A comprehensive review of 'waste-to-energy' management potential in Pakistan

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1 Prologue

Every day, we produce a lot of waste - in our homes, offices and factories, farms and hospitals, and so on. We need to reduce this amount. We also need to re-use as much of our waste as we can.

Presently, the domestic solid waste in Pakistan has not been managed in a satisfactory and adequate manner as far as its collection, transportation & disposal or dumping are concerned regardless of the size of the city. Polluted dust blows and people suffers from living in such conditions. It is estimated that the urban areas of Pakistan generate over 55,000 tonnes of solid wastes daily[1].

In Karachi alone, more than more than 7,000 tons of solid waste is generated every day. There are thousands of auxiliary mismanaged collection dumps all over the city causing noticeable environmental degradation locally street to street. The waste pickers scatter the waste on the public spaces around the "*kutchra kundis*", creating large scale environmental pollution directly or indirectly. Most of the sorting places are located near the storm drains, *the nalas*, under the bridges, in open spaces meant for parks and playgrounds and even at bus stop sheds. This scatter waste creates chocking of the storm drains, being used as sewage trunks, which causes other management problems and pollution to groundwater aquifers. Like in other urban centers of developing countries, the solid waste management services are inadequate unsatisfactory.

Such huge amount of solid wastes can be used as a fuel - and dispose of it at the same time. For instance, wastes can be burnt in purpose-built incinerators. The heat can then be used to generate electricity, or to provide heating for buildings. Advanced technologies have been developed to ensure that the wastes' gases emitted from these facilities, would not be harmful to the environment. Heat and electric power can be generated either by incineration of the solid wastes or by anaerobic composting of solid wastes through proper landfill techniques. In Pakistan no energy-from-citywaste facilities has been built.

A Developed Country like UK produces 28 million tonnes of household waste every year. This could be used to generate 1700MW of energy, which is enough to meet the needs of 2.7 million households. Currently, UK only recovers 11% of this, around 190MW, enough for 300,000 households[2]. In Dundee, power station generates 10.5MW of electricity from incineration of 120,000 tonnes of municipal and commercial waste a year.

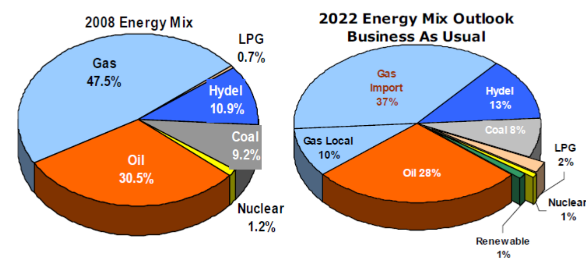

Fig.1.1 Energy Sources Share of Pakistan in 2008 and 2022

2 Waste-to-Energy Status in Pakistan

There is a need to reduce the current levels of waste generation and increase in material and energy recovery, which are considered as the essential steps towards an environmental-friendly waste management system. Landfill is also no longer the first choice for disposal among the other methods such as recycling, composting and incineration, but a last step after all possible material and energy recovery in solid waste management practices. Initially, incinerators globally were used to reduce waste mass but energy is being recovered from incinerators nowadays. Electricity and heat is produced from the recovered bio-gas from landfill. From a mass view point of material recycling, composting of organic waste is considered as the most important system[3].

The problems arising from solid waste can be solved by using innovative technologies. Nowadays, different types of waste-to-energy (W-T-E) schemes are available through which energy can be efficiently recovered and used, such as anaerobic digestion (i.e. both dry and wet, thermophilic and mesophilic), thermal conversion (i.e. rotary kiln incineration, mass burn incineration, starved air incineration, fluidized bed combustion, pyrolysis and gasification, plasma technology, thermo-chemical reduction, refuse derived fuel) and landfilling (i.e. landfill gas utilization and bioreactor landfill). Each type of technology handle the specific composition and quantity of solid waste[4]. It seems to be difficult to propose suitable waste management plans and technologies without determining the quantity and composition of generated waste[5].

