SciencePG
Science Publishing Group

Energy Recovery from Solid Waste for Nazareth/Adama City, Ethiopia

Melaku Tafese Awulachew

Department of Food Science and Nutrition Research Process, Ethiopian Institute of Agricultural Research, Kulumsa Agricultural Research Center, Assela, Ethiopia

Email address:
Melakutafese12@gmail.com

Abstract: Major problems facing modern society include the provision of energy with the minimum generation of pollution, and the environmentally friendly disposal of waste. This work was part of a major study that examined the policy and technology implications of alternatives for managing the municipal solid wastes (MSW) of Adama (Nazareth) City (Town). Consequently, to accomplish the objectives both primary and secondary data sources applied for the study. The primary data were collected via questionnaires, interview, and field observations. Whereas the secondary data were extracted from different published and unpublished materials. At this time, of the 71700 metric tons of MSW collected by the town annually are land filled. Despite the heterogeneity of organic materials in MSW, the composite molecular structure can be approximated by the organic compound $C_6H_{10}O_4$. A formula was derived that allows the prediction of the heating value of MSW as a function of moisture content and compares well with experimentally derived values. The performance of a leading Waste-to-Energy plant that utilizes suspension firing of shredded MSW, processes one 71700 metric tons of MSW per year, and generates a net of 3.1 MW/yr electricity was examined. The results of this study showed that WTE processing of the MSW reduces fossil fuel consumption and is environmentally superior to land filling.

Keywords: Municipal Solid Waste, Energy Recovery, Waste-to-Energy Balance, Equipment Sizing, Feasibility Cost Analysis

1. Introduction

One of the greatest challenges facing developing countries is the unhealthy disposal of solid waste which resulted from human activities of development and survival [1]. Most human activities certainly result in the generation of waste which tends to increase with rapid urbanization, improved living standards and changing consumption patterns [2-3]. Solid Waste Management is a vital, ongoing and large public service system, which needs to be efficiently provided to the community to maintain aesthetic and public health standards [4]. The poor state of waste management in the country is caused by inadequate facilities, poor funding, and poor implementation of policies as well as wrong lifestyle. Reviews show that in urban areas, especially in the rapidly urbanizing cities problems and issues of municipal solid waste management (MSWM) are of immediate importance. Most governments have acknowledged the importance of MSWM; however, a rapid population growth overwhelms the capacity of most municipal authorities to provide even the most basic services [14].

The economic development and prosperity are accompanied by the generation of large amounts of wastes that must be re-used in some way or disposed in landfills. Waste generation can be reduced to some extent by improved design of products and packaging materials and by increasing intensity of service per unit mass of material used. However, even after such measures are taken, there will remain a large amount of solid wastes to be disposed of. Solid wastes can be classified into municipal (residential and commercial), industrial, construction and demolition wastes. The municipal solid wastes (MSW) are the most non homogeneous since they consist of the residues of nearly all materials used by humanity: Food and other organic wastes, papers, plastics, fabrics, leather, metals, glass and miscellaneous other materials. Processing or disposal of MSW requires separating

the MSW into a number of streams and subjecting each stream to the most appropriate method of resource recovery.

The aim of this study is to address the health and environmental problem by produce sufficient energy from solid waste that helps the solid waste management system of Nazareth town. Significance of the study is to Increase government revenue, and fulfill social need, Create employments and job opportunity for people, reduces cost spent for electricity and reduce dependent on fossil fuel.

1.1. Solid Waste Management in Adama/Nazareth City

Adama city is located at about 100km southeast of Addis Ababa on the high way to Djibouti.

The separation of MSW components can take place at the source, i.e. households or businesses, or at Materials Recovery Facilities (MRFs) using manual and electromechanical methods. There are four principal methods for resource recovery or disposal of MSW:

a   Recovery of materials: Recovered paper, plastic, metal, and glass can be re-used.
b   Recovery of energy: Energy is stored in chemical form in all MSW materials that contain organic compounds, i.e. everything except metals, glasses, and other inorganic materials. The combustion of these compounds can generate electricity and steam.
c   Bioconversion: The natural organic components of MSW (food and plant wastes, paper, etc.) can be composted aerobically (i.e., in the presence of oxygen) to carbon dioxide, water, and a compost product that can be used as soil conditioner. Anaerobic digestion or fermentation produces methane or alcohol and a compost product.
d   Land filling: MSW materials that cannot be subjected to any of the above three methods, plus any residuals from these processes (e.g., ash from combustion) must be disposed in properly designed landfills.

1.2. Collection of Waste

1.2.1. Primary Solid Waste Collection

Primary collection operation enables to transfer solid waste from the sources of generation to the secondary collection facilities/containers. The identified operational modes of primary collection in Adama city are:

a. Door to door collection:

Regarding door-to-door solid waste collection, households have two options.

The first option is that households take their solid wastes and dispose it in to a container nearest to their home.

The second option is having contract agreement with micro and small enterprise associations to take their wastes to the container. These micros have different material capacity and manpower. Most of them have hand pushed carts and some of them have horse drawn carts. They are serving for more than 2000 households and organizations. They have more than 50 youth workers.

One can observe that most households prefer the first option. This is because it has no collection cost that most households especially low income families prefer. Some middle and most high-income households prefer the second option. According to some surveys, estimation a household should get a container within 200 meters of his vicinity, and one container provides services to a maximum of 2000 people. Based on this estimation, only 48.1% of the households are found within the service area of the container.

b. Street Sweeping

Though inadequate the municipality provides street sweeping services twice in a day for a total of 58 Km. The mode of the service is provided by:

Municipality sanitation workers and three MSE's using tools like straw brooms, wheel barrow and shovel.

Street side posted public dust bins for street users and pedestrians are expected to drop their solid waste piece in the public garbage bins when they are out of their homes and business offices. Wheel barrows are used for primary collection of wastes from street to dump into the municipality assigned two trucks. The annual solid waste collection by the street sweepers is 2340 m^3. This comprises 63% is collected out of the 3750 m cube waste generated from the streets. The low performance is due to the dust bins are inadequate and at the same time the public didn't aware and bring attitudinal change to drop solid wastes, especially paper and plastic materials (festal) on the dust bins.

