LIFE CYCLE ANALYSIS OF THE PROPOSED MUNICIPAL SOLID WASTE MANAGEMENT – WASTE TO ENERGY INCIENRATION SYSTEM IN GAMPAHA DISTRICT

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Degree of Master of Engineering

Department of Mechanical Engineering

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MAY 2019

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Thesis/Dissertation submitted in partial fulfillment of the requirement for the Master of Engineering

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Acknowledgment

This thesis work is accomplished to fulfill the requirement of the Master of Engineering in Energy Technology degree in Department of Mechanical Engineering University of Moratuwa

I would like to thank Dr. Inoka Manthilake for her valuable supervision throughout the study and her invaluable support, without which this work could not have been accomplished.

I would like to express my sincere gratitude to Dr Himan Punchihewa ,Our post graduate course coordinator, for supporting me throughout the course with his continuous guidance .

Also I convey my warm gratitude to my family, My Present and Former Mangers,Mr Ranajan Madugalle,Mr Bandula Arunasiri,Mr Prasnajith Gunawardhane and Mr Channa Fernando ,giving their support to complete my studies .

…….

Danisha Sammani

September 2018

ABSTRACT

Municipal Solid waste ,which is generated from different activities has become a major crisis not only in Srialanka ,but also to the rest of the world . In Sir lanka, we have been struggling with this problem since Avery long time, which we are still failed to adopt a sustainable solid waste magnet system in our country.

There are different waste management methods adopted in different parts of the world to manage this national problem in a sustainable way. Open Dumping, OceanDumping, Sanitary Landfilling ,Composting and recycling, Incineration are the common methods of managing the Municipal

In Srilanka ,Open Dumping is the main and highly adopted method of disposing the waste form their household premises which they called “Managing “.Due to lack of knowledge in waste management and its negative environmental impact to society people tend to dispose there waste even in roads, bare lands etc .Also there are specific locations where garabage is been dumped legally by the local authorities which are now turned in to garbage mountains of large heights.. Meethotamulla,Bluemendal,Karadiyana , are well-known garbage dumping locations which is fed by MSW s every day .

The improper management of waste has created lots of negative impacts in Srilanka in the recent past years. Among them the incident of collapse ”Meethotamulla “ garbage which was collapsed on 14th April 2017 has lost lives of 30 human and destroyed the homes of lot of people lived nearby. So it is no doubt that it is a national problem which all the responsible authorities should address it with a sustainable solution.

The generation of Solid Waste is calculated as 7000-8000 of tons per day in Srilanka, among this amount approximately 3500 tons of MSW is collected per day as rest of the waste is undergone through the different waste disposing methods. According to statistics it is calculated that 58 % of collected waste is from the western province or the waste from Kaluthara,Colombo and Gampaha districts.

As shown by the statistics a higher proportion of waste generation is from the Western Province of the country and due to increasing population it is important to implement sustainable solution to this problem.

After discussing on different feasible options as a solution to this problem government has decided to convert the waste in to energy by waste incineration technology .They have decided to build three waste to energy plants one in Muthurajawela ,Kerawalapiyita, which will manage all the MSW s from Colombo municipal council area which is about 700 MT per day ,also the plant generate 10MW of power and it is fed to the national grid. The other plant will be located in "Muthurajawela" which will convert the 650MT of Solid Waste from the Gamapaha district also add 10MW of electricity power to the national grid. The third plant is to be built in "Karadiyana"to treat 500MT of waste which is also a 10MW plant.

The overall process of the conversion of this MSW in to energy contains bunch of activities which has its own impact to the environment .To identify the impact on the environment by this proposed process can be analysed using well known method ;Life Cycle Analysis .

The Life Cycle Analysis is a good concept of analysing any system to evaluate its overall environmental impact. It shows the areas of impact generation and contribution of each activity for an identified impact. Then a detail analysis can be used to identify the impacts and take necessary actions to reduce them.

Since there is no any life cycle analysis has done for the proposed incineration system which is going to be adopted in Srilanka in the near future this has identified as the knowledge gap which I am going to address in this of research thesis.

For this assessment I have selected the proposed waste to energy incineration system in Muthurajawela which will treat the MSW s in Gamapaha district. Among many available software tools to analyse the LCA, I will be using the" OPEN LCA" with limited to certain boundary conditions.

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LCA Life Cycle Assessment

LCI Life Cycle inventory

LCIA Life Cycle Impact Assessment

CO2 Carbondioxide

NOx Nitrogen Oxides

PM Particulate matter

SOx Surfur Oxides

MSW Municipal Solid Waste

MT Metric Ton

Kg Kilo Gram

CHAPTER 1

1. Introduction

1.1 Background

Municipal solid waste (MSW) is basically the unwanted parts of the things which is consumed by human and animals in their day today life .It is generated from Industrial ,domestic, commercial, and construction activities. Waste can be categorized based on material, such as plastic, paper, glass, metal, and organic waste.With the rapid growth of the p[population the world the generation of the solid waste too get included in higher percentages.

According the world bank surveys , in 2016 the total generation of waste is around 2.01billions of tons annually and waste generation per person per day is around 0.74 kg, But with the development of the population it is expected to have 70% more waste generation which will be around 3.40 billion of tones per year in 2050.

The generation of waste by the developed countries account 34% of the total generation of waste though the population accounts only 16 % of the world population .The following map shows the

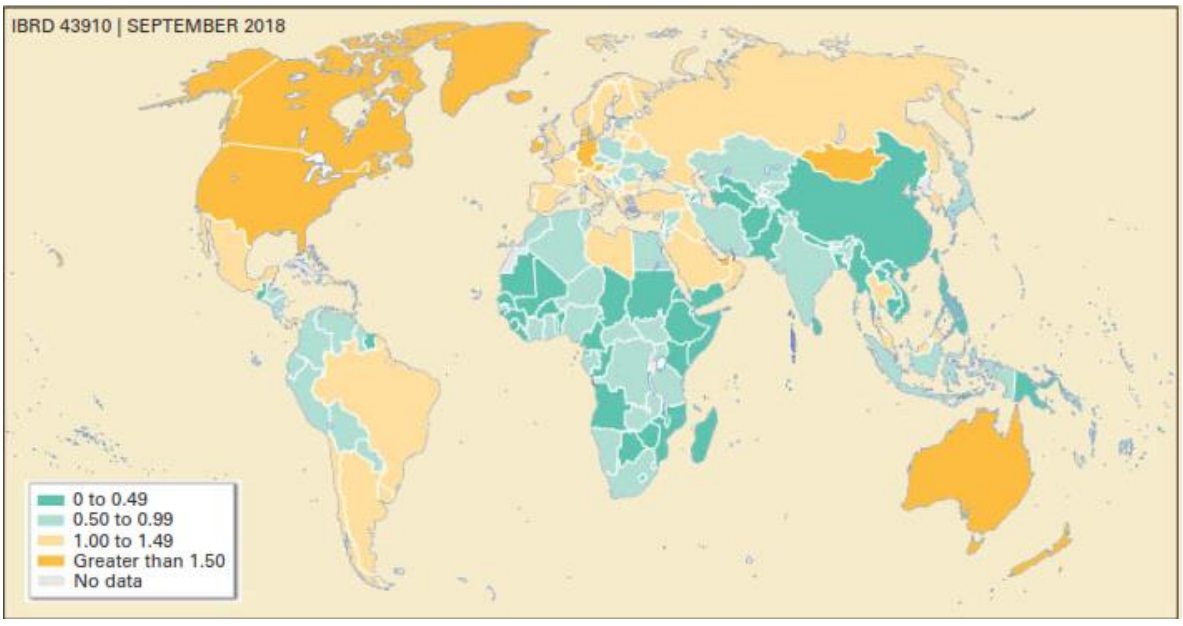


Figure 1-1 Waste generation per capita (source - 3.Urban Development series ,What a Waste ,Global Snapshot of solid waste Management to 2050.World bank Group)

It is predicated that daily per capita waste generation in high income countries is projected to increase by 19 percent by 2050, while the low- and middle-income countries where it is anticipated to increase by approximately 40 percent or more. With these predicted results it is very important to get necessary precautions to manage the solid waste problem in a sustainable way.

As a developing country Srilanka is facing many problem in managing the Municipal Solid Waste since a long time .According to present statistics the total generation of waste is around 7500 MT per day and among the generation only 3500MT is collected by the Local Authorities. The prevailing method adopted by many parts of the country is open dumping of waste in nearby roads, bare lands.

The following table shows the per capita generation of the waste by local authorities

Table 1-1 Waste generation Per Capita (Source – Central Environmental Authority)

Type of Authority	Waste generation per person per day
Colombo Municipal Council	0.8
Municipal Council	0.75
Urban Councils	0.6
Pradeshiya Saba	0.4

Among the total generation of waste, western province accounts 60 % from the total value. The following table shows the percentage collection of waste and the percentage of population in different provinces of country.

The waste collection of the country is managed by the local authorities of the country. In Srilanka number of local authorities which is responsible in collecting the waste is as follows;

Table 1-2 Percentage collection of Waste by province and percentage of population, number of Local Authorities to collect waste in Srilanka

Province	Percentage of waste collection by total	Population percentage	Number of LA s
Western Province	58.5	29	48
Southern	7	9.7	49
Central Province	8	12.5	43
Eastern	8.5	7.7	32
North Western	6	11.3	33
Nothern	3.3	5.3	17
Sabaragamuwa	3.2	12	29
Uva Province	3	6.25	27
North Central Province	2.5	6.25	26

The waste generated by different premises collected by these authorities and taken to the specified central location. Usually this waste is dumped without any proper management in to dump yard which is been used for a long period of time .Sometimes in some parts of the districts a very little percentage of organic is fed to composting plants. Although this problem has now become a crisis but there is no proper management system in Srilanka .

Although we have 309 responsible local authorities which 15 are Municipal Councils (MC), 37 are Urban Councils (UC) and 257 are Pradeshiya sabas (PS) ,only the three main MC 's ,(Dehiwala-Mount Lavinia and Kotte) perform well than the other LA's. Those three main MC ' collects 30-40% of total collection where other LAS have very small contribution such as 10-15%. The collection to generation ratio is 93% in 5% in smaller urban areas. According to surveys it was found that about 87 % LAs collects less than 10 T/d by each. Only five municipalities collect more than 100 T/d by each.

The western province which is urbanized than other provinces contributes 2000 MT or higher amount of waste per day in to the total collection, while Colombo generates 900-1200 MT of waste per day but only around 700MT is collected by the municipal council.

And this waste is taken either to Meethotamulla, Blumendal or Karadiyna waste dumping sites which are located in the western province .Before 2009 Bluemendal site was used by the Colombo Municipal Council to dump their garbage. This garbage dump site extents to approximately 6.5 Ha and heights of these pile are around 30m and it contained 1.5-2.5 million tons of garbage .This large amount of garbage resulted in lot of environmental impacts to its surrounding. The improper discharge of leachate to the soil and water has increased its parameters it to very high numbers. Following table shows the results of water quality and the soil parameters of the Blumendal dump Site.

Table 1-3 Water quality around the Blumendal dump Site.

Component	Result
Organic Matter content	2.73g
Total inorganic and organic Phosphate in soil	150 m distance and 400 m distance from the center of the waste pile was 0.85 mg/l and 0.32mg/l
Soil acidity and water pH	150 m and 400 m radius are between the range of 6.2-7.3 for soil and 6.7 and 7.4 for water
Nitrate ions in soil and water	150 m radius (2.0 mg per liter) compared to that of 400 m (0.4 mg/liter) (Table 1). Nitrate level in water within 150 m radius was 50 mg/ liter
Coli form in water samples	MPN of coliforms 900 x 102 / 100 ml while MPN of E. coli 170 x 102/ 100 ml.

Table 1-4 Heavy metal content and the standard maximum concentration levels (source POTENTIAL ENVIRONMENTAL IMPACTS RELATED WITH OPEN DUMPING SOLID-WASTE AT "BLOEMENDHAL", COLOMBO, SRI LANKS Sathees, LD Amarasinghe*, GS Panagoda, and RCL de Silva)

Heavy metal	Content in 400m boundary /ppm	Drinking water Standards in Srilanka
Pb	0.019	0.05
Cr	0.002	0.05
Mn	11.75	0.5
Ca	19.16	240
Zn	0.138	0.15
Cd	4.427	0.005
Cu	0.033	1.5
Mg	0.207	0.5

The above result shows that water and soil pollution is very high in the dump yard vicinity and, also heavy metal concentration found to be high due to improper heavy metal discharge to the Municipal Waste by different industries. Soil and Water contamination is a major impact of improper garbage dumps .Apart from that unpleasant smell, contamination of air makes lot of social impacts .People are widely suffered from respiratory illnesses due to emission of methane ,Sulpghur Dioxides,Nitrogen Dioxides. The rapid growth of mosquitos spread diseases like Dengue, Malaria.also distributon of Pathogens led to other diseases like Diahria ,Etc.

Since people were suffering from all these impacts for a long period of time and they were frustrated as government was not paid any attention to provide a feasible solution .People from the area started to protest over the issue and in early 2009 a large buildup of Methane gas resulted in partial collapse of the garbage mountain destroying lot of houses in the periphery saving lives of the people as they have attended to a festival in near by Kovil. The Methane gas has caused respiratory illnesses .After march 2009 the disposal of garbage to the Blumendal site is stopped by a Supreme Court order. With this decision Colombo Municipal Council had to face many problems in disposing the

collected garbage, Since there was no any feasible solution to the problem whole waste management system collapsed .People used to throw their garbage bags to nearby streets and roads. Due to this practice whole drainage system has blocked with bags and other items.

After the banning the Bulumendal site authorities decided to dump the garbage to near by site in Kolonnawa ,Meethotamulla .Though people have protested against taking garbage trucks from Colombo district ,Supreme court has ordered the Municipal Council to dump the garbage to Meethotamulla site as a temporary solution ,and also declared two acres of land for the purpose. But the same scenario has applied to this location as well resulting a development of garbage mountains climb up to 300fts .Following map shows the location and the extent of the garbage dump in Meethotamulla site. This site is located close to "Kittampahuwa Ela " which is the connected with Kelani River .Which has higher potential of getting contaminated by the discharge of leachate to soil and water .

Figure 1-2 Meethotamulla dumpsite as appeared in goggle earth in 2019

Following aerial photographs shows the progressive expansion of the Meethotamulla dump site till it becomes a huge disaster in 2017 .

2004

2009

2016

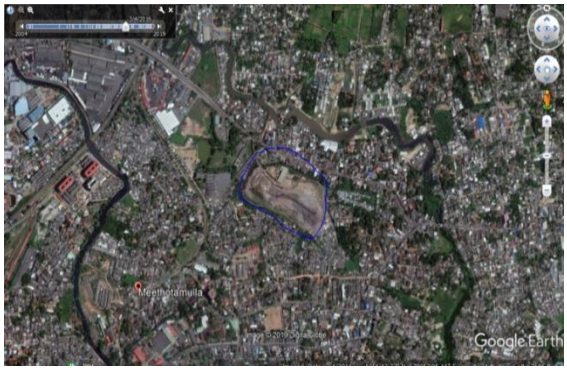


Figure 1-3 Aerial Photographs of the progression of the Meethotamulla dump site

At the time the dump site collapsed in April 2017 ,the extent was around the dump has occupied an area of 78000 m2, having a maximum length of approx. 413m in the NW to SE direction and a approx. width of 189m in NE and SW direction. The maximum crest height of the mound was in the range of 45-50m.

The reason due to this failure is the height of the garbage mountain and the steepness of it has sudden caused rotation movement which drove to a huge disaster killing more than 32peopole,8 missing and 1387 has displaced with their belongings.

It has found the dump site was loaded over capacity by compacting unnecessarily by heavy vehicles. Not only this tragic incident ,the pollution occurred to the environment throughout the years is uncountable. The air pollution due to Methane, Hydrocarbons ,Sulphur dioxides ,Nitrogen ioxide gasses has caused breathing illness. Apart from that contaminants release to the water bodies caused long term impacts such as health problem, ecological problems etc.

After the disaster in Meethotamulla just like what happened in Blumendhal in 2009 ,Government has not taken any sustainable solution to address this national problem .Though seven years has passed the situation was in same place as before.