[1] (WWFP,2010)
[2] (State Bank of Pakistan, 2011)
[3] (Marchettini et al., 2007)
[4] (Tatamiuk, 2007)
[5] (Idris et al., 2004)

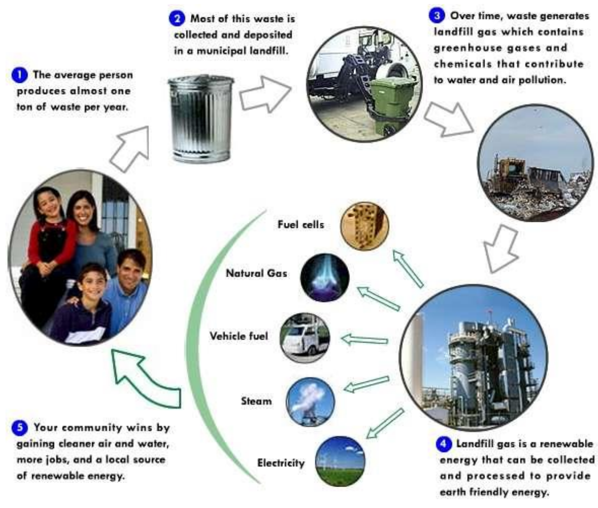

Fig.2.1 Benefit Flow from Waste to Energy Usage

In Pakistan, waste can be used as a resource for the economy. Taking this point of view, some of the private firms and non-governmental organizations (NGOs) are closely working with this industry. They collect the waste and reprocess it for further use. Similarly an NGO established a recycling facility in Karachi where they produce refused derived fuel (RDF) having a concept of waste-to-energy production.
Another NGO is also working in the main cities of Pakistan converting wastes to pellets. The extracted liquid from organic waste is enriched with nutrients and sold in the market as plants fertilizer. In the whole country there are limited numbers of such kind of waste handling organizations. That is why the government should take serious responsibility to this sensitive issue and create opportunities to convert solid waste to energy and other useful purposes.

In Pakistan, a number of illegal, and even some official waste disposal sites, are environmentally unacceptable. They operate without taking any potential measures to avoid infiltration of leachate from open landfill dumping sites to the groundwater. Almost none of the dumping sites have landfill gas excavation system, collection and treatment of leachate. The solid waste treatment and disposal technologies (like incineration, composting and sanitary landfills) are relatively new concepts in Pakistan. Collected waste is commonly dumped on open disposal sites or burnt in open air to reduce its volume, which contributes to air pollution. "At present, there are no landfill regulations or standards that provide a basis for compliance and monitoring, but national guideline for these standards are being prepared by the consultant under the National Environmental Act Plan Support Program (NEAPSP)"[6]. The problems associated with solid waste "more fundamentally, arise from the lack of comprehensive waste management system and strategy that encompasses functions of governance, institutions, finance and technology".

In Pakistan there is a great difference between the generated and collected waste at the disposal sites. According to the Pakistan Environmental Protection Agency (2005) only 51-69% of the generated waste is collected and the rest remains in the streets or collection points. It is estimated that approximately 55,000 tons waste is generated per day[7], based on the assumption that 0.6 to 0.8 kg waste is produced per capita per day.

There is no waste sampling and analysis performed in Pakistan. On all disposal sites (i.e. Mehmood Booti, Saggian and Bagrian disposal sites) except one i.e., Mahmood Booti, no weighing facilities are currently operating. Currently at different steps of solid waste management, scavengers play main role in separating the recyclables[9]. Hazardous waste from hospitals and industries is treated as normal waste. Due to open burning (especially plastic) and open dumping, atmospheric air is being polluted. Further, stagnant ponds which provide breeding ground for mosquitoes and flies with ultimate risks of malaria and cholera are formed due to clogging of drains.