1.2.2. Secondary Collection and Transportation

In Nazareth town the secondary waste collection activity is carried out solely by municipality through:

a. Two Skip Loaders

Communal storage of primarily collection allows the safe retention of the solid waste for a sufficient period of time between primary collection from the different sources and secondary collection and disposal of the solid waste.

In the present context of solid waste management in the city, the municipality is the only institution that provides communal storages and performs secondary collection to the disposal sites. The municipality performs the storage task with a total of 31 communal containers that can be easily mounted on skip loaders to be transported the land fill sites.

This communal storage SSWM has major problems:-

Most of these containers are cited at 10 meters from the premises of the households where as the Sanitation Regulation of the city oblige residences to clean 10 meter radius of their perspective premises is abused by the municipality. Such type of service is against the sanitation regulations and constitutional rights of the residences to live in a clean environment as the result of bad odor from the communal containers.

Trucks have a carrying capacity of weighed 100 to 120 quintals at a time but the skip loaders equipped with a hydraulic lifting mechanism are designed to lift 30 quintals garbage filled contained at a time. As a consequence the trucks are working at 25-30% efficiency because of the existing communal container based solid waste collection, transportation and disposal system in use.

These skip loaders transport the 30 communal containers cited in different part of the city. Each skip loader is expected to cover 8 trips in a day but due to technical and others problems they transport and dispose 25520 m^3 at an efficiency of 62%

b. Two old Trucks

These trucks also providing a primary and secondary waste collection with a capacity of 7m^3 and 8m^3; mainly giving a service to the down city parts with high waste regeneration and streets. These trucks collect and dispose 9401m^3 under efficiency 51% [5].

1.3. Disposal of Waste

The former final disposal site is found on the southwest direction, 9 km away from the town (on the road to Addis Ababa around the wind power). The town uses the lowest type of disposal system that is open dumping. All types of solid wastes generated in the city are dumped indiscriminately at the final disposal site. The total area coverage is 14,000m^2.

1.4. Basic Techniques of Energy Recovery

Energy can be recovered from the organic fraction of waste (biodegradable as well as non-biodegradable) basically through two methods as follows:

a. Thermo-chemical conversion: This process entails thermal de-composition of organic matter to produce either heat energy or fuel oil or gas and

b. Bio-chemical conversion: This process is based on enzymatic decomposition of organic matter by microbial action to produce methane gas or alcohol.

The Thermo-chemical conversion processes are useful for wastes containing high percentage of organic non-biodegradable matter and low moisture content.

1.4.1. Parameters Affecting Energy Recovery

The main parameters which determine the potential of Recovery of Energy from Wastes

(Including MSW) are:

a. Quantity of waste

b. Physical and chemical characteristics of the waste

The actual production of energy will depend upon specific treatment process employed. The important physical parameters requiring consideration include: size of constituents, density and moisture content.

Smaller size of the constituents aids in faster decomposition of the waste. Wastes of the high density reflect a high proportion of biodegradable organic matter and moisture. Low density wastes on the other hand indicate a high proportion of paper plastics and other combustibles. High moisture content causes biodegradable waste fractions to decompose more rapidly than in dry conditions.

The important chemical parameters to be considered for determining the energy Recovery potential and the suitability of waste treatment through bio-chemical or thermo chemical conversion technologies include: - Volatile Solids, Fixed Carbon content, Inert, Calorific Value, C/N ratio (Carbon/Nitrogen ratio) and Toxicity.

However, the components of the wastes vary increasingly with the life style and economic standards of the population. It is therefore necessary to know the exact composition of wastes under study.

The basic component materials in the citywide waste stream can be classified as: Organic or put rescible materials, Paper and cardboard, Plastics and rubber, Glass, Metals and cans, Textile, Inert or residues and Miscellaneous or other waste.

Below is the composition of solid wastes in various studies

Table 1. Composition of municipal waste arising in the European country [6].

Component	U.K	F.R.G	France	Denmark	Italy	Ire-land	Belgium	Lusxburg	Netherland	Average EEC
Putrescibe	21	16	20	15	39	28	43	56	48	25.4
Paper &board	30	27.5	35	35	24	33	30	25	23	28.7
Textile	3	3	4	2	3.5	3	2	1.5	1.8	3.1
Plastic	3	4	5	4	6.5	4	4	4.6	6	4.6
Glass	9	9	8	8	5.5	8	10	5.2	1.3	8.3
Metal	9	6.5	5	4	3.5	4	5	3.6	2.9	6.0
Ashes, dust &other total	25	34	23	32	18	20	6	4.1	5.3	23.9
	100	100	100	100	100	100	100	100	100	100
Mean calorific value kj/kg	9400	7500	8400	8400	6750	9400	7300	7500	7500	7500
Kcal/kg	2250	1800	2000	2000	1300	2250	1750	1800	1800	1800

Table 2. Some comparisons in waste characteristics [7].

Component	United kingdom	Asian city	Middle East city (OPEC)
Vegetables	28	75	50
Paper	37	2	16
Textile	3	3	3
Plastic	9	0.2	2
Metal	9	0.1	5
Other Total	12/100	18.7/100	23/100
Density (kg/m^3)	132	570	211
Weight person^{-1}day^{-1} (kg)	0.845	0.415	1.06
Weight household^{-1}day^{-1} (kg)	1.90	2.49	5.3

1.4.2. Assessment of Energy Recovery Potential from Solid Waste

A detailed assessment of the potential of recovery of energy from MSW through different treatment methods can be made from knowledge of its calorific value and organic fraction. In order to evaluate the feasibility of energy recovery from MSWs, it is of great importance to determine the energy content or calorific value (CV) of the solid waste, which is defined as the number of heat units evolved when unit mass of material is completely burned and is measured in joules per gram (J/g) or British thermal units per pound (Btu/lb). The energy content of any material, such as solid waste, is a function of many parameters, namely, physical composition of the waste, moisture content and ash content. There are several experimental and empirical approaches available for determining the CV of materials such as MSW. Calorimetric measurement is the common method for determining the energy content of MSW. One method of determining the CV of a given material is by means of an open calorimeter in which pressure is maintained at 1atmosphere. Under constant pressure conditions, the heat released is equal to the enthalpy change for the reaction. Another type of calorimeter is the bomb calorimeter in which Combustion is conducted under conditions of constant volume. Regarding the empirical approaches, there are three types of models that are used to predict CV values based on the following analyses.