There were some Solid waste management programmes introduced to the society by responsible authorities. In 2008 a project called PILISARU was initiated by Central Environmental Authority .It is an Integrated Waste management programme having its identifies objectives as follows

- Development of a National Policy on Solid Waste Management
- Development of a National Strategy on SWM
- Effective education & awareness for all stakeholders on SWM including training &capacity building
- Facilitation for LAS for implementation of SWM projects / programs
- Legal reforms to strengthen effective law enforcement

The project was a three year duration plan staring from 1st of 2008 ,and having its scope Collection of information on disposal of solid waste by LAs

- Evaluation of Project proposals
- Establishment of Waste Recycling Banking System
- Establishment of waste collecting centers.
- Technical Support , Institutional strengthening and capacity building
- Strengthening recycling by establishing collection network for metal, plastic, glass,
- and paper wastes
- Establishment of Compost plants at Local Authority level for the treatment of
- biodegradable waste
- Construction of low cost sanitary landfills for disposal of residual waste
- Providing waste handling equipment, machineries and waste transportation vehicles
- Education and awareness creation on the proper waste management
- Promoting Home Composting
- Monitoring and evaluation of the projects / program implemented by the PP
- Legal action against such LAs which do not carry out proper SWM practices

This has been a better project for proper management of MSW and under this programme there were several composting plants started in following district.

- Compost plant at Pothuwilkubura, Kolonnawa
- Compost plant at Pohorawatta, Kalutara
- Compost plant at Keerikkulama at Nuwaragampalatha, Anuradhapura
- Compost plant at Madirigiriya, Polonnaruwa
- Compost plant at Monroviawatta, Hikkaduwa

Construction of Sanitary landfills in different districts is was a key activity of this project and the very first such land fill in Srilanka was constructed in “DOMPE” in 2009 and started the operation in 2015 due to social impacts. This Sanitary land receives 25-30 tons of MSW s from Gampaha district and its calculated the site can be used for 12 years.

While taking the experience from this, Colombo Municipal Council stared designing a semi engineered landfill site in Ja- ela to dispose Colombo Municipal Solid Waste in 2017, But after having many social issues and technical failures the project was abandoned.

CMC was under pressure after Meethotamulla incident and they have taken garbage to several dumping sites until they manage the situation .when all their feasible solutions for the problem were left behind, Then they proposed to build up Waste to Energy Incineration plant in Colombo district, and there will be another plant in Gampaha district as well. The selection if the investors are done in early years and the government is looking forward to operate these two plants in the end of 2020.

As an immediate solution government found the already existing large scale quarry sites in Aruwakkalu can be easily used as landfill site .But it was undergone though lot of assessment as it is located close to wildlife area, After solving problems with the legal institutes ,government has started constructing the landfill site in 2018.The operation of the site is started in March 2019 and only the MSW s from Puttalam district is accepted in the first phase of the development .This project will be fully operated in the end of 2019 and the MSW s from Colombo, Dehiwala and Kolonnawa Municipal Councils will be brought to the land fill site. The Kelaniya transfer station is designed for this purpose and MSW will be transported to landfill by rail way. The land fill can accommodate 1200 tons of garbage per day.

While keeping this landfilling as an immediate solution, government has taken actions to build two Waste to energy plants in Kerawalapitiya as a long term solution for the Municipal Solid waste in Colombo and Gampaha districts. The construction of these plants will be started in the near future and it is expecting to commence the operation within two years' time.

1.2 Problem Formulation

Waste to Energy is a promising solution for the Municipal Solid waste problem in urban cities where larger number of waste is generated. In Srilanka there are two proposed incineration plants to be built in upcoming years .This solution is selected as the feasible and long-term solution over other solid waste management methods available.

It is important to observe the Environmental Impacts of any proposed development before stepping in to implement on stage. Environment in sense, all the impacts caused by the proposed activity which affect air, water, soil, flora and fauna should be properly evaluated .The Incineration of solid wastes produce large amount of flue gases and depend on the compositions and specific parameters the flue gas contains different harmful gases. Not only the incineration other activities related to the system too produce pollutants and release to the environment. It is important to make an in-depth look to every activity and related emissions to evaluate the impacts of the proposed project and to make preventive actions to minimize the impacts.

The overall objective of this thesis research is to undertake a comprehensive life cycle analysis for proposed Waste to Energy Incineration MSW management system in Gampaha District. This study is focused to analyze Global Warming, Acidification and Eutrophication impacts caused by the proposed system. All the activities of the system with in its identified boundary will be assessed in evaluating the above mentioned impacts categories.

The Specific objectives of the Research –

- ✓ To study the present methods of Municipal Solid Waste Management in Gampaha District its impacts on environment.
- ✓ To Study the proposed method of Waste to Energy Incineration process in Gampaha district and analyses their impacts
- ✓ Study the Open LCA software to model the LCA for Proposed waste Management system
- ✓ Carry out LCA for the system and evaluate environmental impacts and discuss the preventive methods.

1.3 Methodology

Life-cycle assessments (LCAs) is a cradle-to-grave analyses of any production systems and it provides comprehensive evaluations of all upstream and downstream energy inputs and all the environmental emissions. LCA not only provides an environmental outlook, but also compiles an inventory of energy and material inputs.

After I selected the topic for research study, I outlined the scope of my study. There I identified the main tasks to be followed as below.

1. Getting a broad knowledge on Municipal Solid Waste Management method in Sri Lanka and the proposed methods for managing the Waste.
2. The technology of Waste to energy Incineration and the all the processes related.
3. The proposed system of the Gampaha district and the activities in the proposed cycle.
4. Learning the Life Cycle Analysis process.
5. Data collection sources and methods of data collection.
6. Observe the available Data analysis software's and learn the selected software.
7. Gather the data and perform the Analysis for the selected impacts.
8. Getting the results and Discuss on it.

After selection of the topic for the research study with the help of my supervisor, first we have outlined the study scope as mentioned above. The knowledge on the present management systems and the past scenarios were collected using paper articles, internet articles, research papers available in the internet and the University library. When reading those material I could gather lot of knowledge on the MSW management practices adopted in Srilanka, and the consequences of wrong management practices. After getting the clear picture on where we stand as a nation on providing a sustainable solution to the solid waste management problem while comparing with the other countries which treat Solid waste as resource of earning money and creating job opportunities, the interest towards this study was inclined and it tend me to know more about Waste management in depth.

I read lot of materials to learn on the Solid waste management methods and the technology of every system. The sources of materials were found in previous research, Feasibility studies,EIA studies, project proposals. Different websites available for online learning helped me to gather information. With the help of my working place I could found all the proposed project details, the technology, other proposed auxiliary systems,etc.

Learning the LCA was a major task in my research, the initial learning was gained by my supervisor and other postgraduate students who are studying the LCA process. It was a combination of Self studying and discussions. Learning on LCA modeling software too was a major task of my research and the selected software “OPEN LCA” was studied using the online tutorials, and modeling examples.
After completing the above mentioned preliminary task the LCA was carried out as follows.

According to the ISO 14040:2006 describes the principles and framework for life cycle assessment (LCA) including:

1. Defining goal and scope of the LCA,
2. the life cycle inventory analysis (LCI) phase,
3. the life cycle impact assessment (LCIA) phase,
4. the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, the relationship between the LCA phases, and conditions for use of value choices and optional elements.

As the first step of the LCA process , the goal and scope was defined. My research was based on the proposed MSW management method (waste to energy incineration) in Gampaha district to treat 685 MT of waste .And it is proposed to be implemented within next two years .

I have read many publications written on the topic and there I found a no proper LCA for the proposed system is not yet carried out , which could have given very important information on possible impacts . The Incineration process mainly releases flue gases and the wastewater. Impacts are caused by these emissions also from other related activities. LCA can be carried out to look on list of impacts ,but In my study I will be observing the major environmental impacts .

The first step of the LCA process is, defining the goal and scope of the study .It is decided to evaluate the main impacts categories , Green House Gas emission, Acidification, Eutrophication caused by incinerating 685MT of solid waste and

converting it to 10MW energy per day. The main factors of defining the goal and scope are defined as follows;

Functional Unit of the product system – Total amount of 685MT Municipal Solid Waste management of per day using Waste to Energy Incineration technology.

System Boundary – The system boundary is defined to cluster the processes that are included in the product system, as well as which inputs and outputs that should be included. Only the activities falls under the system boundary is concerned for the study.

Here in my study I have marked the boundary as Transportation of MSW from 15 local authorities to the incineration plant and all the emissions of related activities in the plant ,transfer of 630Mt of collected Municipal Solid Waste to the Plant premises and transportation of waste residue to land fill site will be assess in the study.

Also environmental impacts occur during manufacturing of plant equipment and other all machineries, vehicles are not considered in the study.

CHAPTER 2

2 What is Solid Waste

Solid waste is the unwanted items generated by the different activities performed in day today life. Solid wastes are generated by Domestic activities like food ,cloths, stationery gardening ,Construction activities ,Agriculture , industrial processes, schools , hospitals, and all the other organizations where human activities are taken placed.

The Solid waste can be categorized in to several major components.

I. Municipal Solid waste
II. Hazardous Wastes:
III. Industrial Wastes:
IV. Agricultural Wastes:
V. Bio-Medical Wastes:

The Municipal Solid wastes are the nonhazardous solid wastes which are collected form the urban cities .This waste consists of disposal items form private homes, schools, other institutes.

The hazardous wastes are the Characteristics of Hazardous Wastes are disposed by the manufacturing companies which are highly involved in chemicals, Chemical manufacturing companies, petroleum refineries, paper mills, smelters and other industries. Plastic industries are some of them .These waste are classified as

1. Toxic wastes:

These wastes are poisonous in small or trace amounts. It may have acute or immediate effect on human or animals. Carcinogenic or mutagenic causing biological changes in children and the exposed people and animals.

Examples: pesticides, heavy metals.

2. Reactive wastes:

This type of wastes has a tendency to react vigorously with air or water.

3. Ignitable waste:

These types of wastes are highly ignitable in low temperatures also capable of spontaneous combustion. Examples: Gasoline, paint thinners and alcohol.

4. Corrosive wastes: These are acids and Bases which destroy the living tissues and materials.

5. Infectious wastes:

Included human tissue from surgery, used bandages and hypoderm needles hospital wastes.

Industrial Wastes –These are the wastes disposed by the processing industries and required special treatment. Sources of these type of wastes are Food processing industries, metallurgical chemical and pharmaceutical unit's breweries, sugar mills, paper and pulp industries, fertilizer and pesticide industries.

The next type of Solid waste are the Agricultural waste which comes from the crops and the livestock. Usually these are again used for agriculture purposes. These agrobased products care waste generated from , rice milling, production of tea, tobacco etc. Agricultural wastes are rice husk, degasses, ground nut shell, maize cobs, straw of cereals etc.

The bio medical wastes are generated in while treating the patients for several diseases. These are properly managed by responsible authorities.

The Municipal Solid Waste is the common form of Solid waste which is usually called Garbage. It consists mainly the following components.

Combustible waste and the Noncombustible waste .Again these both categories have the following components.

Table 2-1 Components of the Municipal Solid Waste.

Combustibles	Non Combustibles
Food	Glass
Paper	Metal
Textile	Soil
Plastic	Other Non Combustibles
Wood	
Rubber/Leather	
Other Combustibles	

The per capita per day waste generation on the average was 0.85 kg in Colombo Municipal Council(CMC), 0.75 kg in other Municipal Councils (MC), 0.60 in Urban Councils (UC) and 0.4 kg inPradeshiya Shabhas (PS).The generation of the MSW is around 0.4kg per person per day in developing countries and it is expect the percapita amount will vary from 0.4 to 0.8 within next five years of time .The waste consists more amount of organic components than the other and it is estimated as shown in the following diagram based on the MSW analysis done by the SLSEA(Srilanka Sustainable Energy Authority)

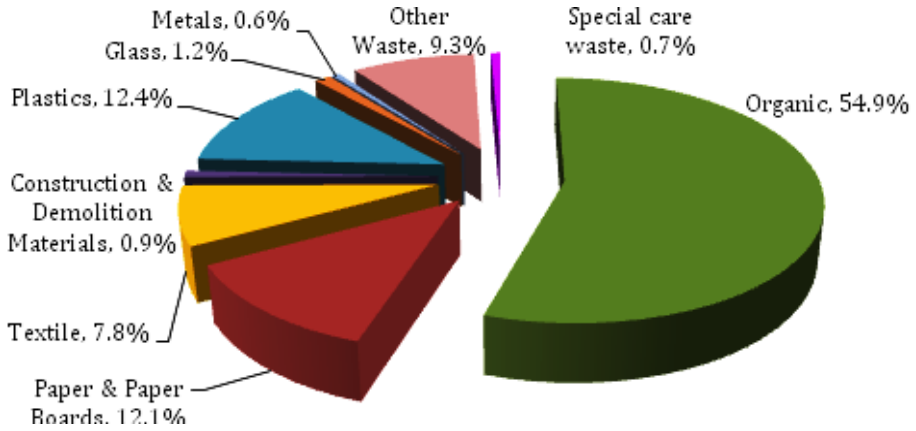


Figure 2-1 Municipal Solid waste Analysis

There are different analysis have been done by the institutes on Municipal Solid waste in Western Province and it has observed that the biodegradable percentage of MSW in Colombo has dropped from 65% to 54% between 2004 and 2015 while polythene and plastics percentages have increased to 14% from 5.4% as well as paper and cardboard percentage has increased to 10% from 7%. The combustible share (paper, cardboard, textile, rubber and leather, wood and timber, polythene and plastics) of MSW receiving in 2004 was only 17% while this share represents 31% in this latest analysis done on percentage composition of organic waste.

The per capita of the Solid waste generation is based different factors ,economic development, density of population, size of the urban habitation and consumption rate of commercial goods. Following figure shows solid waste generated per capita (kg/day) in different low developed countries and rapidly developing countries. Usually low developed countries are having the factor around 0.3-1 and rapidly developed countries are around 1 .

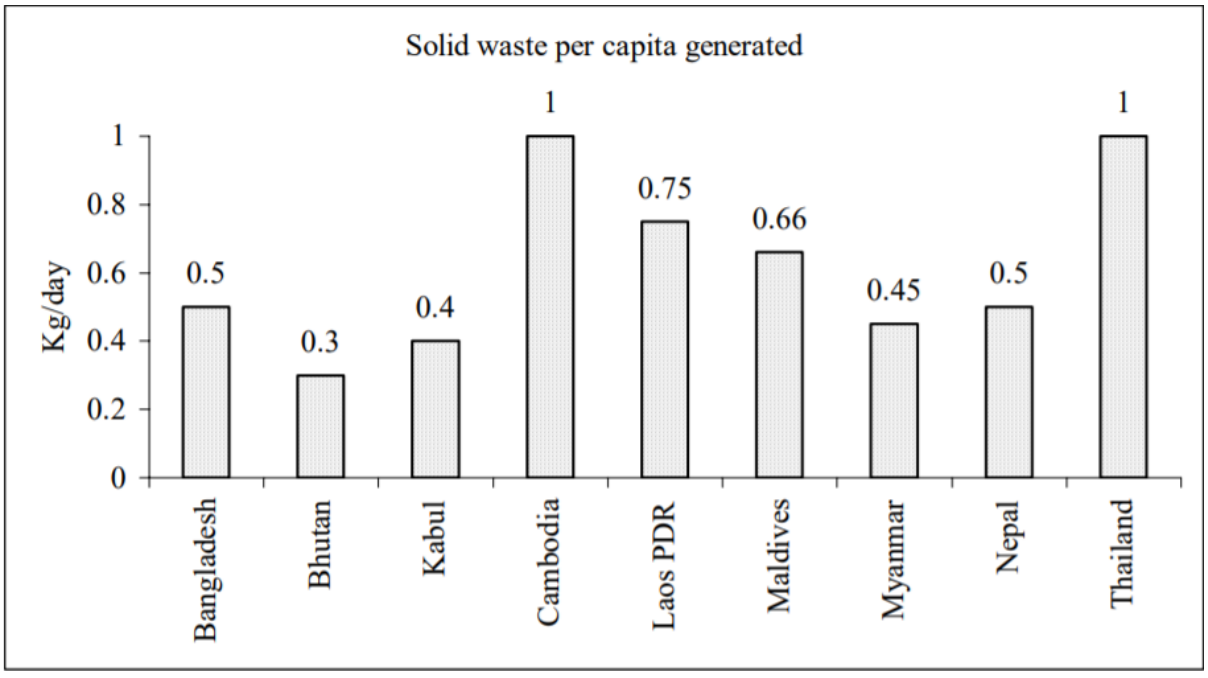


Figure 2-2 Comparison of Per Capita generation of Solid Waste in Asian Countries

(Source; Solid Waste Management in Least Developed Asian Countries –A Comparative Analysis Ulrich Glawe, C. Visvanathan, M. Alamgir)

Municipal Solid waste can be analyzed for its physical and chemical components as shown in the following flowchart. These results were obtained by the testing carried out for the proposed waste to energy plant in Gampaha district.

