A COMPARATIVE ANALYSIS ON WASTE TO ENERGY (WTE) PATHWAYS IN THE PERSPECTIVE OF BANGLADESH

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Declaration

We do hereby declare that this thesis work has been done by us and neither this thesis nor any part of it has been submitted elsewhere for the award of any degree or diploma.

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Abstract

Wastes are a part of our everyday lifestyle. Food wastes, paper, plastic, glass etc. are some of the wastes that we face on a day-to-day basis. Municipal Solid Waste (MSW) is made up of waste, organics and recyclable materials whose disposal are overseen by the municipality. Among the Waste to Energy (WtE) processes, we compare about Incineration, Pyrolysis, Gasification & Plasma Gasification in different countries and analysis of its application in Bangladesh.

Chapter 1

Introduction

1.1 Waste Management

Wastes are unwanted or unusable materials, any substance that is discarded after their primary usage. On the other hand, by-products are joint products of comparatively less economic value. The municipal solid waste industry has four components: recycling, composting, disposal, and waste-to-energy via incineration [1]. Waste management can't be done by a single method. For this reason, the Environmental Protection Agency, a U.S. federal government agency, developed a hierarchy ranking strategy for municipal solid waste [2]. The waste management hierarchy is made up of four levels ordered from most preferred to least preferred methods based on their environmental soundness: Source reduction and reuse; recycling or composting; energy recovery; treatment and disposal [3]. The functional elements of MSW Management are: a) waste generation; b) waste handling and sorting and processing at the source; c) collection; d) sorting, processing and transformation; e) transfer & transport, and f) disposal.

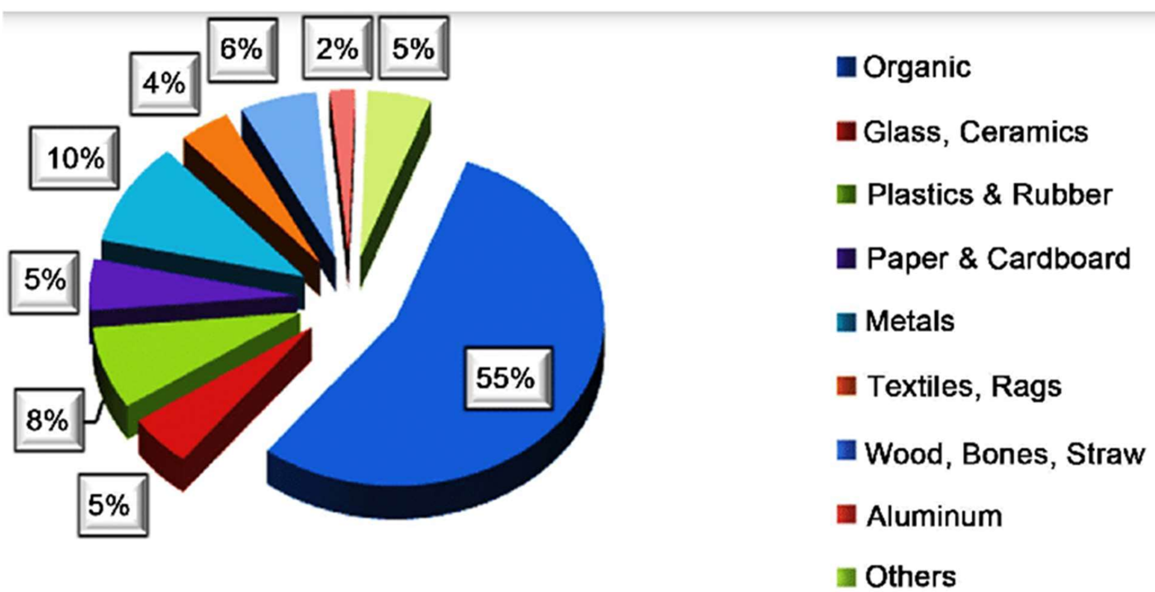

Figure 1: Types of Municipal Solid Wastes

Along with increase of population in the recent years, waste generation in our country has also increased. This is evident from the following graph:

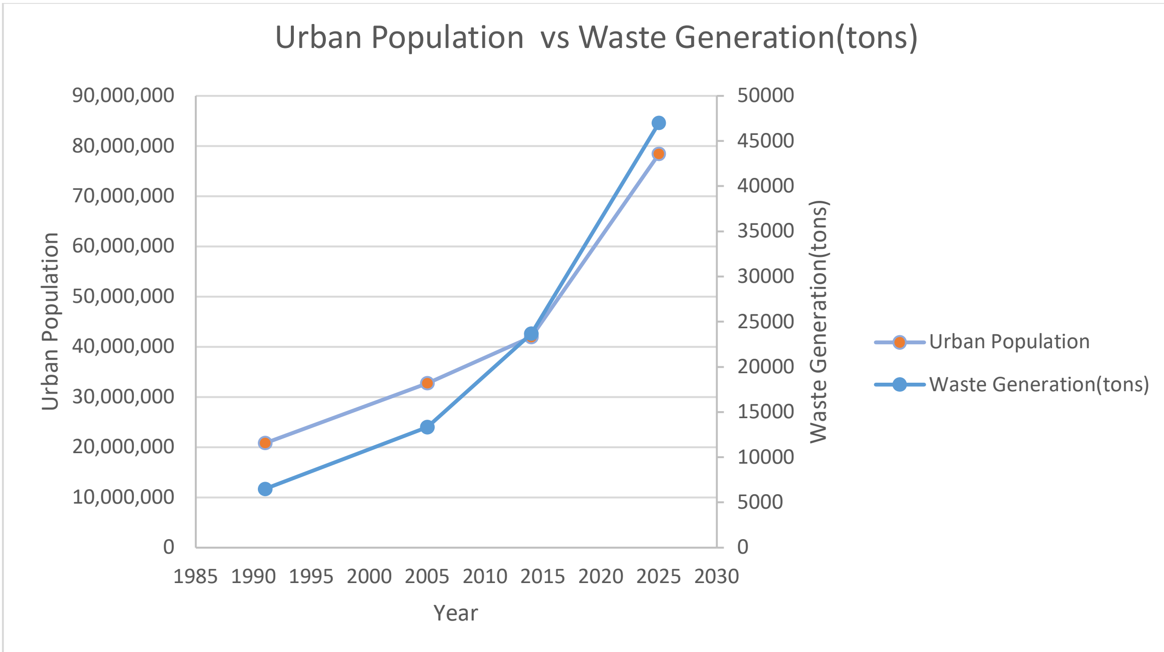

Figure 2: Urban Population vs. Waste Generation (tons)

The waste management hierarchy based on environmental soundness is shown in the following figure:

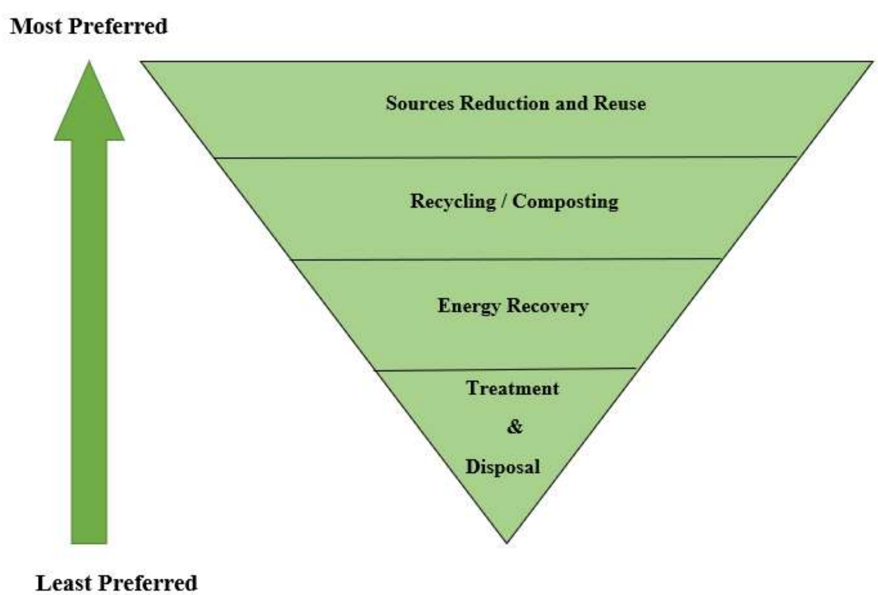

Figure 3: Waste management hierarchy based on environmental soundness

Bangladesh recycles the recyclable wastes while the rest are mostly disposed in landfills. Landfilling is increasing at an alarming rate.