1. Physical composition
2. Ultimate analysis
3. Proximate analysis

Determination of the energy content of the MSW is not an easy task. This is because of the equipment limitation and the complex nature of the wastes. Also, MSW composition varies amongst communities and even within one community from year to year, but the differences is not substantial. Below is the energy content of various types of waste components. The Typical heating values of principal constituents of municipal wastes is given below;

Table 3. *Heating value of each component of solid waste [8].*

Component	calorific value (MJ/KG)
Paper and paper products	12.23-18.56
Plastic-coated paper	17.09
Food and food waste	4.12-38.33
Wood, seasoned	14.97-17.00
Organic garden refuse	4.79-18.59
Tyres	32.12
Leather goods	16.86-18.53
Rubber	26.07
Plastics	
Polyethylene	45.81
Polystyrene	38.22
PVC	22.71
Mixed plastics	32.82
Textiles	
Rags	16.06
Upholstery	16.20

Incineration of solid waste for energy recovery

Incineration is defined as "reducing the volume of solid wastes by use of an enclosed device, using controlled-flame combustion". It is a thermal waste treatment process where raw or unprocessed waste can be used as feedstock. The incineration process takes place in the presence of sufficient quantity of air to oxidize the feedstock (fuel). Waste is combusted at high temperature and in this stage waste converted to carbon dioxide, water and non-combustible materials with solid residue state called incinerator bottom ash (IBA) that always contains a small amount of residual carbon. It is the process of direct burning of wastes in the presence of excess air (oxygen) at temperatures of about 800°_C and above, liberating heat energy, inert gases and ash. Net energy yield depends upon the density and composition of the waste; relative percentage of moisture and inert materials, which add to the heat loss; ignition temperature; size and shape of the constituents; design of the combustion system (fixed bed/ fluidized bed), etc. In practice, about 65 to 80% of the energy content of the organic matter can be recovered as heat energy, which can be utilized either for direct thermal applications, or for producing power via steam turbine.

The combustion temperatures of conventional incinerators fuelled only by wastes are about 870°C in the furnace. These temperatures are needed to avoid odor from incomplete combustion but are insufficient to burn or even melt glass. To avoid the deficiencies of conventional incinerators, some modern incinerators utilize higher temperatures of up to 1650°C using supplementary fuel. These reduce waste volume by 97% and convert metal and glass to ash. Wastes burned solely for volume reduction may not need any auxiliary fuel except for start-up. When the objective is steam production, supplementary fuel may have to be used with the pulverized refuse, because of the variable energy content of the waste or in the event that the quantity of waste available is insufficient. Incineration may also be implemented without energy and materials recovery. In some countries, incinerators built just a few decades ago often did not include a materials separation to remove hazardous, bulky or recyclable materials before combustion. These facilities tended to risk the health of the plant workers and the local environment due to inadequate levels of gas cleaning and combustion process control. Most of these facilities did not generate electricity [9]).

1.4.3. Principles of Incineration

Incineration facilities may use either mass burning systems or prepared fuel systems.

a. Mass burning systems- involve feeding mixed municipal solid waste into a furnace or boiler without mechanically separating or preparing the waste in any way. These facilities can be either large field-erected furnace-boiler systems or smaller modular furnace-boiler systems.

b. Prepared fuel systems- mixed municipal solid waste is mechanically separated and processed to make RDF either as a supplemental fuel for an existing furnace-

boiler or to be used alone in a dedicated furnace-boiler.

From the experiences of some Developed countries, Energy recovery is rarely associated with small incinerators; incinerators burning less than 250 tons per day do not produce cost effective steam. This steam can then be used to generate electricity, power industrial processes, or provide heat. Incinerators may be classified in a variety of fashions.

This classification can have one of the following forms:

By type and form of the waste input.

1. By the throughput capacity (with or without heat recovery).
2. By the rate of heat production (for systems with energy recovery).
3. By the state in which the residue emerges from the combustion chamber and
4. By the shape and number of furnaces (e.g., rectangular, multiple).

The key system elements involved in the incineration of urban solid wastes are: Tipping area, Storage pit, Equipment for charging the incinerator, Combustion chamber, Bottom ash removal system, and Gas cleaning equipment (i.e., air pollution control system). If energy is to be recovered, a Boiler is included.

1.4.4. Combustion Air

Combustion air may be classified either as "under-fire" or as "over-fire" air. Under-fire air is that which is forced into the furnace through and around the grates. Over-fire air is forced into the furnace through the sides or the ceiling. Over-fire air typically is introduced through jets located at specific points in the furnace. It is used to regulate and complete the combustion of combustible gases evolved by the thermal reactions that are occurring in the lower part of the furnace. The flow of air and combustion gases through the furnace can be controlled by means of forced draft and induced draft fans. The forced draft fan, as its name implies, forces air into the furnace, while the induced draft fan draws the air.

2. Material and Method

2.1. Method of Data Collection

2.1.1. Primary Data

During conducting the study in Adama city the following primary information were collected using:-

1. A well structured questionnaire.
2. Interview the organization (private, association and municipality) that are engaged in municipal solid waste management.
3. visual observation

2.1.2. Secondary Data

Various laboratory result, literature books, from Adama city administration recorded data and internet have been used to carry out the study.

2.2. Experimentation

2.2.1. Lab Analysis

I moisture content

673 g of wet sample of Solid waste was oven dried at 60°C for 6 hr and 626g of dry weight was determined. The percent moisture content can be calculated as a percentage loss in weight before and after drying as follows:

$$\% \text{ Moisture content} = \frac{\text{Wet Weight} - \text{Dry Weight}}{\text{Wet Weight}} X100\%$$

$$= \frac{673g - 626g}{673g} X100\% = 7\%$$

II Composition of solid waste by type

Dry sample gotten (626g) is separated manually and then calculate the composition of each type by mass. The moisture content of the sample is 7%.