Table 2-2 Physical and chemical components of the Waste

	Item	Unit	Karadiyana				Kolonnawa		
		Kg/L	S1	S2	S3	Aver	S1	S2	Av
	Density		0.4	0.39	0.22	0.34	0.29	0.23	0.26
	Food		35.57	53.35	39.40	42.77	23.17	7.14	15.16
	Paper		6.34	6.44	10.61	7.8	8.72	14.78	11.75
	Textile		3.10	2.78	6.54				
	Plastic		9.98	17.28	21.28				
	Wood		11.08	0	0.00				
	Rubber		0.60	0.33	1.49				
	Other		27.72	18.57	13.41				
	Sub tot-1		94.39	98.75	92.73				
	Galss/pottery		2.44	0.53	2.19				
	Metal		0.11	0.52	0				
	Soil		0.00	0.00	00.00				
	Other		3.07	0.2	5.06				
	Sub tot -2		5.61	1.25	7.27	4.71	6.4	10.05	8.23
	TOTAL		100.0	100	100	100	100	100	100

The compositions of combustible and non – combustible components of the MSW in selected sites.

Type	Unit	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Apparent Density	kg/L	0.37	0.49	0.42	0.40	0.39	0.22

combustible	Food		0.2	0.09	0.49	35.57	53.35	39.40
	Paper		3.87	1.22	0.37	6.84	6.44	10.61
	Textile		11.61	2.54	1.7	3.10	2.78	6.54
	Plastic		51.44	49.91	35.24	9.98	17.28	21.28
	Wood		3.35	2.36	1.47	11.08	0.00	0.00
	Rubber/Leather		0.71	0.77	1.39	0.80	0.38	1.49
	Other Combustibles		22.00	30.23	43.66	27.72	18.57	13.41
	Subtotal		93.18	87.22	84.32	94.39	98.57	92.79
Non combustible	Glass		4.55	1.34	3.22	2.44	0.53	2.19
	Metal		1.73	0.63	0.74	0.10	0.52	0.00
	Soil		0.00	0.00	0.25	0.00	0.00	0.00
	Other Non Combustibles		0.54	10.91	11.47	3.07	0.20	5.08
	Sub total		6.82	12.78	15.58	5.61	6.44	7.27
	Total		100.0	100.00	100.00	100.00	100.00	100.00

Table 2-3 Chemical Analysis of the selected waste

Item	Unit	Value
C		47.3
H		5.5
O		29.740
N		0.42
S		0.4
Cl		0.4
Ash		16.49

Table 2-4 Waste generation and its compositions according to the income levels of the world

Summary by Income Level													
Income Level	Number of Countries Included	Organic (%)		Paper (%)		Plastic (%)		Glass (%)		Metal (%)		Other (%)	
		Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit
Lower Income	22	18	88	2	21	1	20	1	8	1	12	1	57
Lower Middle Income	27	20	76	3	34	2	18	1	9	1	20	2	59
Upper Middle Income	25	5	70	7	37	3	36	1	13	1	8	3	43
High Income	35	4	56	4	68	1	24	1	13	1	16	5	63
Total	109												

Summary by Region													
Region	Number of Countries Included	Organic (%)		Paper (%)		Plastic (%)		Glass (%)		Metal (%)		Other (%)	
		Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit
AFR	19	18	88	2	21	1	20	1	5	1	5	1	57
EAP	17	4	71	2	31	2	24	3	9	1	20	2	63
ECA	12	5	65	10	37	3	12	1	13	3	9	11	43
LCR	18	14	69	6	32	4	36	1	8	1	16	3	59
MENA	10	40	70	9	25	4	16	1	5	2	9	2	16
OECD	6	14	56	8	68	1	22	2	13	2	13	5	63
SAR	27	35	80	3	17	2	18	1	4	1	1	5	59
Total	109												

(Source;siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/.../AnnexM.pdf)

The above tables shows the organic composition is comparatively higher in low income level countries whereas inorganic compositions are higher in high income level countries. The observations done by World bank project graphically represent the composition of waste in different income level countries as shown in the following diagram.

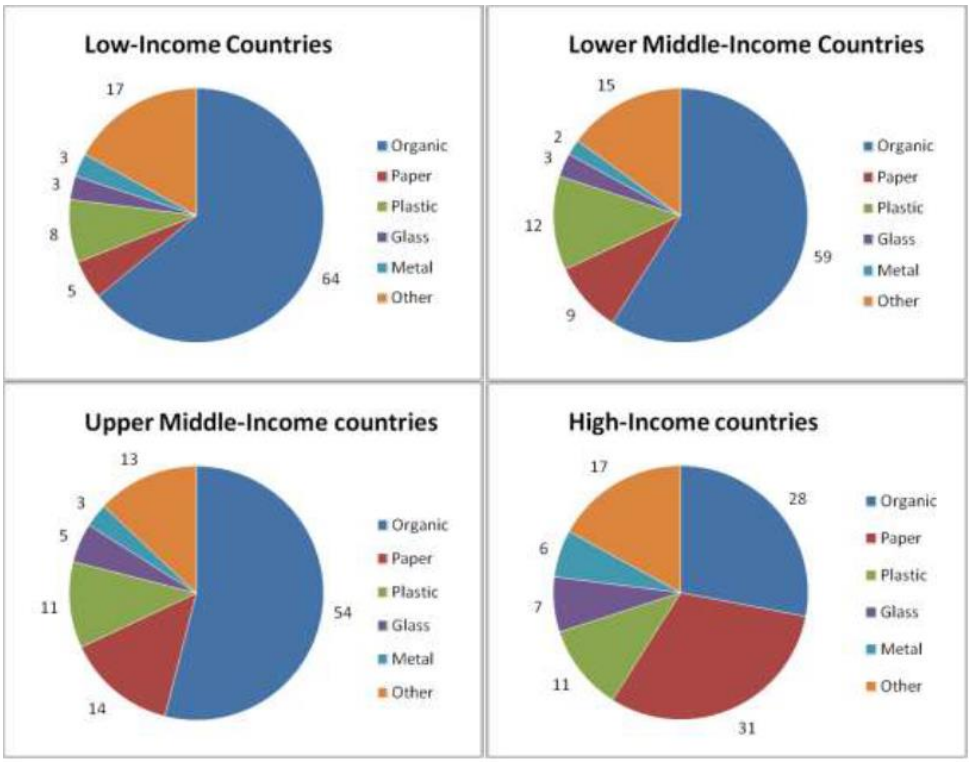


Figure 2-3 Graphical interpretation of waste compositions based on income level

Source-http://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1334852610766/Chap5.pdf

The calorific values of the MSW can be approximately calculated by

Table 2-5 Approximate Calorific Value of Components

Fraction	Calorific Value (MJ/kg)
Paper	16
Organic material	4
Plastic	35
Glass	0
Metal	0
Textile	19
Other	11

According to the above table higher the plastic ,paper content ,higher will be the Calorific value. So the value of the MSW in western province was found to be around 1700Kcal/kg to 2300Kcal/kg .

2.1 Municipal Solid Waste Management

As we discussed in the above sections Municipal Solid Waste has become a major responsibility of a country .Providing environmentally friendly management system is a challenging task for all the countries.

MSW management is process of several key activities,

• Storage

• Collection

• Transportation

• Segregation & Processing

• Disposal

As a practice most parts of the world store the waste in different bins which are having standard color code for different components, In Srilanka we the following color code is used for the bin identification in some parts of the country. This color code varies based on the country.

Organic waste –green

Paper- Blue

Glass – Red

Metal – Brown

Plastic/polythene – Orange

The general practice of MSW management process is ; The waste which is been stored on those bins will be collected by the local authorities and transfer it to transfer stations where further segregation or processing is done. Then the waste is disposed using different methods as ;

- Sanitary Landfilling

- Composting
- Recycling
- Incineration

Apart from the technically correct methods of waste management, there are many more methods practiced by people which bring highly negative impacts to environment.

Open dumping ,Ocean dumping ,open burning ,are environmentally negative practice with following uncontrollable impacts ,

- Spreading bacteria and other pathogens form organic waste which are exposed to environment.
- Block the public drainage system with garbage dumps which ultimately cause flash floods.
- Contamination of water,soil ,air with pollutants which cause serious health effects.
- Unpleasant odour around the open dump yards which also affect the beauty of the vicinity.
- Ocean dumping makes sever effects to the aquatic lives. Depletion of corals, Fish ,Aquatic plants.
- Open burning generate hazardous gases CO, dioxins, etc

1. There are many more impacts to the environment by these misbehaviors of people in MSW management. As we discussed about those practices and its consequences, Srilanka is now keeping its steps towards more technical solutions in Managing waste

2.2 Solid Waste Management methods

i. Composting

Composting is the very famous and well known organic waste management method which is been used by almost all the countries. It has proved positive results to society by providing good nutrients to soil for agricultural purposes.

Composting is s biological method of decomposition of organic waste such as food or plant material by using bacteria, fungi, worms and other organisms .It happens in a controlled aerobic (occurring in the presence of oxygen) conditions. The output of the composting process is a Humus .

For a proper function of compost pile it is required to maintain the C:N ,carbon to nitrogen ration as 1:25-30 , If the C:N ratio is too high (excess carbon), decomposition slows down. If the C:N ratio is too low (excess nitrogen) you will end up with a stinky pile.

There are main factors which support the composting process,

- Moisture content
- Oxygen
- C:N ratio
- Sizes of the particles
- Temperature.

The separated organic waste is initially dump in to the compost yard and following shown bins are used by the people to maintain the compost pile s at their homes .The organic waste is dumped in to the pile with correct C:N ratios.brown and Gren wastes type are named ti identify green as nitrogen rich items whereas brown is carbon rich items.

In the composting process the microbe play a major role.

Figure 2-4 General Compost pile

In the first stage the mesophilic microorganisms start breaking down of the organic items ,as a results heat is release therefore the temperature is of about 68 to 113 degrees Fahrenheit (20 to 45 degrees Celsius), Then Mesophilic microorganisms are replaced by thermophilic microorganisms (microorganisms that thrive in the increased temperatures) during the second stage. This process continues for a few days to several months. The thermophilic microbes work to break down the organic materials into finer pieces. In this stage due to breaking down of proteins, fats and complex carbohydrates amount of heat energy released to the environments higher so that the temperature rise is higher as well. This stage is very critical stage where we have to control the temperature inside the pile so that it doesn't get high, if so it can eventually kill off all the helpful microorganisms.

Aeration or turning over the pile is usually done in this stage .It helps to maintain the temperature below the line of 149 C, also provides oxygen to the Thermophillic microorganism to react well. The last stage takes around several months to further decay the remaining organic material also since there are not much reactions the temperature is low in this stage .

ii. Semi Engineered Land Filling

Landfilling is a technically sound another method used by the Authorities in the world. Now a days sanitary landfills have developed with good construction, operational and proper leachate and methane gas capturing system it reduce the environmental impact.

Landfilling can be simply described as placing solid and semisolid waste on the ground while compacting it and covered with a sand layer to eliminate the contamination with environment. Following image shows the conventional landfill structure.

Emissions – CO2 and Methane gas emissions by degradation of the organic compounds. Carbon dioxide is released both in aerobic and anaerobic degradation .But Methane gas is released only in Anaerobic degradation.

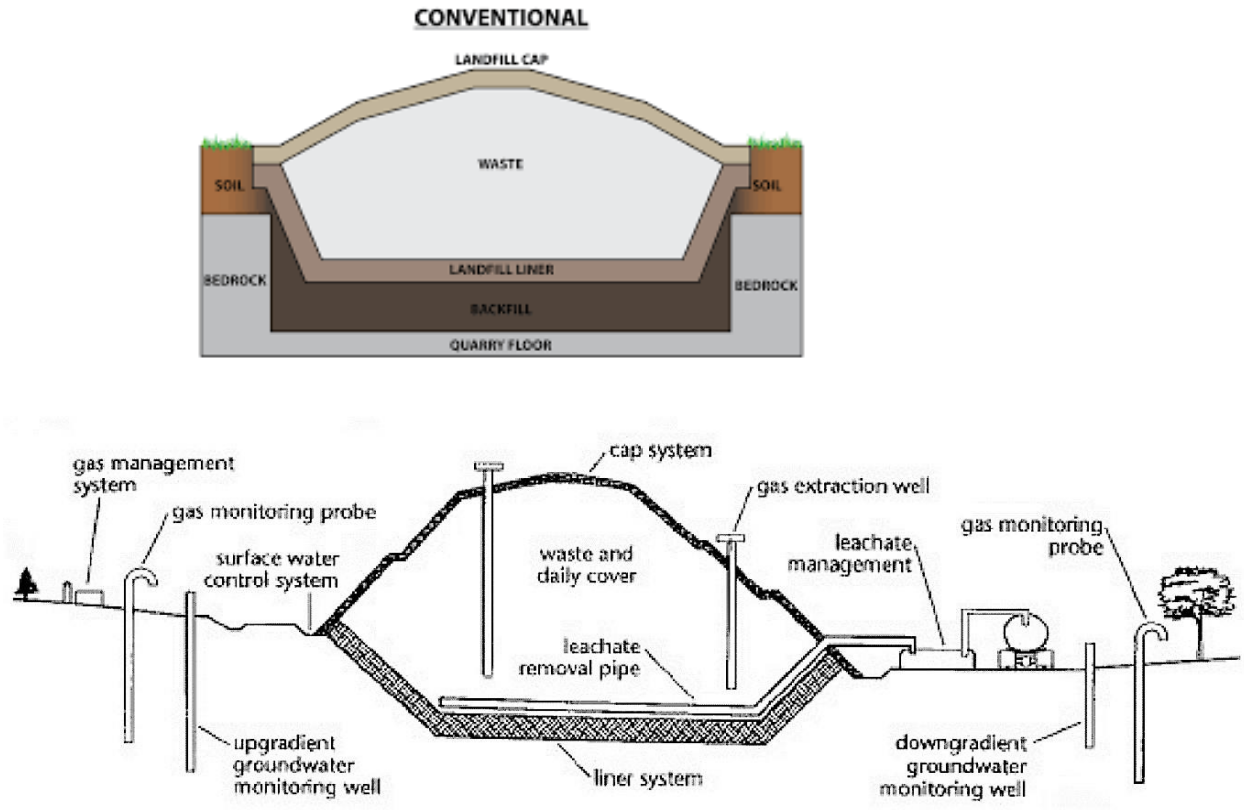


Figure 2-5 Conventional land fill site

Modern type semi engineered land fill site

This type of sites contains following specific parts which are designed for eliminate the environmental impacts caused by the emissions of landfills to water ,soil and air.

- **Bottom liner system** – This layer is placed to separates trash and subsequent leachate from groundwater
- **Cells (old and new)** – This is where the trash is stored within the landfill
- **Storm water drainage system** - collects rain water that falls on the landfill
- **Leachate collection system** – Leachate is been collected and treated before release to the environment.
- **Methane collection system** - collects methane gas that is formed during the breakdown of trash
- **Covering or cap** - seals off the top of the landfill

Once the waste is placed in the landfill area there are three types of layes applid on to protect the emissions to environment.

(1) Daily cover; This is applied end of every working day for about 6 inch thickness. Sand is usually used for this purpose.

(2) side cell intermediate cover; this layer is applied in 6 inch thickness of 1 ft when the working area will be inactive for 1–3 months, and usually clay-sand is used for this purpose.

(3) Interim final cover. This layer is applied a component of final cover and clay/silt is used to 2 ft thickness.

Daily cover is applied after a working day at 6 in thicknesses. Intermediate cover is applied in 6 in lifts to a thickness of 1 ft when the working area will be inactive for 1–3 months. Interim cover pertains to the material that becomes a component of the final cover of the landfill. Interim cover is applied in 6 in lifts to a 2 ft thickness.

iii. Recycling

Recycling of waste is a modern method of Managing Waste. According to 3 R principle for Solid Waste Management Reduce ,Reuse and Recycle ,is to increase the percentage of using recyclable material hence minimizing the resources and energy for production while minimizing the waste problem.

Recycling of waste consists of I collection, sorting, marketing, and processing, .The specific solid waste component which is extracted from the missed stream is sent through further manufacturing or transformation process to change it to different other useful products.