Fig.2.2 Mahmood Booti Landfill Site

The amount of waste production is directly linked with increase in gross domestic production, steady increase in population growth rate and change of life style[8]. Energy can be produced and utilized from the generated solid waste, especially in mega cities of Pakistan like Lahore, Karachi and Multan etc. Due to lack of management, the generated waste which has

[6] (Joeng et al., 2007)

[7] (Pakistan Environmental Protection Agency, 2005)

[8] (The World Bank, 2007)

potential to generate energy, is dispersed all-around the environment. Energy can be recovered from it in the following forms e.g. bio-gas, electricity and fertilizers etc. These beneficial components are currently either being released into the atmosphere due to open burning and dumping or into the ground water due to poor landfill conditions. In most cities, largest part of the budget is fixed for solid waste services. But still approximately less than 50% of the generated solid waste is collected, but instead improperly disposed at landfills, road sides or burnt openly without taking care of air and water pollution control[9].

The socio-economic, environmental and human health components are directly linked with environmental practices. Solid waste management is one of the main environmental practices that is negatively affecting the socio-economic-ecological and well-being health due to poor handling and treatment of generated waste. According to a recent study by Batool et al., (2006) in Lahore, Pakistan, if the recycling practices are adapted as an industry, they can generate revenue of Rs. 530 million, i.e., US$ 8.8 million/year with the saving of large quantities of energy and natural resources[10]. Different types of benefits could be achieved, if energy recovering and natural resources are considered as creation of jobs, reduction of environmental impacts and provisions of economic opportunities.

Limited awareness and financial and institutional capacities are hindering the exploration of different types of waste treatment technologies and in this regard only very few number of treatment plants i.e. composting plants are operating in Pakistan. There is, therefore a need to analyze the different types of waste-to-energy technologies used in the world regarding their socio-economic and environmental considerations and evaluate the most suitable treatment facility that will be acceptable on the basis of above described parameters.

3 Waste-to-Energy Treatment Options in Pakistan

3.1. Anaerobic Digestion

Anaerobic digestion is a process where biodegradable material is breakdown through microbes in the absence of oxygen. Special reactors are used for digestion process and controlled specific conditions are provided inside reactors such as pH, moisture content and temperature etc. The purpose of these conditions is to provide favorable environment to microbes and allow them to increase their number and to enhance the degradation process to produce methane[11]. The organic fraction may contain yard waste, paper waste, food waste and any other type of organic matter. The anaerobic digestion process is highly successful if the wastes are containing high quantity of organics, primarily this process produces methane (CH_4) and carbon monoxide (CO) and also with small fraction of other gas gases such as H_2S [4].

Anaerobic digestion requires low capital and operational costs compared to thermal technologies. Surplus energy can be recovered in the form of CH_4 and also revenue generated through its sale. Pollution control is possible through appropriate control technology. Anaerobic digestion diverts most of organic components from landfills and also reduces risk of gas and leachate production. Well maintained and controlled system ensures low level of environmental pollution[12]. After anaerobic digestion of waste, the waste can be aerobically treated and can get benefits in the form of produced gas and soil conditioner from process for energy production and soil amendment respectively.

3.2. Incineration

Incineration is also known as combustion and thermal treatment of raw waste feed into the system. Only the organic fraction such as plastic, combustible and putrescible are burnt in the system and as a result of which gases and residues are produced. Thermal treatment has ability to reduce volume of waste and considerable amount of solid waste diverts from landfills[13]. According to EPA (2004) the bottom ash from the system may have approximately 10% by volume and 20 to 35% by weight of original waste stream which is fed into the system. Thermal treatment facility has ability to recover energy, variety of chemicals and minerals could also be recovered and reused from waste stream. Incineration facilities have the ability to destroy number of toxic substances present in solid waste.