Table 4. Laboratory result of solid waste composition of our sample.

Type	Mass in (g)	%by mass
Paper	70.5	12.26
Plastic	30.33	4.84
Food	95.15	15.2
Wood	46.52	7.43
Textile	62	9.9
Combustible leaves and grass	83	13.25
Fine	178.5	28.5
Metal	22.536	3.6
Stone and glass	37.56	6

This table shows the laboratory result of solid waste composition of Nazareth city. this laboratory activity done for three times by taking the samples of solid waste from different part of city and then determined the composition of these all sample and then this value in table is average value of those sample.

When we compare this composition with literature value it almost exists in the interval of literature value composition of the solid waste.

III Determination of total mass of wastes

The analysis is done for 2006 since it represents the recent data on wastes. A total of 71700m^3 waste is collected in wet basis and the total mass the component is determined by density values of the components and the total volume of waste (m=ρv).

Hence calculate the dry mass of total waste;

Dry mass= 93% x total mass in wet basis

=0.93 x 71700m^3 =66681m^3

Combustible Components

a. Mass of paper

ρ=150.66 kg/m^3 (average value)

Mass of paper=%paper x density x total volume

=0.1126X150.66kg/m^3 x 66681 m^3/year

=1131197.555Kg/year

b. Mass of plastics

ρ=72kg/m^3 (average value)

Mass of plastics=%plastics x density x total volume

=0.0484 x 72 x 66681

=232369.95kg/year

c. Mass of Food waste

ρ=628.66 kg/m^3 (average value)

Mass of food waste=%food waste x density x total volume

=0.152 x 628.66 x 66681

=6371790.974kg/year

d. Mass of wood waste

ρ=156 kg/m^3 (Average value)

Mass of wood waste=%wood waste x density x total volume

= 0.0743 x 156 x 66681

=772886.13kg/year

e. Mass of Textiles

ρ=140.66 kg/m^3 (average value)

Mass of textiles=%textiles x density x total volume

=0.099 x 140.66 x 66681

=928555.59kg/year

f. Mass of combustible leaves, Grass

ρ=254.33 kg/m^3 (average value)

Mass of combustible leaves, Grass=%leaves x density x total volume

=0.1325 x 254.33 x 66681

=2247064.68Kg/year

g. Mass of Fines

ρ =300Kg/m^3 (average value)

Mass of fines =%fines x density x total volume

=0.285 x 300 x 66681 =5701225.5Kg/year

Total mass of combustibles=11013299.4Kg/year so the combustible components generated annually are summed up to give 11013.299tons/year.

Incombustible Components

h. Mass of metal

Mass of metal=% metal x density x total volume

=0.036 x 120 x 66681

=288061.92kg/year

i. Mass of stone, glass and non combustible component

Mass of =%stone, glass and NC x density x total volume

=0.06 x 411 x 66681

=1644353.46kg/year

The incombustible components are summed up to give 1932415.38Kg/year (1932.415ton/year)

The total mass of combustible and incombustible components generated annually 12945714.78kg/year (12945.714ton/year).

Determination of ash content

Ash content of solid waste is determined by burning the solid waste that contain all components in proportion and then balance the ash after the ignition is happened. According to our project we are taken 100g of our sample for ignition in the furnace and we have gotten 20g of ash. Those, solid waste in Nazareth town have been determine about 20% of ash content.

The ash meets the EPA non-toxic criteria (TCLP test, Wiles 1997) and can be used as landfill cover and in other beneficial uses.

IV Heating value determination

One method of determining the CV of a given material is by means of bomb calorimeter in which pressure compressed in compressor is maintained at 3atmospheres. This type of calorimeter is in which combustion is conducted under conditions of constant volume. In order to determine the CV of MSW, samples of MSW are selected combustible part from solid waste sample (food, paper, plastic, grass, wood, textile, fine). The CV can be measured for each of the components individually by burning a weighed sample in an oxygen bomb calorimeter and measure the reference and final temperature.

We were prepared the sample as a powder form and 1g of sample was pressed by sample presser, then Placed the sample in the bomb and 3atm oxygen gas was compressed on the bomb. Then we put the bomb on the calorimetric and add distilled water to the calorimeter and connect the bomb calorimeter with digital thermometer to read the temperature, finally we were start ignition and read temperature.

Table 5. Heating value of MSW (MJ/kg).

Type	Heating value (MJ/kg)
Paper	15.3995
Plastic	32.83
Food	21.225
Wood	15.985
Textile	16.06
Combustible leaves and grass	11.69
Fine	8.534

The annual generation rate and the corresponding heating values of each component of MSW are taken in to account to compute the available energy. The heating value of each component is calculated from the basic thermodynamic equation;

Q=m x q

Where Q =the available heat in the component stream

m=the mass of the component (annually generated)

q=the specific heat of the component

For Paper

For better computation the average calorific values are taken

Q=m x q

m=the annual generation of paper=1131197.55kg/year

q=15.395MJ/kg

Q=1131197.55kg/year   x   15.395MJ/kg   = 17414786.28MJ/year

For plastics (mixed)

Q=m x q =232369.95 x 32.83 =7628705.459MJ/year

For Food waste

Q=m x q =637179.97 x 21.225 =13524144.86MJ/year

For Wood waste

Q=m x q =772886.1 x 15.985 =12354584.31MJ/year

For Textiles

Q=m x q =928555.59kg/year x 16.06MJ/kg

=149126002.78MJ/year

For combustible leaves and grass

Q=m   x   q   =2247064.68Kg/year   x   11.69MJ/kg =2626818.11MJ/year

For Fines

Q=m   x   q   =5701225.5Kg/year   x   8.534MJ/kg =48654258.42MJ/year

Total available energy

The available heat in the combustible components of MSW is summed up to give

Q $_{combustibles}$=233914513.9MJ/year

=233914.5139GJ/year

V Heat loss due to moisture

The presence of moisture affects the available heating value. Therefore it is necessary to account for this effect. Based on the laboratory result wastes from Nazareth town contains around 7%. So this value is taken for the analysis.