There are some items which we use in our day today life having the quality of re-manufacture .Those are

2. Paper
3. Cardboard
4. Newspaper/magazines

5. Glass items
6. Metal items
7. Plastics

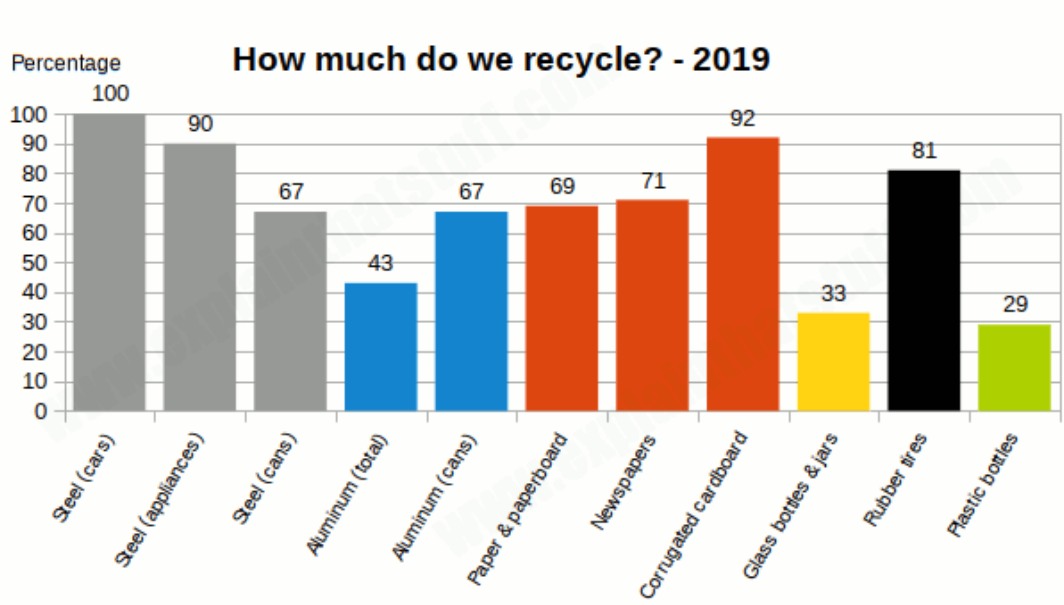


Figure 2-6 Recycling rates in United States of America

Chart: Percentage recycling rates in the United States for various materials. Drawn in 2019 by explainthatstuff.com using the latest available data, taken from the following sources: Steel: US Geological Survey; Aluminum: US Geological Survey; Aluminum cans: Aluminum Association; Paper: US EPA; Glass: Glass Packaging Institute; Rubber: US Tire Manufacturers Association; Plastic: Association of Plastic Recyclers (APR) and the American Chemistry Council (ACC).

According to the above figure of percentages of recyclable material in highly developed USA shows there is a great capability of reproducing those materials. As an example, the sorted organic waste is recycled to compost which is a fertilizer .More details are in previous sections.

The inorganic waste components like Paper which is discarded from offices schools can be recycled several times as it contains the Plant fiber as the raw material and as long as they recycled the fiber get shrinked so as the paper. When the quality of the original paper is high then the recycled papers also make good quality products. Before the

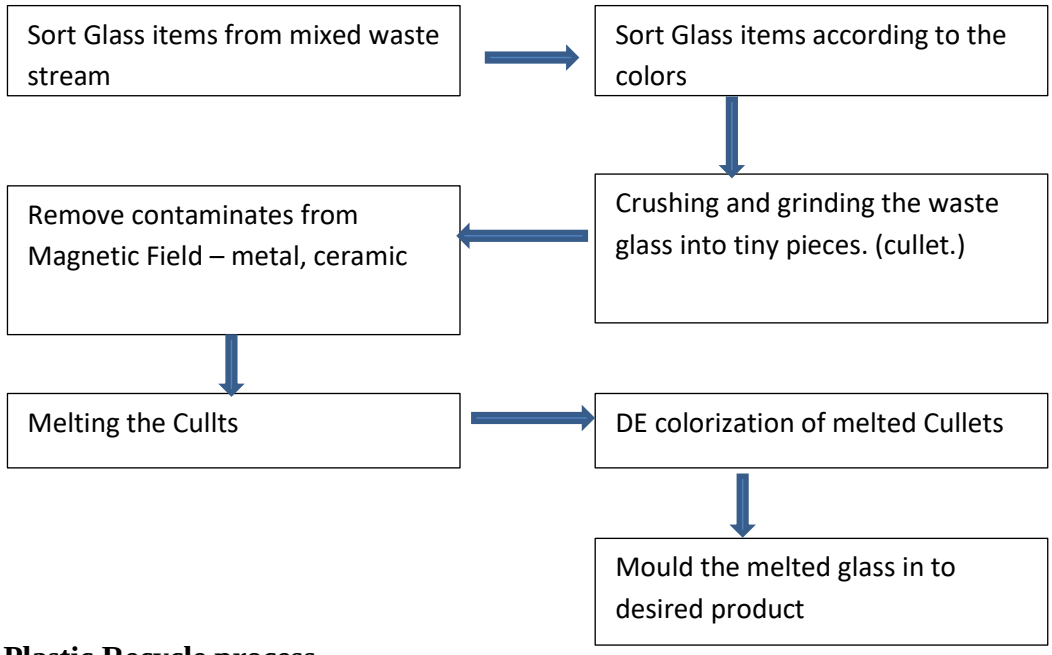
papers are recycled it is been sent to remove the ink , which becomes harmful to the environment .

Metals which comes as food cans basically contains of Aluminium , and this can be easily recovered. Glass items can be easily recycled many times by melting the old glass items .

Wood , Plastic too are very common materials which are been recycled for several products.

Following Shown flow charts describe the steps of two recyclable materials.

Glass recycle process



Plastic Recycle process

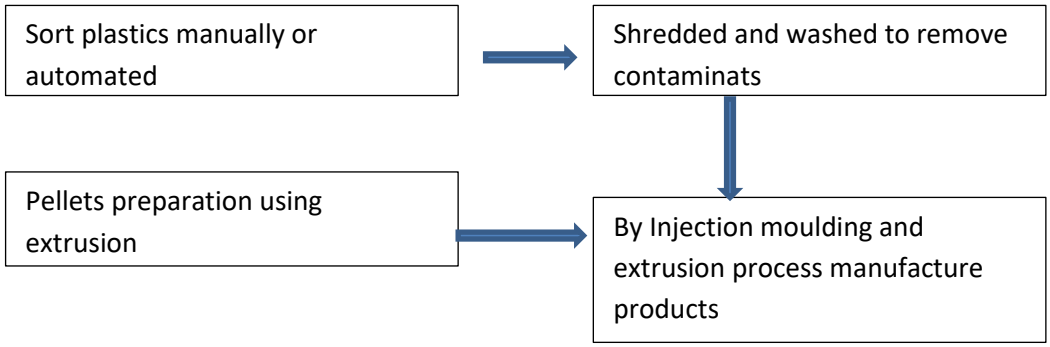


Figure 2-7 Recycling process for waste glass and plastic

Iv Incineration

Incineration is a method of converting the waste material in to as, Ash, flue gas, and heat. Usually some industries incinerate their waste and the ash generated is sent to landfill sites.

Waste Incineration technology can be installed in several industries to treat hazardous waste, refining residues, chemical waste, pharmaceutical waste, hospital & medical waste, waste water plant sludge, NORM (natural radioactive) waste, etc.

Waste Incineration is used as an energy source by heat recovery in today's world. Developed countries use waste to energy technology as energy source in their country while managing MSW.

Waste to Energy Incineration Technology

Waste to energy is a trending waste management method all over the world since incineration itself reduce the amount of waste which is to be landfilled. This method is a controlled burning of waste in high temperatures and convert the release energy in to useful energy .This method is very important for urban zones .Incineration is a high cost technology as it compromises of several systems to reduce the environmental impacts of the emissions.

Municipal solid waste is a mixed of both organic and inorganic components. Incineration is used to both. The calorific value of the waste stream changes according to the waste compounds. Incineration process has its benefits over other management methods since it has following advantages.

i) The total quantity of solid waste can be reduced up to 90%,
ii) Land requirement for the landfilling is reduced , which is already scarce in cities
iii) The cost of transportation of waste to far-away landfill sites also gets reduced
iv) Proper management methods will reduction in environmental pollution

Waste incineration system consist of following

1. Waste In Reception of incoming waste
2. Storage of waste and raw materials

3. Pre-treatment of waste
4. Loading of waste into the process
5. Thermal treatment of the waste
6. Energy recovery and conversion
7. Flue-gas cleaning
8. Flue-gas cleaning residue management
9. Flue-gas discharge
10. Emissions monitoring and control
11. Waste water control and treatment (e.g. from site drainage, flue-gas treatment, storage) Ash/bottom ash management and treatment (arising from the combustion stage)
12. Solid residue discharge

There are major concerns of solving the issues of the different components of the plant, most of the developing countries lack in internal expertise to solve the matters related and thus result in major failures of the plant.

The whole plant configuration can be divided in to four parts;

a. Pre-treatment
b. Combustion system
c. Energy recovery
d. Flue gas cleaning

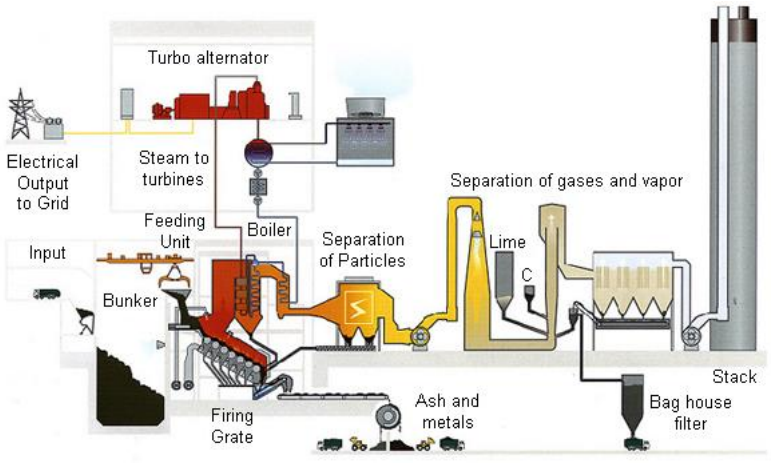


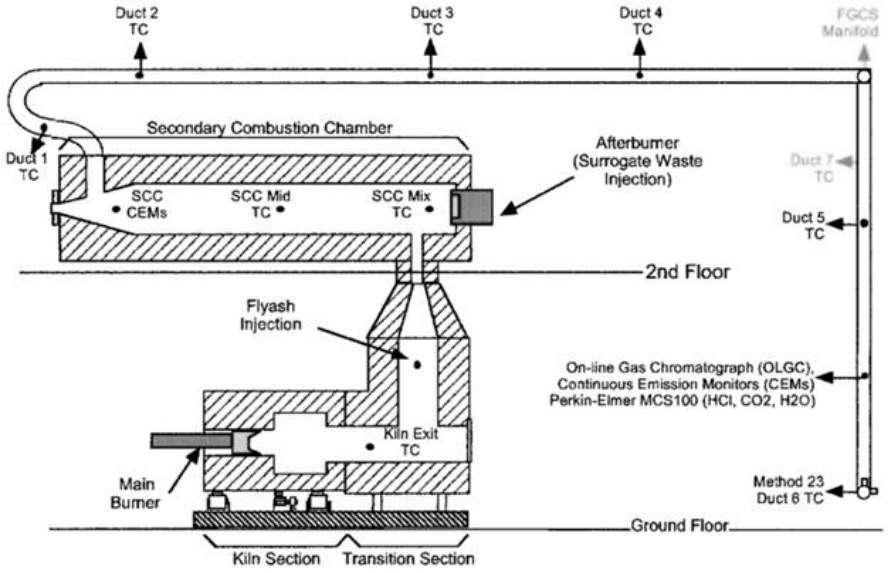
Figure 2-8 Schematic representation of the waste to energy process

There are different kinds of incinerators available.

1. ROTARY KILN
2. FLUIDIZED BED
3. LIQUID INJECTION
4. MULTIPLE HEARTH
5. CATALYTIC COMBUSTION
6. WASTE-GAS FLARE
7. DIRECT-FLAME

Among these rotary kiln, fluidized bed, and liquid injection are the most common type as it can be operated under large scales, Also it is capable of working pyrolysis, less oxygen conditions. For higher calorific value waste streams are recommended as it releases higher energy.

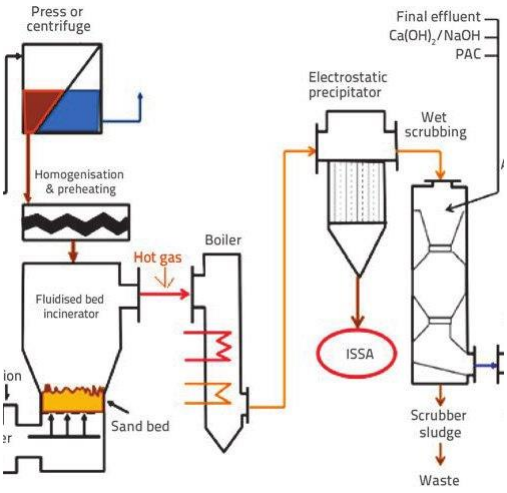
Rotary Kiln



Rotary kiln incinerator can be sued to treat all types of wastes irrespective of contamination, calorific value and consistency. This incinerators are having high temperatures of more than 1100C are mainly used for special waste incineration. This equipment consist of separate waste storage, feed devices for all types of waste, the

rotary kiln, a secondary combustion chamber, a heat recovery steam generator, and flue gas cleaning.

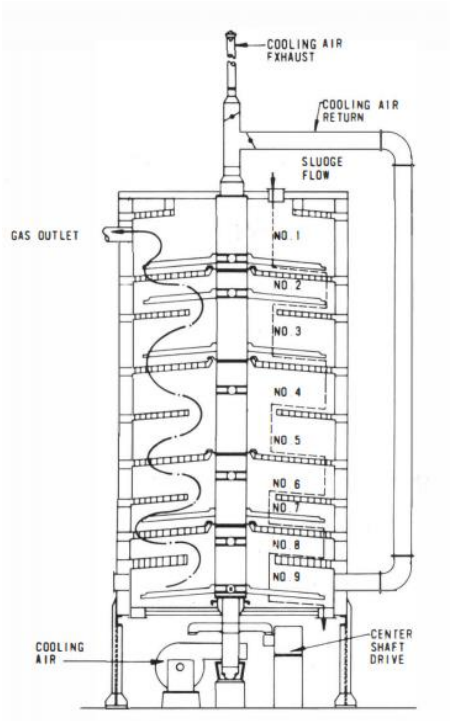
Fluidized Bed Incinerators



Fluidized bed incinerators are used both the industrial and sewage sludge incineration processes. Inside the fluidized bed the granular material in a solid state is turned into a fluid-like state by passing a fluid (liquid or gas) through it. When fluid passes through granular material the particles are moved away from each other overcoming the gravity by drag forces, in a stage the velocity slows and the force of gravity overcomes the drag forces result in falling back of the particles and fluidize again.

In the case of fluidized bed sewage sludge incinerators, preheated air is used to fluidize a bed of sand. The fluidized sand bed mixes violently and serves to distribute and break up the sewage sludge as it is pumped in, while simultaneously providing a very large surface area and well distributed supply of oxygen to promote combustion.

Multiple hearth furnace



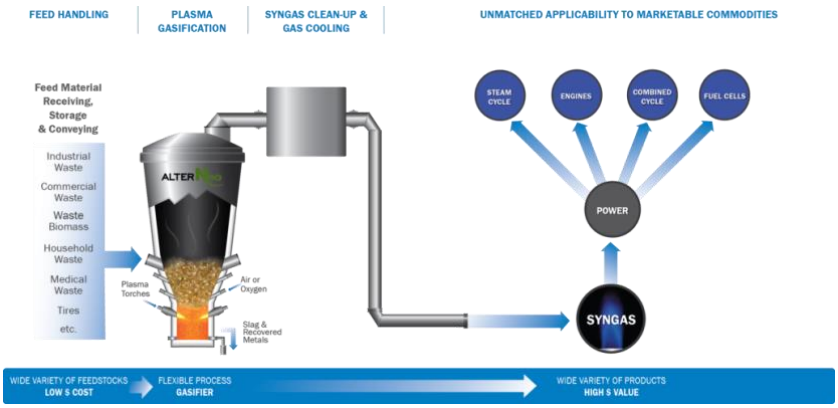
Multiple hearth furnace is been used to manage sewer sludge to sanitized residues. This furnace is a cylindrical steel shell lined with refractory material. Waste material after removing the water called filter cake is fed into the top hearth. The material is moved by rabble teeth and falls hearth by gravity. From the bottom, the ash is collected and removed. The combustion air which is introduced from the bottom flows upwards to reduce the temperature of the bottom ash and to combustion zone to dry the filter cake .Then the gas leaves at the top ,usually outlet temperature is maintained around 800-900° F (700-755K).