3.3. Pyrolysis Technology

In pyrolysis, thermal degradation of biomass waste take place in the absence of Oxygen. Pyrolysis and gasification depends on external source of heat. In case of pyrolysis, the conversion of organic matter to liquid, solid and gaseous components takes place through thermal cracking and condensation. Pyrolysis

[9] (Energy Sector Management Assistance Program, 2010)
[10] (Batool et.al 2006)
[11] (FCM, 2004)
[12] (Gruner, 2007)
[13] (STANTEC, 2010)

technology has ability to divert large quantity of waste stream from landfills. It can produce different types of products like fuel oil, gases and also recover recyclables at the frontend of technology.

3.4. Gasification Technology

According to Tatamiuk (2007) gasification is a modified form of pyrolysis system, using small amount of O_2 which produces sufficient heat that enables the system to be self-sustained. Gasification like pyrolysis have high tendency to reduce particulates and sulfur dioxide (SO_2) emissions from process. The syngas (consists of CO, H_2 with little concentration of H_2O, CH_4, N_2 and CO_2) produced from gasification system can be used to generate heat and electricity. This technology is basically formulated to produce and use of syngas from system[15]. Gasification is not an incineration system but a combustion technology, where efficiently energy is recovered from the system. This technology is more attractive due to high production of energy[15].

3.5. Landfill Gas Production and Utilization

Anaerobic digestion of organic components from solid waste stream which are helpful for the production of landfill gas[14]. Production of landfill gas from sanitary landfill facility is comparable with anaerobic digestion but make difference only at the operational control on sanitary landfill. If we compare landfill gas and anaerobic digestion systems, landfill gas requires less operational and maintenance costs. Landfill gas is an important source of waste-to-energy and worldwide energy recovery projects on landfill sites are considerably increasing, approximately 10% growth rate per year since 1990.

3.6. Pelletization

The process of producing fuel pellets from solid waste stream called pelletization. The complete process consists of drying, removal of non-combustibles, grinding and mixing steps. Pellets having higher calorific value as compared to raw garbage and also known as refused derived fuel. These pellets could be used and valuable for the production of energy[15].

3.7. Plasma arc (Pyro-Plasma Process)

Plasma arc technology uses plasma arc flame as a source of heat. This technology has ability to utilize organic and inorganic components of waste stream. At commercial level, a full pilot project is yet to be established. This facility is proposed and cloud be used for hazardous waste treatment.

3.8. Fermentation Process

Fermentation technology utilizes biological conversion technique to produce ethanol. Appropriate feedstock for this process is wood, agriculture residues, grasses and the organic fractions of municipal solid waste.

3.9. Refused derived fuel (RDF)

Refused derived fuel is a process where efficiently remove the inert fractions from waste and produces a uniform fuel that could be used in waste-to-energy plants and also in other thermoelectric plants as an alternative fuel source. During the processing of waste stream to refused derived fuel it could be possible to add calcium (Ca), which is helpful in reduction of hydrogen chloride emissions during combustion process[16].

3.10. Fluidized bed combustion

Fluidized bed combustion technology only utilizes the combustible fractions, after the removal of inert substances from waste like glass and metals etc. The required feedstock is fed up on the top of a fluidized bed of sand or limestone. Typically, the temperate requires for this process is in the range of 830 to 910ºC and may can utilize more fuel if feedstock having high moisture content[18].

4 Conceptual Framework for W2E Management

The framework structure in Figure 4.1, deals with the solid waste management strategies. This waste management process mainly revolves around the socio-environmental, economic issues, technical analysis and political decision making factors. The planners/solid waste professionals have in-depth knowledge about the technical issues of different waste-to-energy recovery technologies and are able to carry-out technical analysis, they have the ability to provide correct information and advice to political leaders, who are the decision making bodies for the implementation of waste-to-energy facility. However, the selection of appropriate waste-to-energy recovery facility mainly depends on socio-economic and environmental factors.