The heat required to completely vaporize the moisture in the waste stream at 100°C is calculated as Q$_{H2O}$= mass of moisture in MSW x heat capacity of water in MSW x change in temperature

Q$_{H2O}$=m x c$_p$ x ΔT

But ΔT the deference between final temperature (100°C) and initial temperature of water in MSW assumed to be the average annual temperature in Adama (28°C).

ΔT = (100 + 273) – (28 + 273) = 72K.

The mass of moisture is given as

m=%moisture x density x total volume

ρ=965Kg/m^3 [density of impure water]

m =0.07 x 965Kg/m3 x 71700 m^3

m =4843335Kg/year

Thus the heat loss due to the moisture in the feed is Q$_{H2O}$

= 4843335Kg/year x 0.0042MJ/KgK x 72K

Q$_{H2O}$=1464624.5MJ/year

2.2.2. Method of Energy Recovery Process

Solid waste generation

Solid waste generate from different sources in Nazareth (Adama) town such as; households, Street, commercial and institutional firms, industries, hotels and hospitals.

Solid waste collection and storage

solid waste collection is handled in three ways: door-to-door collection for households along accessible streets; block collection for clients (large hotels, enterprises, and institutions) requesting the municipality to provide them with refuse containers and containers system, which expects residents to carry and dump their waste in 10m^3 containers placed supposedly accessible sites. Collect in the waste by using two or more plastic bags for their daily solid waste based on the amount of solid waste that they have been generating daily.

Transportation

Then transporting the collected solid waste by using pushcarts to temporary storage container and there is large amount of solid waste in temporary storage container then transport to central storage container by using trucks. The vehicles carry only a single container at a time to disposal site. A trip is made to and from collection sites only for single container of maximum capacity of 10m^3 or 2160kg.

Sorting

After collecting to central storage container sorting the raw material that can be burn and cannot burn in furnace manually.

Size reduction and sieving

Size reduction is an essential step in mechanical processing of mixed wastes and the operation reduces bulky items to particles, the sizes of which are compatible with the processing equipment. Size reduction also brings about a degree of uniformity in terms of the maximum particle size of the diverse components or particle size distribution of the incoming waste stream. The particle size greater than ten millimeter is separate using sieve and recycles again in the crasher.

Incineration

The most common and list cost form of incineration of MSW is mass burn. This involves a series of furnaces into which the waste is fed and where temperatures are in the region of 850°C to1200°C the, optimum temperature being 1100°C. The waste remains in the furnace for 45 to 70 minutes to ensure complete combustion. There may be auxiliary burners as part of the furnace to ensure that temperatures are maintained. The solid fraction of the combusted waste, the bottom ash is removed via conveyor belt and collected for disposal or further use.

Energy generation

The heat (850-1200°C) can be used to produce steam in boiler and the compressed steam at high speed move the turbine forms mechanical energy and then the generator changes mechanical energy to electrical energy.

Flue gas treatment

The flue gas constitutes of dust and hazardous substances in gaseous and particulate form that needs to be removed before the flue gas is released into the atmosphere, in order to fulfill the environmental standards. The concentration of the pollutants of the flue gas depends on the waste composition and also on the incineration conditions. The two applied flue

gas treatment process require bag filters, and wet scrubbers, which are described below.

Wet scrubber

The basic concept for the wet scrubber, is to accelerate the hot flue gas together with injected water so that the water droplets collect the dust particles and precipitate in a settling chamber. The wet scrubbers have a wide area of use, for example when the flue gas contains moisture and acid with separation rate.

Bag filter

Bag filter are widely used in incineration plants. The dust-laden gas passes through a filter and is transported through cylindrical bags where the particles are collected, the bag filters has a high cleaning efficiency, with a separation rate of over 99.95 percent. Filtration efficiencies are very high across a wide range of particle sizes.

2.2.3. Material and Energy Balance

i Material balance

From the experimental result we have to sorting the incinerating solid waste material from the total solid waste.

Assumption: The process is steady state, Take basis 1hour, Water inlet on wet scrubber=1500kg/hr, Air inlet in the furnace=120kg/hr, The input that removed (residue) in the wet scrubber is 60%, 2% of the stuck gas in the wet scrubber is water and 5.6% of input in the bag filter is residue.

a. Material balance on furnace

From general mass balance; Input = output

Solid waste +air = ash + flue gas

1529.6kg/hr + 120kg/hr = 0.2 x 1529.6 + m_1

m_1 = 1343.68kg/hr

b. Material balance on wet scrubber

Input = output

Flue gas + water = stuck gas + waste water

1343.68kg/hr + 1500kg/hr = 1470kg/hr + 0.6 x 1343.68kg/hr + m2 +0.02 x 1500kg/hr

m_2 = 537.47kg/hr

c. Material balance on bag filter

Input = output

Stuck gas = clean gas + residue=537.47kg/hr − 0.056 x 537.4kg/hr = 507.4 kg/hr

Heating value of the combustible component

The component of sample was sorted in each species and balanced the weight to determine the mass fraction of each component and the heating value of the combustible component was determined by bomb calorimeter.

ii Energy balance

Assumption: Energy in = energy out (stead state process), Sensible heat q_S, Latent heat q_L, Boiler, temperature = 210°C, Inlet temperature of water = 25°C and Cp of water =4.2kJ/kg.

a. Energy balance on furnace

Waste (1529.6kg/hr), m_1=1343.68kg/hr (flue gas), h=21248KJ/Kg, h1=?

Input=output

The heat content of solid waste = heat loss in to the ash + heat added to the boiler

1529.6kg/hr x 21248kJ/hr =h1 x 1343.68kJ/kg

+6500188.16kJ/hr

h_1 = 19350.4KJ/kg

b. Energy balance on boiler

Assumption:

The energy loss with ash in boiler is neglected.

m_{water} kg/hr (T_i=25°C), Q_{in} (m x h), Q_{out} (output energy at T_o=210°C)

From thermodynamics table

h_1@ 100°C saturated liquid 419.1kJ/kg, h_2 @ 100°C saturated vapor 2569kJ/kg, h_3 @ 210°C super heated saturated vapor 2800kJ/kg; qs = cpΔT = 315kJ/kg

Heat gained from furnace 7222.4 kw

Energy taken by water in the boiler = h3 + h2 + q_s = 2800 + 2569 + 315 = 5788.1kJ/kg

Then the mass of utility required for this duty can be calculated as:

$$m_{water} = \frac{7222.4kwx3600se}{5788.1kJ/kgxhr} = 4497.1kg/hr$$

Working energy (output energy) = m_{water} x h_3 = 4492.1kg/hr x 2800kJ/kg= 3493.9kw

c. Energy balance on wet scrubber

Water 1500kg/hr (T = 25°C), Flue gas (T=150°C), stuck gas (T=70°C), Out let water (T=80°C)

The heat loss of the wet scrubber is the product amount of flow and specific heat of water with changing temperature.