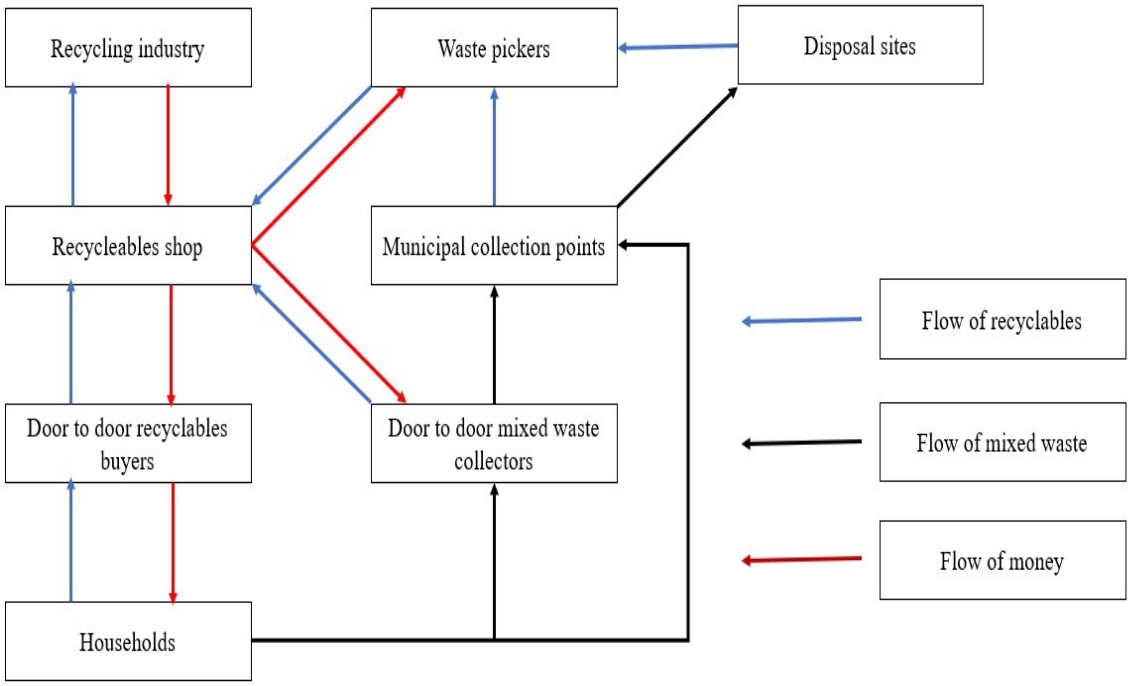

Figure 4: Flow of waste, recyclables and money in MSW management in Dhaka

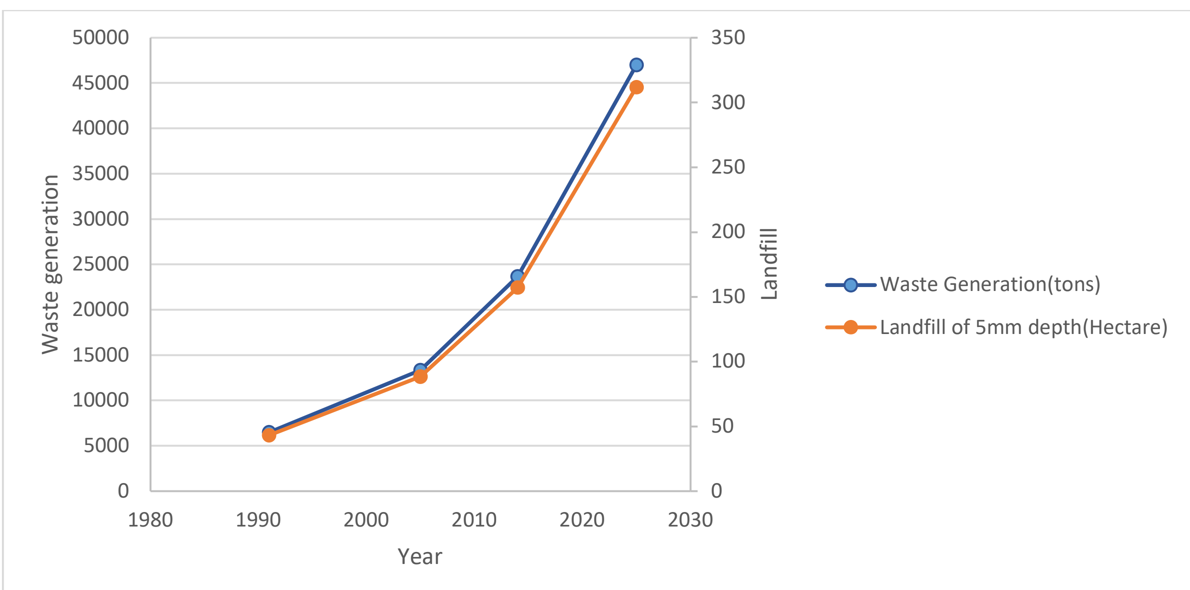

Figure 5: Waste generation vs Landfill area for Bangladesh

1.2 Costs

Waste Management comes with certain costs ot effects. These are described below:

1.2.1 Economic Costs

The economic cost of waste management is very high. This is usually paid off by municipal governments [4]. This cost can be cut down through public education, efficiently designed collection routes etc. Environmental policies such as "pay as you throw" or waste recovery methods like recycling and reusing can reduce the amount of waste to be managed and in turn, the management cost like extraction and transportation of waste. Moreover, the location of waste treatment and disposal facilities reduce the value of the properties of the surroundings due to pollution, negative stigma, smell etc.

1.2.2 Social Costs

The increasing municipal solid waste (MSW) requires a sustainable waste management strategy. At the same time, addressing climate change and security of energy supply concerns requires increased use of low-carbon and domestic sources of energy. The need for expansion and siting of waste treatment and disposal facilities is increasing all around the world. There is now a developing market in the transboundary movement of waste, and although most waste that flows between countries goes between developed countries, a significant amount of waste is moved from developed to developing countries [5].

1.2.3 Environmental Costs

Unmanaged or poorly treated wastes can attract rodents and insects, that are likely to spread various harmful diseases among humans. Moreover, more hazardous waste like toxic waste materials left unchecked can contaminate water and air, which affects not only the humans but also other species and the ecosystem as a whole [6]. Waste treatment and disposal produces significant greenhouse gas (GHG) emissions, notably methane, which are contributing significantly to global warming [7].