In the binging, it is important to define the system boundaries, which will involve what types of the waste planning activities will be considered during the solid waste management practice i.e. waste minimization,

[14] (Willumsen, 2009)
[15] (Kumar, 2000)
[16] (Themelis, 2002)

segregation, recycling of products, and the remaining waste is available for energy recovery technologies, which can be utilized to produce "green energy" in the form of heat and electricity etc. respectively has complex process.

In the second step, the selection procedure depends on the available options i.e. waste-to-energy technologies, and generally given preferences to those technologies that is successfully operating locally, regionally and implemented worldwide. There must be criteria for selection of reasonable facilities according to local needs, mainly depends on a variety of important factors such as social, environmental, economic and technical issues. It is necessary to give more technical feedback on various technologies and local needs. The technical constrains play crucial role to predict the volume, type and quantity of generated solid waste which are suitable for specific type of waste-to-energy technology.

In the third step, through this strategy, each type of waste-to-energy recovery technology should be evaluated and ranked and then the recommendation should be forwarded to political decision makers. In the final step, results forwarded to politician decision body for final approval, they may give their decision either in-line with professionals/experts opinions or

This selection process or flow is more general and may differ in each case. In the real life political leaders have power and make their own decision for the implementation of facility either their decision is right or wrong. There are different influencing factors (Figure 4.2) for the selection and finally implementation of feasible waste-to-energy recovery technology like environmental, economic, social, technical and political factors. These factors may have different importance or values according to different country rules and regulation and also depends on the local area requirements. After in-depth analysis of each facility at the end if most feasible technology is selected and successfully implemented may generate numerous befits in the form of job creation, resource conservation, reduce environmental impacts, source of renewable energy, low cost energy, land preservation and lower health impacts etc.

according to their own wills for an implementation of waste-to-energy technology in study area.

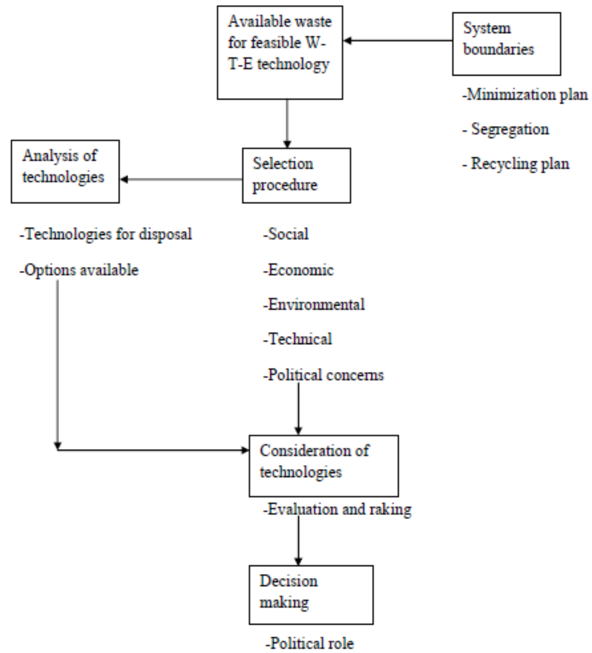

Fig. 4.1. Decision framework for waste-to-energy recovery technology implementation

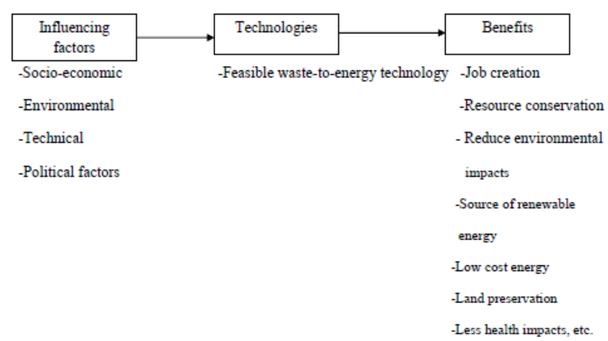

Fig. 4.2. Possible benefits from the best selection of waste-to-energy recovery technology

5 W2E Management Constraints in Pakistan

It is anticipated that the existing solid waste management system is a source of health and environmental concerns for the citizens because of; no containment of municipal solid waste, low waste collection rate, haphazard waste disposal, occupational health and safety concerns and low managerial and technical skills of existing waste disposal staff etc.