Q = m_w x c_p x (80°C - 25°C) = 1500 x 4.2 x (80°C - 25°C) = 346500kJ/hr (loss)

The most common type of turbine used to generate electric city for steam power plant (incineration plant) is jet steam turbine. Mostly the efficiency of jet steam turbine is 80 – 90% from this we take 85% and generator efficiency is 95%. In order to proceed with the next step of converting energy that must be used to calculate the potential energy generation.

The output energy is: 0.85 x 0.95x25156080kwh/year

E =20313534.6kwh/year

2.2.4. Sizing of Main Equipment

Basis: Solid waste input1529.6kg/hr (36710.4kg/day); The factory work 24hr per day and 300 days per year.

a. Design of furnace

1. To design the furnace, the following should be either known or initially assumed

Total required heater duty [kJ/hr];

Efficiency (η), Fuel value [kj/kg], Temperature of inlet air [°C].

2. 2. Heat librated by fuel (Qf) = Qtot x η = 32500.9 MJ/hr x 0.79 = 26000.2MJ/hr

3. Mass of fuel = $\frac{Qt}{q}$ = 32500.9MJ/hr/21248Kj/kg= 1529.6kg/hr

4. Total required amount of air = 3 x Mair = 3 x 29 = 120 kg/hr

5. Inlet heat by air, Qinlet = Mair x CPair (ΔT) = 29kg x 4.38kJ/kgk x 28°C = 3556.5kJ/hr

6. Heat absorbed by furnace wall, Qwall = 2%Qf = 52MJ/hr

Density air (ρ_{air}) =1.12kg/m^3

7. Volume $= \frac{\text{mass of air}}{\text{Density of air}} = \frac{120}{1.12} = 107\text{m3/hr}$

The furnace volume required for our purpose is then:

$V_{total} = V_{air} + V_{combustible}$

$V_{total} = 4.26 + 107 = 111.26\text{m}^3$

The available furnace exists on the market that have relative capacity with our design is 120m^3.

b. Design of boiler

From energy balance the amount of water (utility) entered to the boiler is calculated is 4497.1kg/hr.

Thermal conductivity (assume the boiler made of carbon steel and tubular structure) = 0.08W/m^2

Heat load on the boiler = 9.6MW

$$\text{Area of the boiler (A)} = \frac{Q \times L}{M \times K \times \Delta T}$$

= 9.6MW/4497.1kg/hr x 0.04W/m^2 x 185°C = 144m^2

We choose the tube outside diameter (D_o) = 60mm, inside diameter (D_i) = 58mm and L=8m

Area of one tube = L x D x π

= 8m x 0.058 x π = 1.5m^2

Water mass velocity = 4497.1kg/hr/8m^2

= 562.14kgm^2/hr

Number of tube (n) $= \frac{A}{A1} = $144m^2/1.5m^2 = 96

Total flow area (A_f) = πD_i^2 x n

= 152m^2

As we know the density of water (ρ_{water}) = 1000kg/m^3

Volume of boiler (V_{water}) = mass of water/density of water = 4497.1kg/hr/1000kg/m^3 = 4497lit/hr

Then depend on the amount of utility entered to the boiler, the volume of boiler required for our capacity we select is 5000lit.

c. Design of the fan

The criteria of the fan have to be fulfilled is: 200rpm (tangential velocity of the fan), Θ = 12° (0.03 revolution) inlet angle of fluid to the fan Average temperature of Adama city at atmospheric pressure is 28^0 c.

The amount of air required for combustion in this process determined at material balance is 120kg/hr.

M = 28.9kg/kmol, R = 8314.3KJ/kg, T = 28+272 = 300K

ρ_{air} = m/v = PM/RT

where M-molecular weight of air, P-pressure of air (1atm), R-universal gas constant, T-temperature of air in Kelvin, ρ_{air} = 1x10^{5}x28.9/8314.3x300 = 1.16kg/m^3

Density of air = mass air/volume of air

Volume of air = mass of air/density of air = 120/1.16 = 103.4m^3/hr =0.02872m^3/hr.

The capacity (Q) of fan is the calculated as:-

Q = V x D_f x Θ, V = π x D_f x U

Where, V- velocity air, D_f fan diameter, U- Tangential velocity of fan, Θ - angle of air at which it inlet to the fan. Substitute the velocity equation to the capacity equation and solve for diameter then the equation is become to:

D_f = $\sqrt{(Q / \pi \times u \times \Theta)}$ = $\sqrt{(0.02872/3.14 \times 3.3 \times 0.03)}$ = 0.34m = 13.4inch. Then the fan diameter relative to our design exist is 15inch. Therefore we select 15inch diameter fan for plant design in case of our project.

Bag filter

Calculating the volume of bag filter

Mass in let 537.47kg/hr, Density of stuck gas is 1.45kg/m^3

$v = \frac{m}{\rho}$ = 4447.4m^3

Average filtration = 50L/m^2/hr to finish the filtration in 6hr

$$\text{The filteration area required} = \frac{4447.4L}{50L/m^2 hr \times 6hr} = 14.8m^2$$

Scrubber

The volume of scrubber 2500L, Average scrubbing rate 75 L/m^2/hr

To finish the scrubbing in 6 hours the scrubbing area required can be calculated as

$$\text{Scrubbing area} = \frac{25000L}{\frac{75L}{m^2 hr} \times 6hr} = 55.56m^2$$

2.2.5. Economical Analysis
Plant Components and Cost Breakdown

Table 6. Summarized equipment capacity and price [10].