1.3 Energy Recovery

The process of extracting electricity, heat or any other forms of energy by implementing processes like Combustion, Incineration, gasification etc. of waste materials aren't recyclable. The focus of our thesis paper is on the processes of Incineration, Pyrolysis, Gasification and Plasma Gasification which will be discussed later.

1.4 Objectives of the study

The objectives of our study are to:

- Know about harmful effects of MSW.
- Find effective pathways for solid waste management.
- Propose the most effective output of municipal solid waste management.

Chapter 2

Literature review

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In most parts of the world, Generation of electricity depends heavily on fossil fuels. But producing electricity from this source is environmentally unsustainable. It is one of the major causes of global warming. Generation and consumption of electricity is one of the key drivers of urban life and prosperity. Singapore generates more than 95% of its electrical power from the natural gas supplied by Malaysia and Indonesia. The remaining installed capacity generates electricity from fuel oil, coal and incineration of solid waste. Current state of nuclear power technology was also deemed to be too risky for a densely populated city like Singapore. This paper analyses the sustainability of increasing the energy mix of these two sources for Singapore's electricity generation. Natural gas contributes the highest impacts due to its high proportion (> 95%) in the energy mix. Even though these impacts are in high percentage, these did not contribute in proportion to the energy contribution. The cradle-to gate results of the various energy options showed that switching to renewable energy sources does not necessarily reduce environmental impacts.

