fuels [70]. The pyrolysis oils derived from a variety of wastes have also been shown to be complex in composition and contain a wide variety of chemicals which may be used as chemical feedstock.

Pyrolysis process is efficient in reducing such pollutants [70] and also produce fuels [71] and value added products [72]. In addition, combustion of waste cause pollution due to emission of SOx, NOx, etc [71,73], which can be eliminated in the pyrolysis due to presence of inert atmosphere. The waste to energy techniques and their products [8,74].

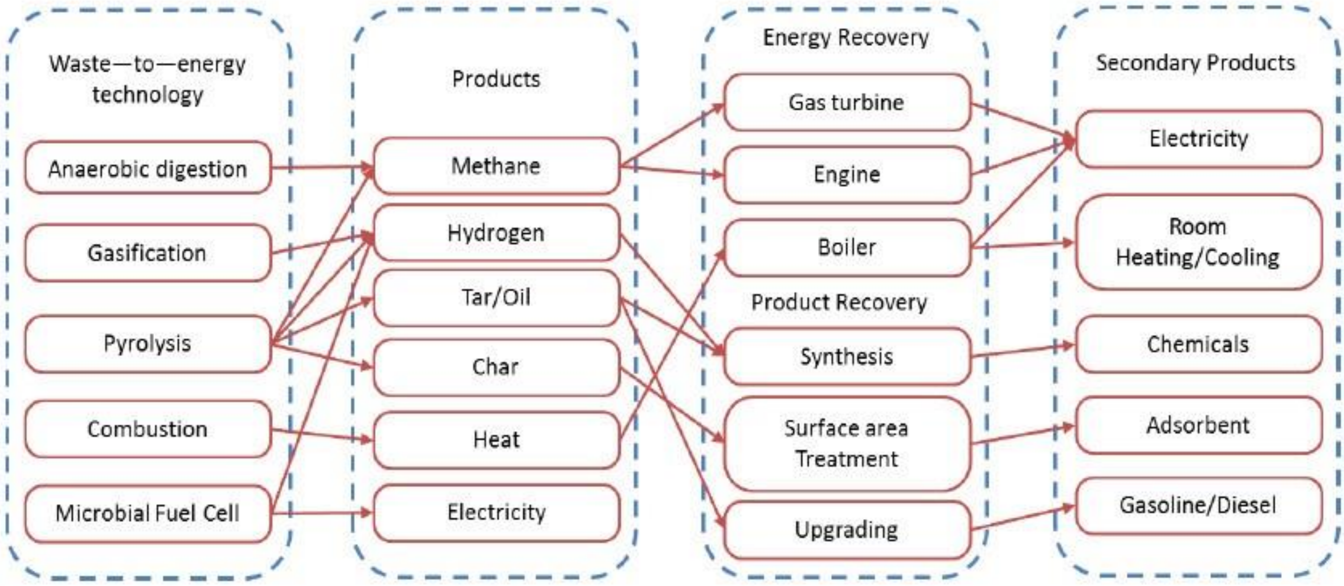

Figure 2.8 show waste to energy technology [8].

2.13.6.2 Current study Pyrolysis products from waste

An exhaustive qualitative and quantitative analysis carried out of pyrolysis oil from sewage sludge at temperature range 350 °C to 950 °C [74,75]. The char yield reduced with increase in temperature while the gas yield was fairly constant from 350 °C to 550 °C and increased significantly later [73].

There are three types of pyrolysis fast pyrolysis and slow pyrolysis and vacuum pyrolysis [74].

2.14 Slow pyrolysis

Slow pyrolysis is one of the type of pyrolysis treatments [74,75].

2.14.1 Principle

Pyrolysis is the thermal decomposition of organic molecules in the absence of air to obtain solids (biochar or charcoal), liquids (tar, bio-oil and pyrolytic water) and gaseous products, which can be used as fuels, solvents and chemicals [76].

2.14.2 Parameters affecting slow pyrolysis

Process parameters such as temperature, pressure, particle size, heating rate, pyrolysis time and nature of feedstock (ash content, lignocellulosic composition, etc.) have a substantial effect on pyrolysis products [77].

2.14.2.1 Temperature

The influence of process parameters such as temperature, pressure, heating rate and residence time has been extensively studied [78]. When temperature increases under normal pyrolysis conditions the char yield decreases and the release of volatile matter increases [79]. With regards to the char quality, an increase in temperature will increase the ash and fixed carbon content [80,81]. Consequently, there is a decrease in volatile matter in the char with an increase in pyrolysis temperatures [82]. Therefore, higher temperatures yield chars of greater quality, although the char yield diminishes. The optimal yield for bio-oil is reached at an intermediate temperature. At higher temperatures more compounds are degraded, leading to the formation of non-condensable gases and a decrease in bio-oil yields [83].