5.1. Environmental and health impacts

Potential environmental and health impacts are generated due to inappropriate handling, design, operation and maintenance of disposal sites. These inadequate waste management practices lead to transmission of diseases or may also threaten local people's health. Decomposable organics are the major source of health risks as they provide suitable breeding grounds for disease vectors like flies, mosquitoes and rats etc. Those who closely deal with solid waste like waste pickers and handler are more susceptible to diseases and may also act as a transmitter of these diseases, especially when they are engaged with the handling of animal or human or hazardous waste mixed with solid municipal waste stream. Other nearby community members are also at high risk for facing serious problems such as birth defects, cancer, poisoning and other diseases[17].

5.1.1. Water contamination

Contamination of surface and ground water occurs when it is mixed with dumped solid waste leachate containing different types of pathogens and toxic substances in it[19].

5.1.2. Air pollution and Greenhouse gas (GHG) production

After the disposal of solid waste stream in dumping site, degradation of organic fractions due to anaerobic process results in the production of CH_4 greenhouse gas which is stronger than CO_2. Often the collected waste in streets or in dumping sites is openly burnt aiming to reduce its volume which become a source of carbon monoxide, nitrogen oxide and soot that are harmful for human health and also a source of air pollution. Lethal gases i.e. carcinogenic dioxins are produced by burning of polyvinyl chlorides[19].

5.1.3. Ecosystem disturbance

Dumping of solid waste in streams and rivers could produce alarming situation for both aquatic and terrestrial flora and fauna. Eutrophication conditions are produced due to high concentration of nutrients flow from waste stream into water body and some of heavy solids settle down and changes water flow pattern and also its bottom habitat. Development of waste disposal site in fragile ecosystems may have adverse effect on important natural resources and its services.

5.1.4. Local flooding and property value

Heaps of waste streams in streets may clog drains and create flooding situation. Presence of dumping or landfill sites near the residential areas may injure the local inhabitants and destroy property.

5.2. Social Impacts

The social impacts faced by community related to solid waste can be categorized into following groups like direct, indirect impacts and also transport related problems.

5.2.1. Direct impacts

Some direct social impacts are raised from the garbage such as spreading of bad smell during transportation of waste, facilitation of breeding grounds for disease vectors due to the fallen garbage along roads during transportation and sitting landfill sites, reduction of the property value and production of unpleasant odor from landfill sites[18].

5.2.2. Indirect impacts

Some indirect social impacts are also faced by community from garbage such as increased frequency of floods during rainy season, improper personal safety raised during smoke and production of toxic gases from open burning of garbage, more vulnerability of children to diseases raised from improper solid waste disposal like skin diseases etc.

5.3. Transport related social issues

The transport related social issues include road traffic congestion through solid waste transfer vehicles, aesthetic nuisance from improper cover of garbage bags on trucks may fall from trucks during its transportation along main roads, dust pollution and deterioration of roads due to heavy transportation which results an increase in the maintenance cost.

5.4. Economic issues

According to Lal et al., (2006) cost associated with poor waste management can be defined as "the direct and indirect cost associated with the current level of waste management that could be avoided if better management services were provided." Currently implemented waste management level and efficiency of the system defines the economic cost and the direct impacts of waste including the quantity of recycling of recyclable components from waste, linkage among waste and its impacts on aesthetic values, health and environment. The indirect impacts of waste management cover the impacts on fisheries yield, tourism and local economy. The cost associated with these impacts may be borne by individual or government or whole society.