Producing energy from Municipal waste is not only limited to waste incineration technology there are other newer technologies as well. Following are well known technologies in used of different parts of the world where waste management is treated as priority.

- Plasma Gasification Waste to Energy system
- Pyrolysis
- Gasification
- Anaerobic digestion

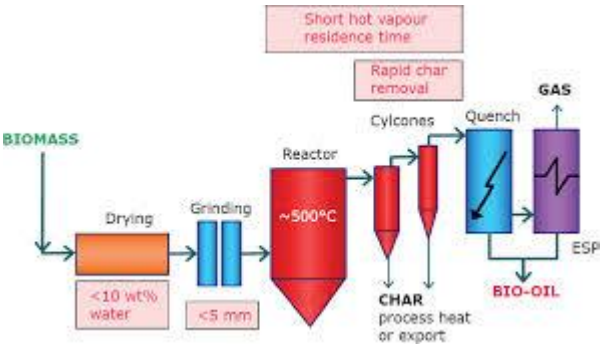
Plasma gasification

This waste management method is found In 174,and it a designed furnace where waste is pyrolized in between plasma torches. In incinerator process the waste is burnt and by products like ash,gas emissions, the ash mostly contains of heavy metals which is taken to landfills ,incineration produce harmful products to environment. In plasma arc gasifies the carbon-containing materials in the waste produce synthesis gas (syngas) composed primarily of carbon monoxide and hydrogen, which can be used to produce energy through reciprocating engine generators - gas turbines and steam boilers in integrated gasification combine circle (IGCC), and/or liquid fuels.The overall thermal efficiency of Gasification process is more than 75%.



Pyrolysis

Pyrolysis is the thermal degradation of organic materials in the absence of oxygen. The organic components stars to decompose at 350°C–550°C and goes up to 700°C–800°C in the absence of air/oxygen. In pyrolysis process, first the MSW is separated to glass, metals and inert materials prior to processing the remaining waste in a pyrolysis reactor. Rotary kilns, rotary hearth furnaces, and fluidized bed furnaces are usually used for the process. The main products obtained from pyrolysis of municipal wastes are a high calorific value gas (synthesis gas or syngas), a biofuel (bio oil or pyrolysis oil) and a solid residue (char). Syngas, or synthesis gas, is a fuel gas mixture consisting primarily of hydrogen, carbon monoxide, and very often some carbon dioxide



Gasification

Gasification is an alternative process of treatment of Municipal solid waste which produces Syn gas as a product which can be used as a gas fuel to run gas engine and convert to electricity.

2.3 Waste to energy Incineration System

- **Waste Reception System**

The plant consists of air tight pit bunker having a storage capacity of five (5) days and additional space to store three (3) day's waste for the emergency. The waste dumping truck is weighted by weigh bridge. The waste bunker is equipped with waste cranes.

- **Waste Combustion and Heat Recovery Steam Generating System**

The fuel (Municipal solid waste) will be fed from the waste feeding system to the combustion grate of the incinerator via a hydraulic ram feeder system. The primary air suction opening is located within the waste bunker. The ingested air (odors) is regulated and fed to the underside of the grate. A suitable firing method as a primary measure for emission reduction (CO, NO_x, Dioxins and Furans) in the combustion chamber is adjusting the surplus air e.g. O_2 content in the flue gas. The secondary air is ingested from upper part of the boiler house.

- **Waste feeding system**

The waste will be fed by the waste cranes from the bunker into the waste hopper. The waste hopper has a square inlet opening and is designed to prevent bridging.

- **Energy Processing and Output System**

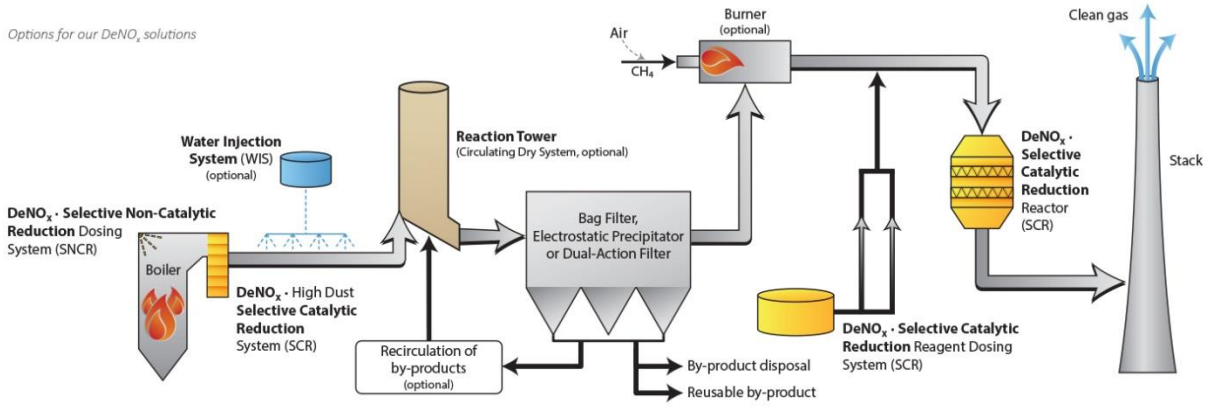
The function of the system is to use the thermal energy of the waste incineration to generate electric power and thermal heat. The water steam cycle consists mainly of the following equipment :

- ✓ Steam turbine and generator
- ✓ Condenser
- ✓ Condensate system
- ✓ Feed water system

Steam turbine- The steam generated by the boilers is used to produce electric power by a condensing type steam turbine (turbo generator). The steam turbine is designed for the best possible performance at 100% load.

Flue Gas Treatment System

This is the most important system of the incineration plant and special technical assistance is required for proper functioning of this. The system can be dived to few parts as mentioned below with its tasks.



SNCR (Selective non catalytic reduction)

The selective non catalytic reduction

(SNCR) is method for reduction of Nitrogen oxides (NOx): The flue gas generated by the combustion of municipal waste contents usually 350 – 450 mg/m3 of NOx content. These total NOx-value normally consists of more than 90% NO, and less the 10% NO2.

It is necessary to operate the SNCR-system within an optimized flue gas temperature range in order to comply with the daily average value. For this purpose injection nozzles for urea are installed in three different levels of the first boiler pass. Only the injection level in the best temperature range will be operated in order to achieve high NOx reduction efficiency and low ammonia slip.

- Semi-dry reactor

The flue gas passing through the air preheater enters the Semi-dry Reactor System to remove acidic gases such as SOx, HCl and HF in the gas. In the reactor, The acidic gases are removed by chemical reactions with the sprayed lime slurry.

The lime slurry is prepared by (CaO) mixed with water as a burnt Lime (Ca(OH)2. The reaction products are evaporated in the reactor into dry power. The flue gas with unreacted reagent then proceeds to the bag filter. The bag filter serves as a fixed bed reactor for the neutralization of acid gases.

- Activated carbon feeding system

To achieve the desired dioxin/furan removal, the adsorptive characteristics of activated carbon are utilized. Activated carbon is injected into the inlet duct of the bag filter.

- Bag filter

This is used for the filtering of the solids from the flue gas. This filter consists of four compartments connected in parallel, each equipped with a filter-bag assembly. The raw gas flow passes through the filter bags which collect the particles precipitated on the filtration surfaces.

Induced Fans are installed to downstream of the bag filter to convey the flue gas to the stack to release to the environment.

- Stack

Stack is constructed with proper monitoring and controlling for the release of flue gas which is brought after the necessary treatments.

- Fly and Bottom Ash Handling System

During incineration, bottom ash and a small amount of siftings are discharged from the grate. The bottom ash and siftings are transferred through grate hoppers to wet bottom ash discharger after the bottom ash discharger the ash are transported to ash arm roll box which will be transported to the outside by arm roll truck.

- Fly ash handling system

Fly ash collected from SDR and bag filter into ton bag will be transported to fly ash storage space.

Table 2-6 Summary of the parts of the waste to energy incineration system.

Process	Unit
Waste Incineration and Energy recovery system	incinerator with waste heat boiler
Energy processing and output system	Steam turbine generator MWe (Net) - Condensate System - Deaerator, Boiler Feedwater Pump, Condensate Pump
Flue gas treatment system	SNCR + SDR + Bag filter + I.D fan + Stack - Activated carbon feeding system
Auxiliary System	-Water treatment (demineralized water) system - Compressed air system - Cooling water system - Waste water treatment system

2.4 Life Cycle Analysis

The “Product “ is a result of a chain of processes which starts from Raw material extraction from many different sources and going through a series of inputs and outputs and processes. These processes have impacts on environment and it is very important to identify the impacts to design the overall design. The life cycle analysis is the tool to analyze the impacts of those.

Life cycle analysis is a cradle to grave analysis of a product, from its birth, including design, raw material extraction, material production, part production, and assembly, through its use, and final disposal.

The LCA process consists of four components: goal definition and scoping, inventory analysis, impact assessment, and interpretation.

1.**Goal definition and scoping**

This stage is for Define and describes the product, process or activity. Here the assessment context is established and the boundaries and effects are defined.

2.**Inventory analysis**

This stage all the information related to usage of energy, water and materials usage and environmental releases (e.g., air emissions, solid waste disposal, waste water discharges).

3.**Impact assessment**

Assess the potential human and ecological effects of energy, water, and material usage and the environmental releases identified in the inventory analysis.

4.Interpretation

Evaluate the results of the inventory analysis and impact assessment to select the preferred product, process or service with a clear understanding of the uncertainty and the assumptions used to generate the results.

The LCA studies are carried out according to the ISO standards. The original ISO 14040 series of standards were published in 1997.It has gone through several revisions.

The first step or the most important step of the study is to define the goal of the study. Before staring the collection of data, the clear definition of the goal is important to arrange the methodology of the LCA process. It is a very important phase of LCA methodology because this is where the exact approach to be followed is determined.

In the First step following are defined ;

Goal and scope defining is the prominent task of the LCA study .In this preliminary stage the general factors leading to carry out the study is defined.

In the Goal defining following factors should be considered

- Intended application- The application of the study example – marketing ,planning ,product development
- Purpose- whether to published, internally reviewed
- Intended audience- who are going to use the results of the study ,(industry, researchers, etc)
- Comparative analysis – usage of the results for comparative analysis.

In the next step as the scope defining, the product or process system to be studied is detailed for the assumptions, and the methodology to be adopted .Following factors are clearly defined.

Function of the product

- Functional unit
- Reference flow
- Description of the system
- System boundaries
- Allocation procedures
- Impact categories and the impact assessment method
- Data requirements

- Data assumptions
- Limitations
- Data quality requirements
- Peer review
- Reporting type

Function of the system

In a product system there are different functionalities.it is required to clearly define which functions are considered for the LCA .

Functional Unit

The functional unit is the quantified definition of the function of a product. In order to compare two products, their functional units must be equivalent. Example – Packaging of 1000 liters of drinks in both types of containers, Glass bottles and Paper packaging

System boundary – It defines which processes are included in the LCA study

There are four main options to define the system boundaries used (shown in Figure 4):

- **Cradle to Grave:**

Includes the material and energy production chain and all processes from the raw material extraction through the production, transportation and use phase up to the product's end of life treatment.

- **Cradle to Gate:**

Includes all processes from the raw material extraction through the production phase (gate of the factory); used to determine the environmental impact of the production of a product.

- **Gate to Grave:**

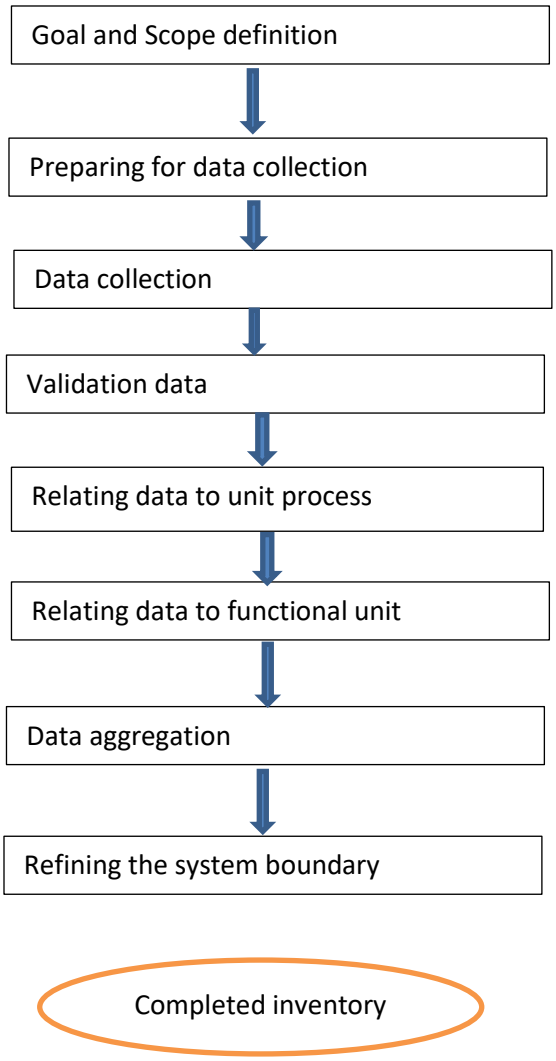
Includes the processes from the use and end-of-life phases (everything post production); used to determine the environmental impacts of a product once it leaves the factory.

- **Gate to Gate:**

Includes the processes from the production phase only; used to determine the environmental impacts of a single production step or process.

2.4.1 Life cycle Inventory

In this phase of the study the inputs and outputs for a given product system throughout its life cycle or for single processes will be collected. The inventory analysis includes data collection and the compilation of the data.



In the process of the life cycle inventory, or in the data collection part, limitation to data and the requirement of more data is identified to achieve the goal and scope. Depend on some issues related to data collection sometimes redefining of the goal and scope taken

place. After collecting all the process data, LCI table for the whole product system is created. The LCI table consists of all the material and energy inputs and output of the system.

Following energy inputs

- raw material inputs
- ancillary inputs
- other physical inputs
- products
- co-products
- wastes
- emissions to air, water and soil

In the process of calculating LCI, following tasks should be done

1.Data validation

2.Relating the data to unit process

3.Relating data functional unit

There are several software which can be used to perform LCI which leads to LCA ,the well-established software are;

- ❖ Gabi
- ❖ Simpro
- ❖ Open LCA

8. Life cycle Impact Assessment

In this step of the study, the LCA can be done using two different assessment methods. CML and TRACI. Under each impact method there are list if impact categories. There are different Environmental impact categories for each of these methods and most of them are common though the measuring units are different.

IMPACT CATEOGORY – CML	UNIT	IMPACT CATEOGORY - TRACI	UNIT
Global warming	Kg (CO2)	Global warming	Kg (CO2)
Ozone layer depletion	Kg-R11	Ozone layer depletion	Kg-CFC
Acidification	Kg (SO2)	9. Acidification	10. H+mol
Eutrophication	Kg(PO43-)	Eutrophication	Kg-N
Human Toxity potential	Kg (DCB)	Ecotoxity air	Kg-2.4-Dichlophenoxace
Abiotic depletion	Kg-Sb		KG-2.5
Freshwater aquatic ecotoxity	Kg-DCB		
Marine aquatic ecotoxity	Kg-Sb		

Not only those two methods are available for LCA ,there are few more methods like

- Eco indicator 99
- ILCD
- Recipe Endpoint
- Cumulative energy Demand

CML method is introduced by Centre for Environmental Studies (CML) of the University of Leiden and it talks about series of environmental impact. The Tool for the Reduction and Assessment of Chemical and other Environmental Impacts, called TRACI method is developed by the U.S. Environmental Protection Agency (EPA) and is primarily used in the US.

The Environmental Impact categories should be selected according to the decided goal and scope. The emissions of the different process will be assigned to related impact and if any emission lead for two different impacts it should be counted accordingly .As an example NOx leads to acidification and eutrophication.

It is very important to have an understanding on the impacts and how it is caused for a proper LCA follower. Following is a small description for above mentioned impact categories.

Acidification

Acidic gases react with water in the atmosphere and form “acid rain, and falls on earth resulting acid deposition. Gases that cause acid deposition include ammonia (NH3), nitrogen oxides (NOx) and sulphur oxides (SOx).