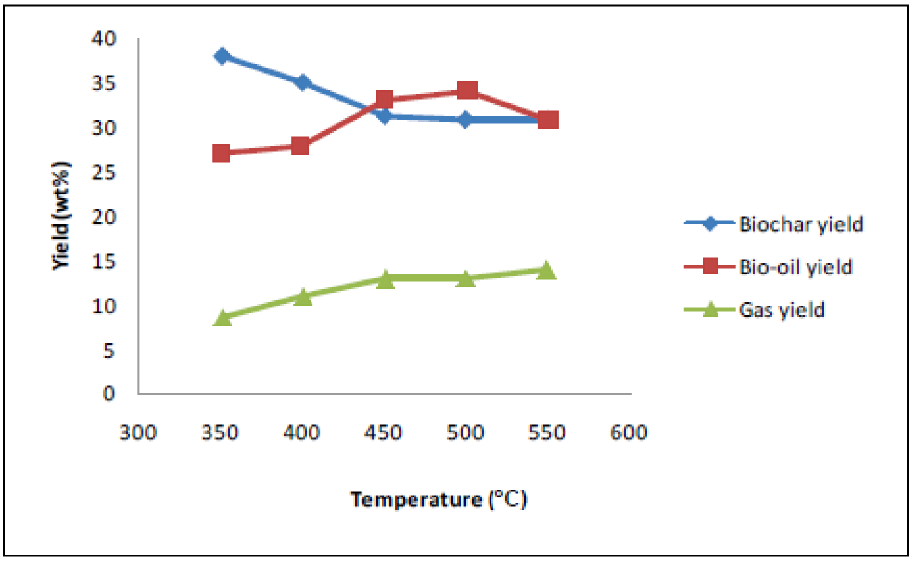

Figure 2.9: Effect of temperature on product yields from slow pyrolysis [83].

2.14.2.2 Pressure

High pressure leads to the decrease in total surface area and swelling at low pressures [80]. Pyrolysis pressure influences the size and shape of the char due to changes in the void fraction in the char. Increased pressure during pyrolysis of cellulose favored the formation of char and CO2 and reduced the CO content. High pressure increases the rate of decomposition reactions and prolongs the residence time for vapor-particle interaction [81,82].

Figure 2.9 shows the effect of slow pyrolysis of cellulose pressure on char yield from [11].

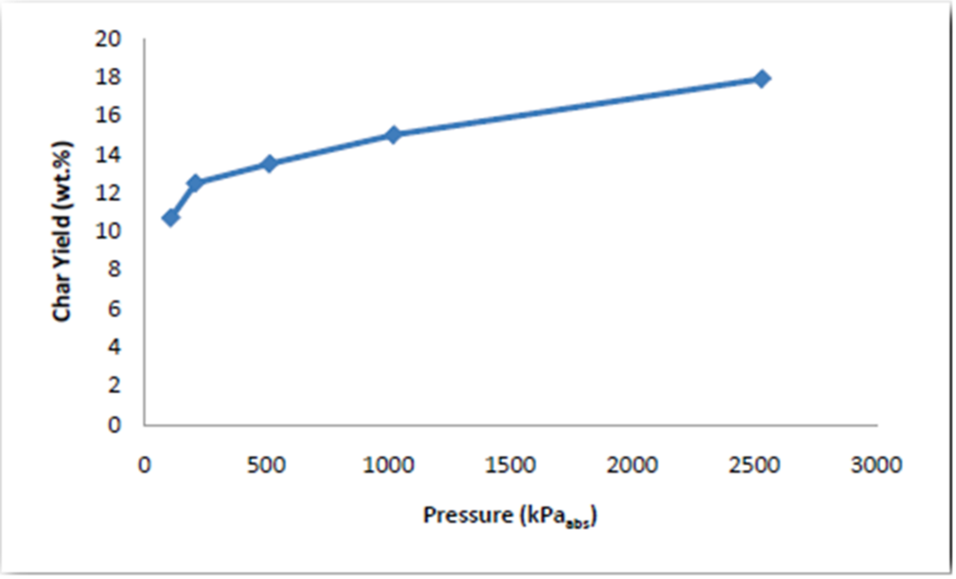

Figure 2.10: Effect of pressure on char yield from slow pyrolysis of cellulose at 500°C with 20 cm3/min [84].

2.14.2.3 Heating rate

Heating rate is one of the most important parameters that affect pyrolysis products, their structure and chemistry. Studied the effect of heating rate on product yields from the pyrolysis of tea waste. High heating rates caused a sharp increase in the yield of the liquid products due to heat and mass transfer limitations. Char yield decreased from 34.3 to 27.1% when heating rate increased from 5 to 700 °C/min. This decrease in char yield has been reported by many researchers [83].

2.14.2.4 Hold time

Hold time refers to the period of reaction. Reported that at longer hold times, more volatiles from char are released corresponding to an increase in fixed carbon content of the char. investigated the pyrolysis of sewage sludge and the influence of temperatures (450-850°C) and the effect of hold time (0.5-3h) on the BET surface areas of the chars. At lower temperatures (550 and 450°C), a maximum hold time gave the highest surface area. The overall highest surface area was approached at 850°C and a 2h hold time. When hold time increased to 3h, surface areas decreased due to the blockage of pores by sintering at high temperatures and long hold time [26,80].

2.14.2.5 Particle size

It is generally assumed that an increase in particle size causes greater temperature gradients inside the particle. Due to the temperature gradient, at a given time the temperature of the core is lower than the surface temperature. The cores of larger particles become carbonized but cannot be decomposed completely, which results in an increase in char yield but a decrease in liquids and gases. Smaller particles provide a greater reaction surface and a high heating rate, which allows a quicker decomposition of the biomass [84].