Economic cost associated with waste stream could be estimated through with and without benefit cost analysis (BCA) which can be define as the difference between the economic net benefits of present waste

17 (LAC, 2001)

18 (Bandara et al., 2003)

management system (with waste condition) and the economic net benefits with improved waste management system (without waste condition). This analysis may be effective with and without analysis of cost and can also be reduced to an analysis of economic cost with waste with and without improvement in waste management[19].

The cost associated with and without improvement in waste management system varies dramatically. With improved waste management scenario, cost associated with waste impacts reduces. In case of with waste conditions, the direct economic cost of waste impacts includes the cost of poor human health due to improper waste management system. It covers the hospital cost, private doctors cost in terms of fees, medicine cost, importance of human life-in case of death, or its cost of suffering. The direct cost is associated with taking preventive measures to control different factors that may cause the human health impacts and also the loss of cost from recyclables which are directly dump into the disposal site. The indirect economic cost of improper waste management includes the loss fisheries, reduction in tourism earning and loss of aesthetic values.

Potential W2E Solutions in Pakistan

Different types of waste-to-energy recovery technologies are considered in view of the main factors such as social, environmental and economic which play an important role while the selection of best energy recovery technology(ies) for urban centers. The cost associated with each type of energy recovery technology is directly linked with the available quantity of waste stream for processing as well as its composition. From social and environmental issues, environmental impacts of technologies are more important and must be considered separately. The mitigation of impacts adds extra costs in technologies.

Following are the most feasible form(s) of technology/ies selected for large towns in Pakistan, especially Lahore, Karachi and Rawalpindi:

1. Landfill/bioreactor landfill gas production and utilization
2. Mass burn incineration

Landfill gas recovery technology (sanitary landfill/bioreactor landfill) is the most socially acceptable, environmentally friendly and the cheapest one among all other available worldwide waste-to-energy technologies for large towns.

Mass burn incineration is the second best option because it is relatively socially unacceptable, more source of pollution and likewise more costly than the landfill gas recovery facility. From both fluidized bed combustion and gasification/pyrolysis waste-to-energy technologies one could be the third best option for waste management of big towns, but in both cases major different types of drawbacks are present. Even fluidized bed combustion is relatively cheap but it is a source of pollution. Moreover, the plants with this thermal technology have not enough capacity to treat whole waste per day. The major drawback of gasification or pyrolysis technologies is that these are the emerging technologies and their outcomes/results could be haphazard[20].

The other remaining waste-to-energy recovery options such as anaerobic digestion, rotary kiln incineration, starved air incineration and refused derived fuel are excluded because of their technical viability, social, environmental and economic factors.

Conclusion and Recommendations

The study about the feasibility of waste-to-energy recovery technologies have never been carried out in any province of Pakistan. In this assignment, it has been tried to estimate the current composition and quantity of produced waste in Pakistan and also to explore the social, environmental and economic issues closely related to improper solid waste management and in-depth study of technologies which are especially designed for the handling of waste.

Local municipalities should consider waste-to-energy recovery technologies for the handling of their generated solid waste to save the more extraction of natural resources, to generate revenue and improve local socio-environmental conditions of an area. However, to implement waste-to-energy facility in large cities, following things must be considered:

- Large towns should be divided into different sectors such as commercial, residential and industrial sectors etc. in order to determine the exact composition and quantity of generated waste from sector for effective solid waste management.
- Solid waste composition and quantity should be determined throughout years for all

[19] (Lal et al., 2006)

[20] (Zaman, 2009)

seasons and also separately for different income groups etc.

- Educate people about improper solid waste issues and also give awareness about benefits of waste-to-energy technologies for effective cooperation between municipalities and communities.
- In future, further research should consider more new and emerging waste treatment technologies.
- The decision about the final implementation of waste-to-energy technology, politician should make their decisions strictly in-line with experts/professionals findings.

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