No	Equip name	Quantity	Material	Capacity	Unit price ($)	Amount price ($)
1	Furnace	1	Carbon steel	1600kg/hr	263000	263000
2	Boiler	1	Carbon steel	3000kg/hr	767500	767500
3	wet scrubber	1	Carbon steel	56m^2	4300	4300
4	Bag Filter	1	Carbon steel	15m^2	16000	16000
5	Fan	4	Carbon steel	15inch	1400	5600
Total						1056400

Total purchasing equipment cost = $1056400

Purchased equipment cost = 40% fixed capital investment

$$\text{FCI} = \frac{\$1056400 = \$2641000}{0.4}$$

TCI = FCI + WC

WC = 15% TCI

TCI = FCI + 15%TCI

TCI – 0.15TCI = FCI

0.85TCI = FCI

$$\text{TCI} = \frac{\$2641000 = \$3107058.8}{0.85}$$

WC = 0.15 x $3107058.8 = $466058.8

Table 7. *Summarized value of direct and indirect costs.*

a. Direct cost

Component	Average% of FCI	Amount ($)
Purchased equipment cost	40	1056400
Purchased equipment installation cost	10	264100
Instrumentation and control cost	5	132050
Piping cost	9	237690
Electrical and size reduction equipment cost	6	158460
Building	10	264100
Service facilities	14	369740
Yard improvement	3	79230
Total	82	2561770

b. Indirect cost

Component	Average% of FCI	Amount ($)
Engineering super vision	8	211280
Construction expense	7	184870
Contractor fee	3	79230
Total		475380

TFCI is equals to Total direct and indirect cost (D+I) = $2561770 + $475380 = $3037150

Total product cost estimation

Total product cost = manufacturing cost +general expense

Raw material cost = (10-50% of total product cost)

Since the raw material cost is included in working capital investment

Direct production cost (DPC) about 60% of TPEC (total Purchased equipment installation cost)

DPC = 0.6 x $264100 = $158460

Raw material cost = 50% working capital
　　　　　　 = 0.5 x $466058.8

Working capital cost= 50%Total product cost

Total product cost (TPC) = $23302.94/0.5 = $46605.88

i Operating Labor (OL): (10-20% of total product cost) Consider the cost of operating labor = 15% of total product cost
=0.15 x $46605.88 = $6990.88

ii Direct Supervisory and Clerical Labor (DS & CL): (10-25% of OL) Consider the cost for Direct supervisory and clerical labor = 12% of OL
= 0.12 x $6990.88 = $838.9

iii Utilities: (10-40%) of total product cost) Consider the cost of Utilities = 30% of total product cost
Utilities cost =$0.3 x TPC =0.3 x $46605.88 =$13981.7

iv Maintenance and repairs (M & R): (2-10% of fixed capital investment) Consider the maintenance and repair cost = 3% of fixed capital investment

v Maintenance and repair cost = 0.03 x $2641000= $79230

vi Operating Supplies: (10-20% of M & R or 0.5-1% of FCI)
Consider the cost of Operating supplies = 10% of M & R
Operating supplies cost = 0.1x $79230 = $7923

vii Patent and Royalties: (5% of total product cost)
= $0.05 x 46605.88 =$2330.3
Fixed charge = 15% Total product cost

= 0.15 x $46605.88 = $ 6990.88

Plant overhead cost = 10% Total product cost
= 0.1 x $46605.88= $4660.6

Manufacturing cost = Direct production cost + Fixed charge + Plant over head cost
=$158460 + $6990.88 + $4660.6 = $170111.48

a. General expense

General expenses = Administrative costs + distribution and selling costs + research and development costs.

i Administrative costs:(3% of TPC)
Administrative costs = 0.03 x $ 46605.88 =$1398.2

ii Distribution and Selling costs: (2-20% of total product cost); this includes costs for sales offices, salesmen, and advertising. Consider the Distribution and selling costs is eqaul 10% of total product cost. Distribution and selling costs = 0.1 × $46605.88 =$4660.6

iii Research and Development costs: (about 3% of total product cost)

Consider the Research and development costs = 3% of total product cost

Research and development costs = 0.03 x $46605.88 =$1398.2

D. Financing (interest); (5% of TCI) = 0.05 x $3107058.8 = $155352.94

Let now calculate the Gross profit and Net profit

Gross profit = total income – total production cost – depreciation cost

Depreciation cost = 6%FCI
= 0.06 x $2641000 = $158460

For our production rate = 20313534.6KWh/year

In Ethiopian selling price standard 1kw/hr = 0.35ethio birr = $0.0175

Income = selling price x production per day x working day per year
 = $0.0175/kwh x 20313534kwh/year =$355486.9/year

Gross profit = total income – total production cost
= $355486.9 –$46605.88= $308880.97

Net profit = Gross profit (1–income tax rate)
= (1–0.02) x $308880.97
=$302703.35/year

E. Rate of Return on Initial Investment (ROI)

$$\text{ROI} = \frac{net\ profit}{total\ capital\ investment} = \frac{\$302703.35}{3107058.8} \; x \; 100 = 10\%$$

Commonly used profitability standards generally based on the highest rate of Earning. Taking 5% of new capacity with established of energy generation from the power plant from this result the project is feasible.

F. Payback period

Salvage value of the factory is $150000

$$\text{PBP} = \frac{FCI-salvage}{net\ profit+depriciation} = \frac{\$2641000-\$150000}{\$302703.35+\$158460} = 5.6 \text{ year}$$

2.2.6. Environmental Analysis and Plant SITE

(I) Environmental analysis

Environmental benefit of energy generation from solid waste plant is:

Use solid waste for the source of energy generation is avoid the environmental impact such as health problems, pollute the soil and water, gases emission to the atmosphere from the disposal site and others.

In the other case solid waste is one of the alternative energy sources. This shows that solid waste use for energy generation minimizing the environmental impact by reducing the usage of non renewable energy sources.