Climate Change

Climate change can be defined as the change in global temperature caused by the greenhouse effect that the release of “greenhouse gases” by human activity creates

Depletion of abiotic resources

Decrease of the availability of non-biological resources (non- and renewable) as a result of their unsustainable use

Ecotoxity

Environmental toxicity is measured in three separate impact categories which are freshwater, marine and land. It is due to emission of some substances, such as heavy metals.

Eutrophication

Eutrophication is the caused by build-up of a concentration of chemical nutrients in an ecosystem hence result in excessive plant growth .This leads reductions in water quality and animal populations. The Emissions of ammonia, nitrates, nitrogen oxides and phosphorous to air or water all have an impact on eutrophication.

Ozone Layer Depletion

Ozone layer depletion is caused by the gases which can damage the stratospheric ozone or the ozone layer .CFCs, halons and HCFCs are the major causes of ozone depletion. When the ozone layer get damaged, it reduces its ability to prevent ultraviolet (UV) light entering the earth’s atmosphere, increasing the amount of carcinogenic UVB light reaching the earth’s surface.

In lCA process there are few optional elements ;Normalization, Grouping,Weighting, these are used only in certain conditions according to the requirement of LCA interpretation.

LCA interpretation

This phase of the study is the compulsory stage of whole work. One of the key aims of LCA is to provide the decision makers with comprehensive and understandable information. This can be achieved by having a comprehensive interpretation of the results relating to the goal and scope of the study .

There are two important steps in LCA interpretation

1. Identification of significant issues;
2. Evaluation

Significant issues can be encountered in Inventory analysis due to large amount of data gathering, in impact category. In Evaluation step the three methods are used. Completeness test, sensitivity check and consistency check.

Conclusion , Recommendations and Reporting

The final stage of the study is to provide conclusion based on the goal and scope of the study and provide recommendations for the audience. In reporting , the results of the Life Cycle Assessment is assembled in a comprehensive report to present the results in a clear, transparent and structured manner.

CHAPTER 3

3 Data Collection

Municipal Solid Waste is a key factor of any country. A proper management can be done with having accurate figures of those generation and its categories.

When I discussed this research study with my supervisor, I was guided to collect background information of the Municipal Solid waste management in Srilanka. Within the given two weeks of time period I access following sources.

1. Internet Articles written on MSW ,history of Srilankan MSW management and incidents faced due to wrong management practices .Waste management of other countries ,and their waste management technologies.
2. Research articles ,published in internet in different websites.
3. University library – books, journals, past student's thesis submissions.
4. My Offices premises – Library

The information collected through above sources given me very good understanding. After collecting the background information on my study topic ,then I started studying in the waste management technologies practiced in Srilanka and other countries. The Sources to collect those data and information I spent around three weeks time.

Initially I started browsing internet to find on waste management technologies available in the world .Research papers, articles ,books were collected from university library and office library on the topic .Waste to energy technologies and its practical aspects were identified after reading on relevant materials.

My next task was to collect information and data on application of waste to energy technology in Srilanka to treat MSW in proposed two Locations. The required data related to solid waste generation from each location, categories and percentages were obtained from the published data from Solid Waste Management Authority, Colombo Municipal Council.

Also after having discussion with the relevant organizations which are responsible in so called waste management by waste to energy , they were ready to share their analysis

results which they have done for the MSW in development area. That analysis consists of waste collection from different locations and the composition analysis of those collections. The test reports consist of chemical and physical analysis of the Municipal solid waste collected from the project implementing locations.

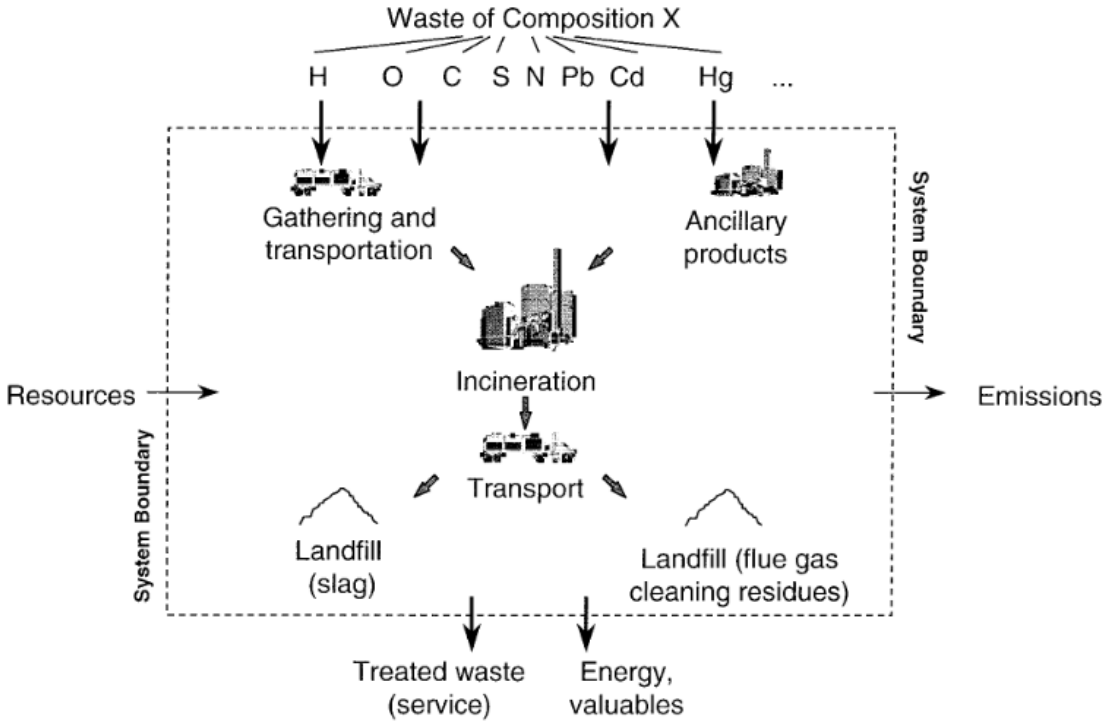
Learning the OPEN LCA software was an important task of my research project. Data collection was not only limited to Life cycle inventory of the Life Cycle Assessment ,collecting information and familiarize with OPEN LCA too become important.

The Software was available freely and some data sets were downloaded and fed in to the software. Data set was based on agricultural product and Plastic bottle production .Using the tutorial and data some analysis was done to get knowledge on working with OPEN LCA.

After the proper knowledge of OPEN LCA and how to carry out LCA study with the software .When collecting data /life cycle inventory first I divided the whole product system in to three phrases

- Data /information of related activities before feeding to Incineration plant
- Process/Activities related in incineration /waste to energy conversion
- Process/actives related after the conversion process.

The life cycle assessment itself should be contained with all the related activities its emissions form its cradle to grave. In this analysis according the defined scope and system boundary the activities are limited from collecting the MSW form 15 central collecting locations to plant premises.

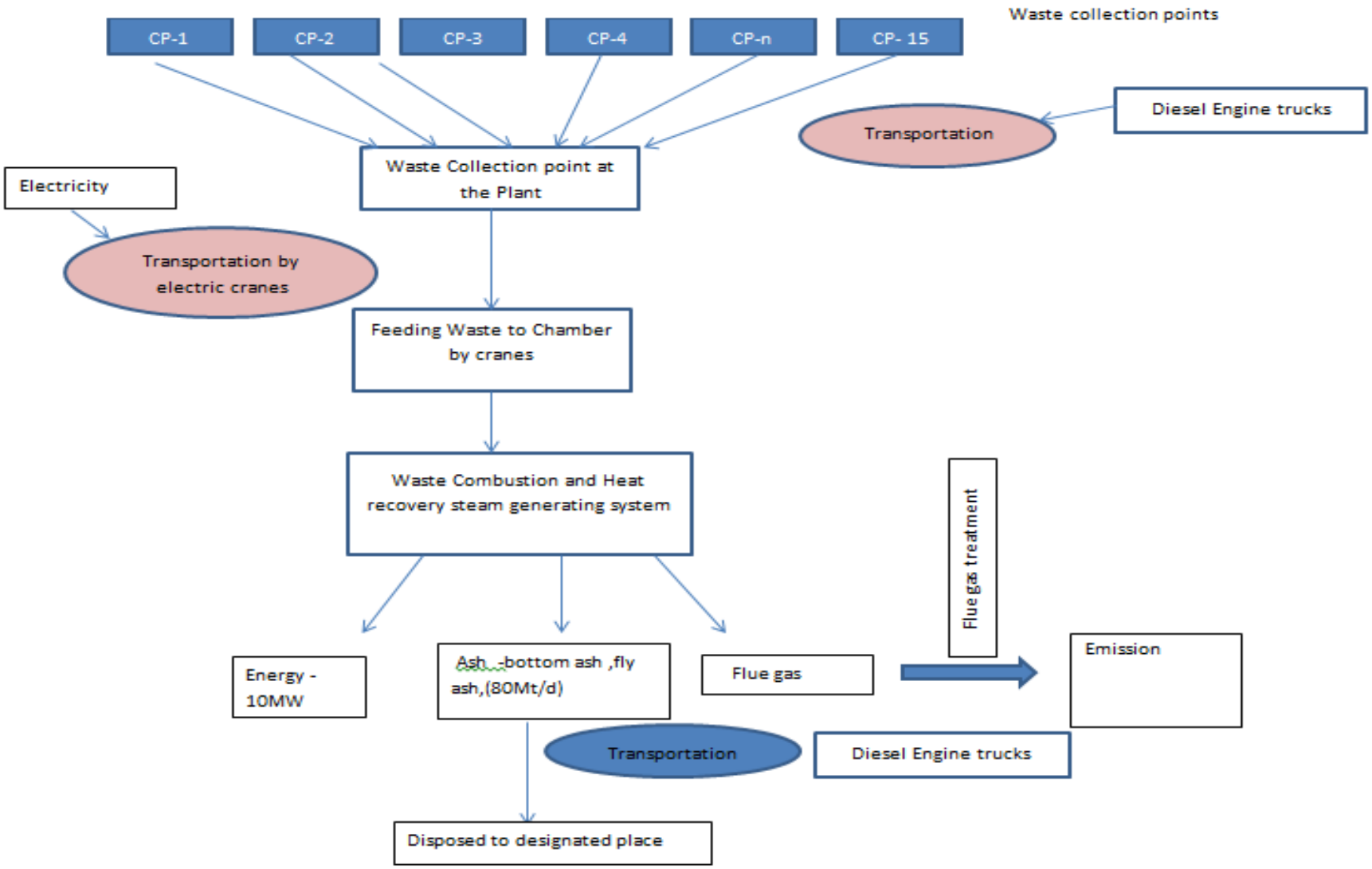


There for this stage following processes and activities are taken in to account

1.Gathering and transportation of MSW to the plant premises. In this process the activities included and emissions related to chain of process are described.

- Manufacturing of relevant transportation vehicles, emissions caused by every process starting from resources extraction to final output of the vehicle.
- Emissions related to vehicle fuel production
- Emissions caused by combustion of fuel while transportation of MSW s to plant location.

Figure 3-1 Process flowchart of waste to energy incineration plant



In this LCA process the emissions related to manufacture of transportation vehicles are not collected as it is a very complicated process and availability of such data is hardly few. So the data collection was not performed for this.

But with a proper database which supports OPEN LCA ,data related to manufacturing of vehicles and other equipment are contained .So the results can be obtained with all those related processes. For manual calculations this process is kept apart because of unavailability of the data.

The next is the processes and inputs related to incineration phase .

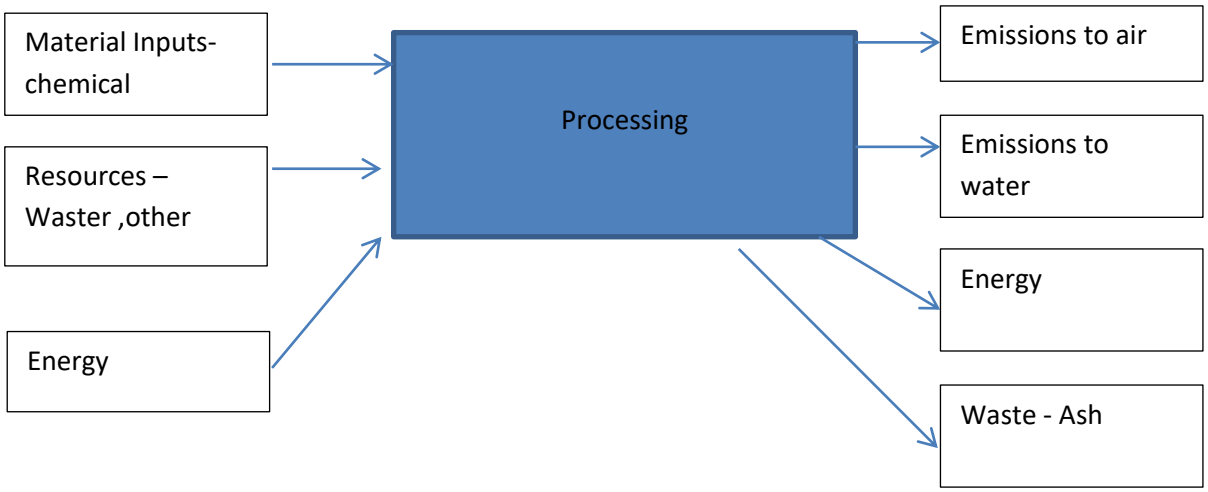


Figure 3-2 Schematic representation of conversion process stage

In this stage following inputs and processes are listed .Since the availability to data is very limited emissions of some of the inputs are taken in to account. But it should be noted the limitations are only applied only when in manual calculations.

While considering item no s 1- 4 ,it contains chain of processes in manufacturing those materials, and emissions related to required amount cannot be found directly and it also an individual study to calculate its impacts.

Table 3-1 Process inputs

	Process- inputs	Flow number	Product stage
1	Chemicals required in waste water treatment ,Flue gas treatment ,	F1	Raw material
2	Industrial processes water	F2	Raw material
3	Electricity	F3	Raw material
4	Diesel fuel for burners	F4	Raw material
5	Plant and equipment	F5	Raw material
6	Transportation of waste and chemicals to plant premises	F6	Transfer
7	Incineration emissions from flue gas	F8	Process
8	Emissions from waste water disposal	F9	Process
9	Emissions from heavy metal components	F10	Process

In calculating the material inputs to the system, all the reactions and the every process is considered .according to design norms and the requirement of the chemicals were calculated.

Electricity requirement is calculated based on the rated consumption of electricity for each equipment. Emissions related to production of electricity also can be found, and it should be noted the all practical methods of producing electricity like hydro,coal,solar should be taken in to account for the counting emissions.

Requirement of the fuel for transportation was found by the transportation distance and the vehicle features. The emissions resulted to combustion of the fuel can be calculated by chemical reactions.

$2C_8H_{18} + 25O_2 \longrightarrow 16CO_2 + 18H_2O$ these emissions directly add to the environment without any pre-treatment and hence leads to climate change impact.

The emissions from the incineration are not directly release to the environment .It goes through the flue gas treatment system and only the standard limits are allowed to release to the environment. Therefore in my calculations the emissions are counted as according to the marinated standards.