The flue gas constitutes of dust and hazardous substances in gaseous form that needs to be removed before the flue gas is released into the atmosphere in order to fulfill the environmental standards. The concentration of the pollutants of the flue gas depends on the waste composition and also on the incineration conditions. The air pollution Problems are solved primarily by building tall stacks. The wet scrubbers are often used in flue gas treatment to reduce substances as hydrogen chloride (HCl), hydrogen fluoride (HF) and sulphur oxides (SOx) emission in atmosphere after this equipment the bag filer used to also removed the particulate matter. The waste water from wet flue gas cleaning must be treated at the site in accordance with the local waste water standards before being discharged to a sewer or directly into the final recipient. The presence of small concentrations of toxic materials in the salty waste water requires sophisticated chemical treatment technology to meet common standard.

(II) Plant site

Site selection criteria:

a. The availability of transportation considered
b. A good working environment is preferable for the workers
c. Distance from waste generation area must be also considered
d. Type of soil is also must be considered to avoid lechate
e. Population density or number of people live that area also considered

Therefore depending on the above criteria we choose Nazareth (Adama) town waste disposal area (on the road of Addis Ababa around the wind power) is better for erecting of energy recovery plant from solid waste than another place since that area is not good much for living of population because of geographical sitting.

3. Result

Based on the data gathered through questioner, observation, from primary and secondary sources, the Municipal solid waste management system setup, i.e., the solid waste collection and disposal operation in the city generated data given here under Table 8 below.

Table 8. The total energy gain from solid waste disposal operation and profit in Adama city generated data.

Total waste	Capacity of Energy generation	Payback time	profit	Rate of Return on Initial Investment
71700 m³ annually	3.1MW annually	5.6 year	$302703.35/year	10%

4. Discussion

Disposal of Solid waste suffers both Health problem and environmental pollution. Still Ethiopia is pure in treatment of solid waste management system and this study gives a good outlook for countries like Ethiopia to play and implement in effective policy design and emphasis to development of energy generation plant from solid waste and enhancing modern access at all city's level.

Moreover, energy that recovers from solid waste had different uses such as industrial, domestics and commercial purpose. Incinerator of solid waste for energy recovery is important technology that reduces the environmental impact and increase economic profit. Thus, collected solid waste from Adama (Nazareth) city; (71700 m³) annually and can generate 20313534.6 kwh /year energy or 3.1MW electricity and the profit is $302703.35/year. The Payback period of the investment of the plant was determined within acceptable level of time (5.6year). So, economically, socially and politically site of view those study give impasses to the faceable Waste-to-Energy scheme and to implement into a larger scale because the revenue from the electricity sales will be able to offset the operating costs in a shorter time span and introduce energy generation plant from solid waste in Nazareth-Ethiopia. Those, Adama/Nazareth city Administration could be more profitable, implement incineration with energy recovery plant for better production of electricity. Further study should be carried out under ideal circumstances of sorting, processing, and recycling these materials should go to different destinations.

5. Conclusion

Awareness amongst the city administrative about the benefits of integration of various technologies for Municipal solid waste processing is lacking. This is necessary as different technological options are required for Treating the different components of waste, such as Composting/ Biomethanation process for Organic component, incineration/ gasification/ Refused derived fuel process for Combustibles portion of waste, inert management facility for Construction and Demolition waste, etc.

Government should have a role to play at all levels federal and state in effective policy design and emphasis could be given to development of energy generation plant from solid waste and enhancing modern access at all city level of Ethiopia.

Labor that work at power plant should easily accessible for educational program. The waste that generates from the plant is must not disposed to the environment before treatment. As a general recommendation the implementation of waste to energy should be transform

into large-scale schemes.

References

[1]   Ayodeji Ifegbesan, Exploring secondary school students' understanding and practices of waste management in Ogun State, Nigeria, International jornual of environmental &science education, Vol. 5, No. 2, April 2010, 201-215.

[2]   L. A. Guerrero, G. Maas, and W. Hogland, *Solid waste management challenges for cities in developing countries.* Waste Management, 2013. 33: p. 220-232.

[3]   R. Marshall, and K. Farahbakhsh, *Systems approaches to integrated solid waste management in developing countries.* Waste Management, 2013. 33: p. 988-1003.

[4]   Mesfin Assefa1, Muktar Mohammed2, Solid Waste Generation Rate and Characterization Study for Laga Tafo Laga Dadi Town, Oromia, Ethiopia, International Journal of Environmental Protection and Policy 2017; 5 (6): 84-93.

[5]   Adama town Administration Municipality, 2005.

[6]   *Harker JH, Buckhurst JR. Fuel and energy*, Composition of municipal waste arising in the European country, *London: Academic Press, 1981*.

[7]   *John W. Bartok,* Heating value of each component of solid waste *(Approximate Heating Value of Common Fuels), December 2004)*

[8]   *Journal of the Air and Waste Management Association, 1996.*

[9]   http://www.matche.com, 2013.

[10]   Kreith F. (1994), Hand book of Solid Waste Management, Mc Graw-Hill Inc. U.S.A.

[11]   Berenyi, E. (1999), Methane Recovery from Landfill Yearbook, 5th Edition, Governmental Advisory Associates, Westport, CT.

[12]   Brady, M. H. (2000), "Materials and Energy Recovery from the Dry Stream of New York City's Residential Waste", M. S. Thesis, Earth and Environmental Engineering, Columbia University, New York, NY 10027.

[13]   Municipal solid wastes (management and handling) rules, 2000 annual report 2004-2005.

[14]   Tchobanoglous G., Theisen H., and Eliasssen R., 1977. Principles and Management Issues Mc Grow-Hill Kogakush, Tokyo. Solid Waste Engineering.

[15]   Brady, M. H. (2000) "Materials and Energy Recovery from the Dry Stream of New York City's Residential Waste", M. S. Thesis, Earth Resources Engineering, Columbia University.

[16]   Walsh 2000, Walsh, D. C., S. N. Chillrud, H. J. Simpson, and R. F. Bopp, 2000, "Refuse Incinerator Particulate Emissions and Combustion Residues for New York City during the 20th Century", Environmental Science and Technology, in press.

[17]   Lema Asfaw. Truck in a duty of primary and secondary waste collection. Journal of Environmental Science (2004).

[18]   Julius N. Fobil. Evaluation of municipal solid wastes (MSW) for utilization in energy production in developing countries (2005).