Table 3-2 Flue gas emission standards

Emission	Emission factors
Dust particles	10mg /Nm3
NOx	200mg /Nm3
Dioxines	10ng/Nm3
Sox	50mg/Nm3
Air Pollution control-HCl/HF -	10mg/Nm3
Carbon dioxide emission from waste incineration (47% carbon)	
Lead	0.01mg/Nm3
Hg	0.001mg/Nm3

Table 3-3 Tolerance limit for waste water discharge from industrial waste to inland surface water

No.	Parameter	Unit type of limit	Tolerance Limit values
01.	Total suspended solids	mg/l, max.	50
02.	Particle siz of the total suspended solids	µm, less than	850
03.	pH at ambient temperature	-	6.0 - 8.5
04.	Biochemical oxygen demand (BOD_5 in five days at 20^0c or BOD_3 in three days at 27^0c)	mg/l, max.	30
05.	Temperature of discharge	^{0}C, max.	Shall no exceed 40^0 C in any section of the stream within 15 m down stream from the effluent outlet.
06.	Oils and greases	mg/l, max.	10
07.	Phenolic compounds (as C_6H_5OH)	mg/l, max.	1
08.	Chemical oxygen demand (COD)	mg/l, max.	250
09.	Colour	Wavelength Range	Maximum spectral absorption coefficient
		436 nm (Yellow range)	$7m^{-1}$
		525 nm (Red range)	$5m^{-1}$
		620 nm (Blue range)	$3m^{-1}$
10.	Dissolved phosphates (as P)	mg/l, max.	5
11.	Total Kjeldahl nitrogen (as N)	mg/l, max.	150
12.	Ammoniacal nitrogen (as N)	mg/l, max.	50
13.	Cyanide (as CN)	mg/l, max.	0.2
14.	Total residual chlorine	mg/l, max.	1.0
15.	Flourides (as F)	mg/l, max.	2.0
16.	Sulphide (as S)	mg/l, max.	2.0
17.	Arsenic (as As)	mg/l, max.	0.2
18.	Cadmium (as Cd)	mg/l, max.	0.1
19.	Chromium, total (as Cr)	mg/l, max.	0.5
20.	Chromium, Hexavalent (as Cr^{6+})	mg/l, max.	0.1
21.	Copper (as Cu)	mg/l, max.	3.0
22.	Iron (as Fe)	mg/l, max.	3.0
23.	Lead (as Pb)	mg/l, max.	0.1
24.	Mercury (as Hg)	mg/l, max.	0.0005
25.	Nickel (as Ni)	mg/l, max.	3.0
26.	Selenium (as Se)	mg/l, max.	0.05
27.	Zinc (as Zn)	mg/l, max.	2.0
28.	Pesticides	mg/l, max.	0.005
29.	Detergents/surfactants	mg/l, max.	5
30.	Faecal Coliform	MPN/100 ml, max	40
	Radio Active Material :		
31.	(*a*) Alpha emitters	micro curie/ml, max	10^{-8}
	(*b*) Beta emitters	micro curie/ml, max	10^{-7}

Emission limits values (mg/Nm3) for carbon monoxide (CO) in the waste gases:

(a) 50 as daily average value; (b) 100 as half-hourly average value; (c) 150 as 10-minute average value.

The competent authority may authorise exemptions from the emission limit values set out in this point for waste incineration plants using fluidised bed technology, provided that the permit sets an emission limit value for carbon monoxide (CO) of not more than 100 mg/Nm3 as an hourly average value.

The plant is configured according to the given standards and assuming the equipment are designed and installed to achieve the standard.

Reactions taking place inside the incineration and calculation of emissions of each component.

$$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)} \qquad \Delta H^{o} = -393.5 kJ\ mol^{-1}$$

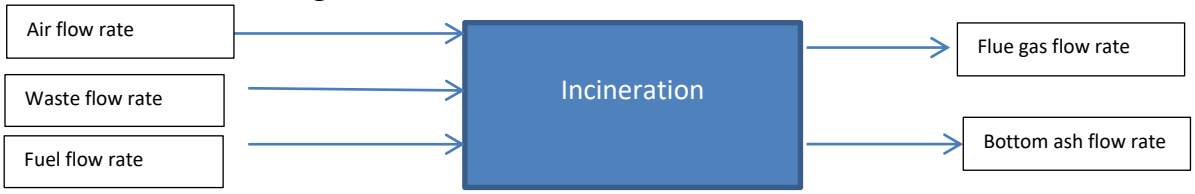
$$C_{(s)} + CO_{2(g)} \rightarrow 2CO_{(g)} \qquad \Delta H^{o} = -221.06 kJ\ mol^{-1}$$

$$H^{+}_{(aq)} + Cl^{-}_{(aq)} \rightarrow HCl_{(aq)} \qquad \Delta H^{o} = -167.2\ kJ\ mol^{-1}$$

$$H_{2(g)} + \frac{1}{2}O_{2(g)} \rightarrow H_2O_{(l)} \qquad \Delta H^{o} = 285.83\ kJ\ mol^{-1}$$

$$S_{(s)} + O_{2(g)} \rightarrow SO_{2(g)} \qquad \Delta H^{o} = -297 kJ\ mol^{-1}$$

The Mass balance for the given reactions are as follows.



The flue gas emission flow rate can be found assuming complete combustion. The concentration of the flue gases in percentage was taken as the average values of O2, N2, CO2, H2O and SO2. After recording the flue gases velocity in m/s ,the measured value of gas concentration, and the density of each identified gas O2, N2, CO2, H2O and SO2 can be used to calculate the mass flow rate using

$m_i = V_i x\ A_i x\ \dot{\rho} i$ where m = mass flow rate of gas h/kg,V = Velocity of flue gas (m/s) and $\dot{\rho}$ = density of the gases (kg/m3).

Energy Balance equation

Energy in = Q (Diesel1) + Q (msw1) +Q (air)

Q (diesel1) = Energy from auxiliary fuel (diesel) (m □

Q (msw1) dry = energy from municipal solid waste

Q (air) = energy from air provide for the combustion

Water requirement, wastewater generation amounts are obtained using the past studies done for the waste to energy conversion processes. However for treatment of so called amount of waste it is estimated the required amount of water would be 1950 ton per for all purposes, including, boiler water make-up, cleaning requirements, boiler bottom ash

systems, blow down cooling, and evaporation of cooling water. Among the consumption 140ton per day is treated by the waste water treatment system and release to the nearby canal.

The effluent standards of the treated water should be strictly within the standards specified by the authorities as given in above tables. For calculation purposes the emissions are considered as the highest level.

CHAPTER 3

4 Results

The flow which are identified in the chapter 3 are having the values as given in the below table.

Emissions from identified flows (F1)

1. The required chemical components for plant operation purposes for treating 630MT of municipal solid waste perday.F1

Table 4-1 Chemical Inputs for plant operation per day

Purpose	Chemical	Consumption kg per day (to treat 630MT of MSW)
Flue gas treatment	Urea (40%)	624.0
	CaO	4008.0
	Activated Carbon	5040.0
Boiler feed water	Phosphate	0.3
	NH_4OH(24%)	0.7
	Hydrazine (35%)	8.9
Demineralized water	Anti scalant	0.0
	NaOH(33%)	0.3
	Sodium Cloride	7.5
Cooling water treatment	Corrosion Inhibitor	172.8
	NaOCl(10%)	92.2
Waste water treatment	NaOH 33% (aqueous solution)	4.8
	$FeCl_3$	516.0
	Polymer	2.4

In the process of LCA ,the emissions related to the manufacturing of above chemicals should be taken into account .There are specific databases which consists of above data in modeling LCA .Since the limitation of the databases these emissions exempted in this study.

2.F2 – Industrial Process Water requirement per day -400m^3/day

It is calculated the water requirement for treating the MSW of given amount is 400m3/day. Production of drinking water is a combination of different process as shown In the below diagram.

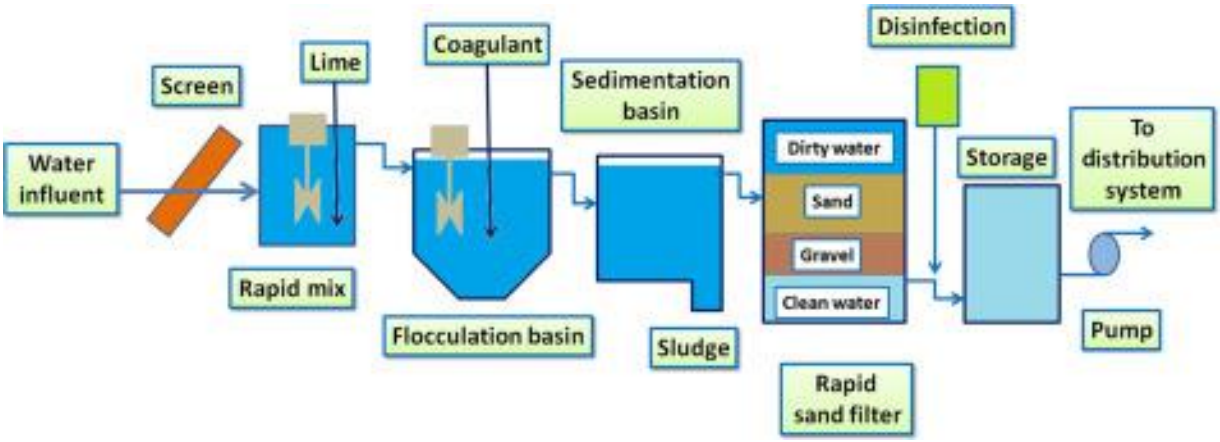


Figure 4-1 Drinking water purification process

As shown in the above sketch there are sequence of activities are taken place to produce one unit of portable water .Different equipment manufacturing, chemical manufacturing ,required energy production all these consists of processes which ultimately supports in environmental pollution by releasing different components.

The data related to these input items also can be obtained by comprehensive data bases in LCA.

3.Electricity Requirement per day -86400MJ

Electricity production in Srilanka is done by different sources. There are few major resources like Hydro power,Coal Power,Solar,Wind ,etc. The energy mix of Srilanka is

- Thermal Coal- 33%
- Hydro- 60%
- Wind- 2%

- Thermal Oil- 1%
- Other

So the emissions related to all those energy production systems should be taken into account while calculating the emissions of the production of energy. Depend on our system boundary this is obtained as a separate study and the data can be taken form data bases like “”ecoinvent. As the limited data is available, the emissions of the production of energy is found using past research papers.

According to past literature following values were found for production of energy .But there can be slight changes in values due to different energy generation sources. Srilanka is more in to Hydro power than other sources .It says hydro power is a clean energy as it does not involves any combustion process ,but according to recent research findings it indicates the water reservoirs built for the hydro energy plants accounts in releasing Methane gas .

Coal	820
Gas	490
Solar PV (Utility)	48
Hydropower*	18.5
Wind Offshore	12
Nuclear	12
Wind Onshore	11

Figure 4-2 Median Life Cycle Carbon Dioxide Equivalent intensity (CO2 kg/kWh)

Source: IPCC/IHA -2018-IHA Study

The past study which was done in Turkey for following mentioned energy mix has obtained the LCA results using ecoinvent database in LCA .it is tabulated in the following table and clearly shows the GW potential is much higher than the other impacts .

Table 4-2 Energy generation by different sources and its percentages

Resource	Percentage
Natural gas	15
Coal	19
Hydro	40
Wind	16
other	10

Table 4-3 Environmental impact counted using LCA study and Ecoinvent database

Environmental Impact	Amount
GW potential (CO2 equivalent /kWh)	468
Acidification (SO2 equivalent /kWh)	6.5
Eutrophication (PO4-3 equivalent/kWh)	0.32

According to the above literature values the carbon dioxide emission can be calculated using percentages .The other emissions are controlled by relevant flue gas treatment methods .So the emissions of those factors are considered

(820*0.33+18.5*0.6+11*0.02)=289kg(CO_2)/kWh equivalent

The requirement of energy consume per day for the incineration system is around =86400MJ/day

Therefore emission of CO_2 during production of electricity =$8*10^{-5}$kg/J

Amount of Carbon dioxide emission = (864*10^8)*(8*10^-5)=6912000kg

According to above analysis the Acidification and Eutrophication impacts for producing the required daily energy requirement is 15600kg (SO2), 768 (PO_4^{-3})

4.Diesel fuel requirement for operation of incinerator burners – 500l/day

Emissions at the Fuel production/fuel oil refinery process is not counted in the manual calculation process since the data is not available.

C 1 3 H 2 8 + 2 0 O 2 → 1 3 C O 2 + 1 4 H 2 O

Density of diesel oil = 0.85kg/l Therefore 500l of diesel contains 2310moles of diesel and according to the stoichiometric balance the emission of carbon dioxide is equal to 2310*13 moles which is 1321kg of carbon dioxide gas. Other components of flue gas emission are controlled by the treatment system.

5. The processes of the production of the incineration plant equipment, other auxiliary equipment also engage in different environmental impacts starting from the raw material extraction to final installation of the plant in the land .But for this study the impacts of those processes are not accounted due to unavailability of the information.

6. Then the transportation of the waste from the main collection points to the central point is calculated as follows ;

Total distance travel form 15 local collecting points to the incineration plant = 587km per day

According to literature, the consumption of diesel by garbage truck is around 3miles per gallon. Which is equivalent to 1.3 km per liter.

The general consumption of fuel per day is around 450 liters per day.

Emissions at the Fuel production/fuel oil refinery process is not counted in the manual calculation process since the data is not available.

C13H28 + 20O2 → 13CO2 +14H2O

Density of diesel oil = 0.85kg/l .Therefore 450l of diesel contains 2078moles of diesel and according to the stoichiometric balance the emission of carbon dioxide is equal to 2078*13 moles which is 1188kg of carbon dioxide gas.

There are other emissions produce by diesel burning in vehicles .Carbon monoxides ,Nirogen Oxides, Particulate matters components of flue gas emission are controlled by the treatment system.

6.b Transportation of chemical compounds to the plant premises

- Requirement of diesel fuel as estimated by the nearest – 128 liters per day
- Distance to travel from the nearest chemical supplier – 250 km per day
- Weight of the chemicals – 148kg

Density of diesel Oil = 0.85kg/l Therefore 250 l of diesel contains 212 kg ,and 980 moles of diesel and according to the stoichiometric balance the emission of carbon dioxide is equal to 980*13 moles which is 560kg of carbon dioxide gas.

7.Transportation of solid residues (ash,used chemicals,) to land fill site using trucks. The landfilling area is located in Puttlam district and this project is designed for transport Solid waste material from Kelanitissa transfer station via the trains. But for my calculation purpose I have taken the distance from Plant site to Puttalama and travelling mode as truck.

- Requirement of diesel – 175 l per day
- Distance travel -120km
- Weight of the compounds chemicals – 58MT day

Density of diesel Oil = 0.85kg/l Therefore 175 l of diesel contains 148 kg ,and 808 moles of diesel and according to the stoichiometric balance the emission of carbon dioxide is equal to 808*13 moles which is 462kg of carbon dioxide gas.

8. Incineration emission inputs to the model

The incineration emissions are calculated according the design emission standards. It is assumed that the emissions are at its highest possible level. According to research it is stated the flue gas emission is around 72000Nm^3/h.

Table 4-4 Flue gas Emissions

Emission	Emission factors	Total emission per day (kg)
Dust particles	10mg /Nm3	17.28
NOx	200mg /Nm3	345.6

Emission	Emission factors	total emission per day (kg)
Dioxines	10ng/Nm3	0.00001728
SOx	50mg/Nm3	2073.6
Air Pollution control-HCl/HF -	10mg/Nm3	414.72
Carbon dioxide emission from waste incineration (47% carbon)		835MT
Lead	0.01mg/Nm3	0.01728
Hg	0.001mg/Nm3	0.001728

9.Emissions from waste water disposal

Table 4-5 Generation of Waste Water

Waste water generation	Amount m3/day
pre treatment facility	23.3
SRF Storage facility	5.6
Turbine generator facility	1.2
Flue gas treatment facility	2.6
Boiler facility	6.8
Control Office and others	16.3
	55.8m3/day

This waste water will be treated using chemical – biological treatment and the treated water will be discharged to Hamilton canal .The estimated emissions from the waste water are as follow.

Table 4-6 Emission of Waste Water after treatment and disposing to Hamilton Canal

Component	mg/l	Kg of emissions per day
BOD	30	1650
C6H5OH	1	55
COD	250	13750
Phosphate	5	275
Nitrate	150	8250
Ammonia	50	2750
floride	2	110

Component	mg/l	Kg of emissions per day
Sulphide	2	110
Chlorine	0.5	27.5
Arsenic	0.2	11
Cadmium	0.1	5.5
Chromium	0.5	27.5
Iron	3	165
Lead	0.1	5.5

The above mentioned emissions are calculated according the plant configurations and standards. Since the database to model the system is not available presently,the calculations and demonstrations for environmental impacts of Climate change impact, Acidification ,Europhications are done using excel software .

- **Climate Change Impact**

Table 4-7 Climate Change impact calculation

Flow	Emission to air CO2	Equivalent/ Kg per day
F1	Data not Available	
F2	6912000	6912000
F3	225	225
F4	1150	1150
F5	Data not Available and not considered in study	
F6	1188	1188
	560	560
F7	472	472
F8	835000	835000
F9		
F10		
		7750531

The available calculated data only contains the Carbondioxide emissions to the air ,therefore climate change impact is **7750531** kg of CO2 equivalent.

Acidification Potential

In open LCA – CML base line V4 impact method, the calculation of the acidification potential is done according to the following components emissions to air.

Table 4-8 Relevant Factors of Calculating Acidification In Open LCA

Ammonia	1.6 kg of eq SO2
Nitrogen Dioxide	0.5 kg of eq SO2
Nitrogen monoxide	0.76 kg of eq SO2
Sulphur dioxide	1.2 kg of eq SO2
Nitrogen oxides	0.5 kg of eq SO2
Sulphur monoxide	1.2 kg of eq SO2
Sulphuric Acid	0.78 kg of eq SO2
Sulhur trioxide	0.96 kg of SO2 eq

Table 4-9 Calculation of emissions related to acidification impact

Flow	Emission to air SOx,NOx	Equivalent/ Kg in SO_2
F1	Data not Available	
F2	Data not Available	
F3		15600
F4	Data not Available	
F5	Data not Available and not considered in study	
F6		
F7		
F8	NOx emission-345kg	17280
	SOx emission-2073kg	10368
F9		
F10		
		43248

Eutrophication

In Open LCA software and CML baseline V4 calculate the eutrophication as follow;

Table 4-10 Relevant Factors of Calculating Eutrophication In Open LCA

Ammonia (emission to air- water)	0.35kg of eq PO_4^{3-}
Ammonium ion emission to water	0.33 of eq PO_4^{3-}

COD emission water	0.022kg of Eq PO_4^{3-}
N2O emission to air	0.22 kg of Eq PO_4^{3-}
NO2-1 emission to air,	0.1 kg of Eq PO_4^{3-}
HNO2 emission to air,water ,soil	0.1 kg of Eq PO_4^{3-}
N emission to air,water ,soil	0.42 kg of Eq PO_4^{3-}
NO2 emission to air,water ,soil	0.13 kg of Eq PO_4^{3-}
NOx emission to air,water ,soil	0.13 kg of Eq PO_4^{3-}
$PO4^{3-}$ emission to air,water ,soil	1 kg of Eq PO_4^{3-}
H3PO4 emission to air,water ,soil	0.97 kg of Eq PO_4^{3-}
P emission to air,water ,soil	3.06 kg of Eq PO_4^{3-}
P_2O_5 emission to air,water ,soil	1.34 kg of Eq PO_4^{3-}

Table 4-11 Calculation of Emissions related to eutrophication

Component	emission	Factor	Eq Kg of PO_4^{3-}
COD	13750	0.022	303
$PO4^{3-}$	1043	1	1043
NO_3^{-1}	8280	0.1	828
NH_3	2750	0.35	963
			3137

4.1 Interpretation of the results

The calculation of the emissions related to set of flows are calculated according the limited availability of the data .This LCA calculations were prepared to be analyzed using Open LCA and ecoinvent data base .But the unavailability of the database resulted in progress with the manual calculations.

There are lot of limitations and data gaps while doing manual calculations for a comprehensive processes as listed in this LCA study .Some calculation standards were based on the research paper outcomes as well as the test reports published by several institutes. And some data were not available in the publications which I had to kept the table blank for some emissions.

Therefore in the above calculations most of the processes are not counted since the data is not available

Ex – Emissions related to required chemicals manufacture, Plant and equipment manufacturing ,

Therefore calculations are required to be further fine-tuned to get the clear picture of the product system and environmental impacts related to it.

In the calculation ,following assumptions are considered and but with the modeling software these might not considered since the real scenario will be counted.

- The transportation in vehicle ,emissions due to diesel fuel combustion is identified as complete combustion of fuel with only emissions of Carbon dioxide and water vapor
- Emissions from flue gas treatment system and emissions from waste water treatment system will be operated according to the relevant emissions standards and for the calculations emission values are considered the maximum disposal levels.
- In flue gas emission volume defining ,the values at the Normal conditions were considered as the actual emissions.

  The three impacts are shown in the following table

Impact	Amount (kg)
Climate Change Impact	7750531
Acidification Impact	43248
Eutrophication Impact	3137

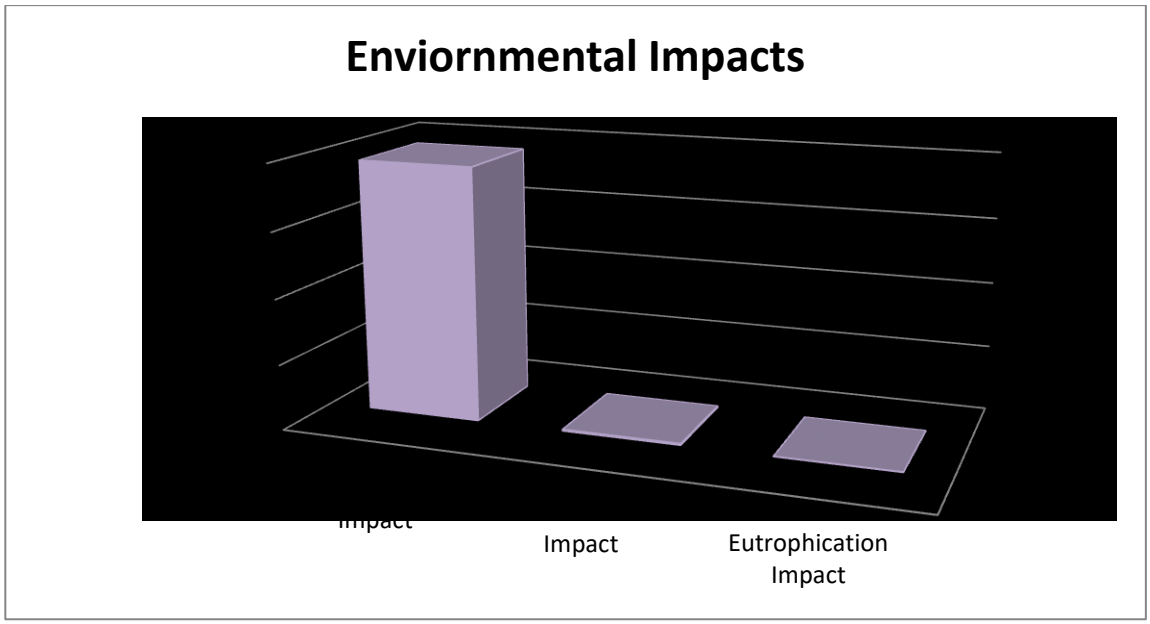


Figure 4-3 Demonstration of Impacts

In this chart the climate change impact bar is much greater than the other two bars It indicates the Climate change impact is higher in the studied system than the other impacts .Most importantly the impact is influenced by emission of carbon dioxide gas to the environment.

Climate Change impact is studied in this system is dominated by the Carbon dioxide emission. Fuel combustion in transportation and fuel combustion in incinerator burners and the combustion of waste.

CHAPTER 5

5 Discussion and Recommendations

According the above shown results it is clear that the Climate change impact is higher than the other impact categories. The main contribution factor for this impact is the emission of carbon dioxide gas by the waste combustion, fuel combustion in different processes. The energy production from the waste heat recovery process should be operated in efficient manner so that the GHG emission from the Waste to energy process should less than emission form the fuel or natural gas combustion energy production to sustain the environment.

There are other methods of energy production in the world and WTE has become a controversial in stating it supports climate change by releasing Carbondioxide gas in combustion. So it was very important to clear the arguments with showing the savings and contributions. The production of Electricity is done in different sources in different countries ,Hydro power, Coal,Solar,Wind etc, depend on the percentages the climate change impact too get change for production of one electricity unit. So it can be counted whether it is environmentally viable to run WTE plants in a country. The heat recovery efficiency is a important factor of the plant designing stage,higher the efficiency higher would be the price so as the saving of the carbon dioxide emission compared to the other production methods. But the unit production price goes up along with the better configurations of the plant, so due to difficulties of selling the production to national grids to higher prices, designers have to face difficulties. So it is the developers and government responsibility to solve the problem which would benefit the country ,investor as well as the environment.

Solid waste disposal is quite a challenging task to perform when considering the impacts to the environment. Though there are different technological solutions to solve the problem but the precaution methods to control the emission is a hard task and it costs much as well.

In this thesis study the basic task was to carry out a proper life cycle assessment to the proposed waste to energy incineration plant which is based on Gampaha district. As

there is no any LCA has done form this new set up ,my intention was to model the whole process using OPEN LCA software with using a suitable data base to calculate the three major environmental impacts which is basically influenced by the flue gas emission and the waste water emission.

The OPEN LCA software is a user friendly software to handle any LCA model with better data base .But in the middle of my study though I got familiar with modeling of my work in above mentioned software finding a database was a difficult task for me. These databases are so much expensive and I was not a feasible task to purchase.

As advised by my supervisor I turned my study from modeling to manual calculations. After defining the study boundary and listing the all processes related to study the, emission calculations were carried out. While calculating the emissions of different listed process past literature results were taken, But following limitations were encountered during the study;

1. Emissions of production of all the chemical compounds for plant operations.
2. Emissions of manufacturing the plant equipment, installation will not be considered in the LCA as it is a long chain of processes.
3. Emissions related to production of portable water to fulfill the water requirement.

According to the results gained using the manual calculations based on the literature values it is shown clearly the climate change impact is higher than the other impacts.
When comparing the waste to energy municipal solid waste management system along with the other waste management technologies like Engineered Landfilling, composting, recycling, the emissions to the environment can be classified as follow.
In the landfilling there are two types of emissions, leachate emission and the gaseous emission. Leachate is liquid state emissions which ultimately penetrates through the soil layers and pollute the ground water as well as surface water table. Volume of leachate produce by solid waste is depend on the moisture content and the rainfall patern of the landfill site premises.In rainy seasons leachate collection os higher than the dry season and precipitation is considered when designing a landfill site and its leachate collection system. Also the distance of the groundwater table Organic waste can be decomposed forming gaseous products. When the degradation process slowly moves from aerobic

condition to anaerobic condition, the carbon dioxide level continues to be high, gradually falling as the methane concentration builds up. The methane gas is collected through gas collection units and used for the energy production .If it release to the environment it makes the impact of climate change 30 times more than the Carbondioxide one mole emission. Earlier days when the proper landfilling was not in practiced methane gas was directly entered the atmosphere claiming GWP. It is same for leachate collection as well, although new technological landfilling consists of leachate collection system still there are some land fillings in developing countries which functions without any gas or liquid collection systems. This has resulted in environmental impacts.

The waste to energy incineration process which produces ash, bottom and fly ash contain components which are hazardous to the environmental and proper elimination should be done in removing them. In terms of the cost ,the half of the total cost is applied in setting up the toxic gasses elimination or hazardous substances elimination .So before the implementation of the plant in financial feasibility stage following factors are being identified to account the viability of the project in long term.

Internal Rate of Return, Payback time, etc. Basically the investor is much interested in covering up his total expense as soon as possible by making good revenue per year.

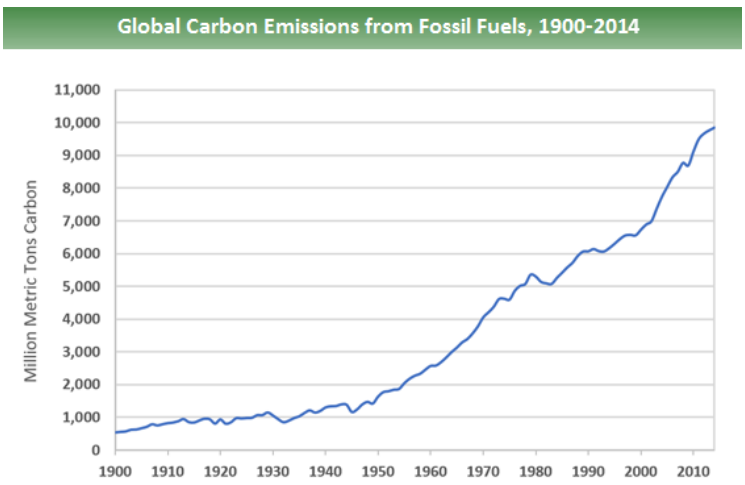
In waste to energy conversion system, the product output is energy units, and it is depend on the calorific value of the waste which is fed in to the system and its moisture content, So countries like Srilanka the Calorific value of waste is low as it contains more on food item rather than other organic wastes type, Also the moisture content is high and it also use portion of heat energy in the preheating stage to eliminate the moisture which could be used in energy generation. There the energy generation becomes low and the production cost get higher. Investors have to increase their selling rate of energy unit to the national grid. This has become the major problem in Srilanka ,the investors who wishes to implement the plant for these sort of things have faced challenge towards the unit cost which the government of Srilanka is not affordable with.

While discussing about the results gained through the study it is necessary to get proper solution to reduce the emission of carbon dioxide in to the environment. The sustainability of the WtE plants in terms of the climatic impact is heavily depend on the

energy recovery efficiency of the plant. Also the contribution of the net electricity to the national grid which could substitute the energy generation from fossil fuels .This can make a saving in CO2 account. The Co2 emission through flue gas too can be captured and stored for different uses. The Co2 capture mechanism is the amine-based chemical absorption process, CO2 is absorbed typically using amines to form a soluble carbonate salt. This reaction is reversible and the CO2 can be released by heating the solution with the carbonate salt in a separate stripping column. This stored carbon dioxide can be used for several purposes like cooling, beverage industry.

The carbon capture and storage plant is an expensive configuration which investors are not showing interest towards.

So considering the practical solutions and its environmental impacts there is an extent which the mitigation measures can be applied. According to worlds statistics it indicates in 2018 the carbon dioxide emission is around 48 gig tons and it is rising drastically each



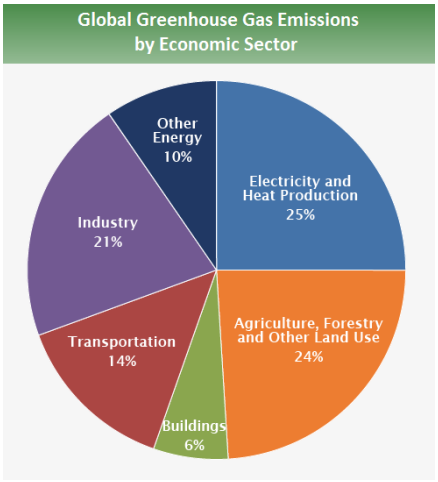


Figure 5-1 Global trend of Carbon dioxide emission

year and contribution towards total carbon dioxide emission is as shown in the pie chart accounting higher percentage in heat and electricity production sector. The global temperature getting incline with the time pass by due to these gas emissions. Seawater level rise, Glaciers melt, Acidity levels of sea water increase due to absorption of carbon dioxide gases and it affects to aquatic life and coral reefs.

So it is clear the waste itself is a major environmental concern and its management methods create number of effects. According to IPCC 2005 it indicates around 3-5% for climate change impact is caused by Municipal Solid Waste management practices all over the world and they have recognized MSW management practices; which could be implemented to convert these methods as GHG savers.

There are three key components use as strategies for waste sector to become a global net GHG emissions saver:

1. Establish integrated waste management systems, with an emphasis on waste reduction and recycling to reduce the drain on material and energy resources,

2. Introduce waste technologies with lower energy consumption and reuse of processed residuals,

3. Recover energy from waste processing and captured landfill gas, for use as electricity or in heating and cooling systems, thereby replacing the use of fossil fuels for energy production

Once the Waste is produced there should be a way of managing it ,so it is recommended to reduce the waste as much as possible from the initial stage itself of every process. There are industries which use Lean system in their floors to minimize every aspects of wastes.

Therefore waste management is a task which should be performed with proper knowledge and it is all of our responsibility to identify the waste generation points and get the precautions to reduce amount of waste ,which will ultimately save resources, energy as well as impacts to the environment which may cause by different so-called waste management methods.

CHAPTER 6

6 Conclusion

The Life cycle assessment which is performed to the proposed Waste to energy incineration system in Gampaha district provides the valuable information about the overall process and the emissions form each related processes and its impacts the environment.

It is very clear that we are living in an era where enormous climatic changes are taken place. Those have come up with many results making problems to which all living beings. Due to very rapid industrialization along with the technological development past few decades contributed huge amount of pollution to overall environment. Since people was not believing the so called word “Climate Change” they used to manage their industries only aiming on profit.

But now is visible that the environment is getting unpredictably changed showing the unsuitable conditions for living. It has opened the eyes of human to think twice on what they do , an one practical tool they use for making decision is the LCA approach ,Since it is giving use full overall knowledge of the system decision can be taken accurately.

This LCA shows the impacts of the incineration of Municipal Solid Waste and mitigation measures to be taken, It is shown that the emission of carbon dioxide gas is very high and it causes Global Warming Potential and proper mechanism should be adopted to reduce the emission of those gases.

While working on the research there were few limitations of accessing to proper data base to run the model. The industry used data abases are high in cost and data related to incineration can be found only from a proper data base. Therefore I used manual calculations in calculating the emissions of flue gases from different processes. Some emissions were assumed and tabulated using literature values found from research papers. So there is an opportunity to further improve this study with a suitable database to obtain the accurate results before implementation of the project. Finally, I want to convey Municipal Solid Waste management is a national level problem where solutions

should be taken with proper understating. It is all of our responsibility to contribute not only with management but also to reduce the generation of waste.

CHAPTER 7

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