India dependency upon fossil fuels causes them to pay a huge amount of bill after a predetermined period. These bills can be cut down by using and exploiting non-conventional energy sources. India has a huge possibility to use many non-conventional energy sources. By changing the lifestyles and increasing PPP of the people of urban area, has increased the per capita waste generation rate in India from 0.44 kg/day in 2001 to 0.5 kg/day in 2011. The results of these kind of activities have increased 50% more waste generated by Indian cities in a span of a decade since 2001. India has 53 cities where a million plus people resides. Which account for 86,000 TPD (31.5 million tons per year) of waste generated. India generates a total amount of Municipal Solid Waste (MSW) estimated 68.8 MTY or 188,500 TPD [8]. The increasing of wastes has become a burden to the nation as well as a threat to the health, safety and environment. Incineration, pyrolysis and gasification techniques are included in thermal conversions of waste. Incineration is used in a large scale as waste treatment techniques in India, which has the ability to reduce waste mass by 70% and volume by up to 90% which aids in energy recovery from the waste for generating electricity [9]. Biochemical conversion of waste to energy is the most environment friendly than the other techniques. Biochemical conversion primarily consists of converting the waste into energy by the action of enzymes of microorganisms. India has attempted many ways to generated energy from wastes but mostly failed. Ten aerobic composting projects in 1970s, a WTE project in 1980s, a large-scale bio methanation project, and two RDF projects in 2003, have all ended up being a failure. The reason of the failure of the Large-scale bio methanation is the absenteeism of source separation. A major plant in Lucknow to produce 6 MW of electricity became disastrous for this reason. In fact, the same type of process became successful on small scale, using kitchen waste, market waste, restaurant waste, etc. India has a total of 5 RDF processing plants. Every one of them have faced operational problems due to lack of proper financial and logistical planning but due to technology. 2 RDF plants have already been shut down [8].

In 2010, the average amount of waste generated in Ghana was 0.51 kg per capita per day with annual waste generation capacity of about 4.5 million tons [10,11]. Only about 10% were handled successfully through proper incineration and landfilling. It is highly feasible to generate electricity in Ghana from MSW as most of the wastes are not being efficiently managed. Even though the costs of these power plants are high at present, the rationale for putting up these plants should be waste management to improve environmental safety. It was found out from the various feasibility studies that landfills with already existing engineering sites have the potential of being the most economical method of managing waste as well as producing electricity. Moreover, anaerobic digestion(landfilling) has the advantages of producing energy, high quality fertilizer and also preventing the transmission of disease through good sanitation. It is therefore recommended in this study that if any project would be taken up in Ghana as a waste management technology, an engineered landfill power plant is highly considerable.

In Taiwan, Incineration is the most adopted method for MSW. The generation of electricity from domestic biomass materials is especially noted in that it not only enhances fuel diversification but also mitigates the environmental pollution and (GHG) greenhouse gases emissions. For all these reasons, transformation of the large-scale MSW incinerators into the local electricity utility centers has become a great interest. By utilizing this, the power can be generated by joint incineration of MSW with non-hazardous industrial waste, tree trimmings, tree debris and agricultural wastes/residues (e.g., bamboo, mushroom breeding remains) in response to the significant decrease in the incinerated MSW amounts due to the new recycling policy. The Taiwanese government started to adopt large-scale MSW incineration plants for integrated, sustainable resource and waste management policies during the 1990s. Under the government policy, these MSW incineration facilities have installed their generation systems for the purpose of selling their surplus electric power to Taipower, a state-owned company in Taiwan. By the end of 2008, the design treatment capacities and installed generation capacities totaled over 24,000 tons per day and about 622.5 MW, respectively. Based on the power generated from waste-to-energy in 2008 (i.e., 2967 GWh), the environmental benefit of mitigating CO2 emissions and the economic benefit of selling electricity were preliminary calculated to be around 1.9x106 tons and US $ 1.5X108, respectively [12]. Furthermore, using the heat content and incinerated amount of MSW and the methodologies recommended.

In Malaysia, the generation of the average amount of municipal solid waste (MSW) is 0.5–0.8 kg/ person/day and has increased to 1.7 kg/person/day in major cities. This paper highlights the MSW characteristics for the city of Kuala Lumpur. Big cities in Malaysia are switching to incineration. An evaluation was directed to know the amount of energy recovered if MSW were to be incinerated. The city council planning to take an approach for the management of solid waste as an alternative to the previous concept which is just dumping all the waste that is generated. This new outlook by the city council has brought about activities such as waste recycling and recovery followed by incinerating the waste to recover the energy with only the final inert material being considered for land filling [13,14].

A feasibility analysis was carried out in order to define the viability of an incineration plant with a capacity of 100 t/d, with energy recovery and environmental safety, in Greece. Using realistic estimates of waste composition and heat content, an appropriate incineration method was selected, as well as near optimum operating conditions of process equipment. The European and Greek legislation related to environmental protection was reviewed. The application of stricter requirements for the incineration of domestic wastes has resulted in increased investment and operational costs. Six emission abatement options were studied and the increase of the total investment and operational cost of their use was estimated. What resulted is that a capacity of 100 t/d incineration with energy recovery and environmental safety is an expensive method, and the increase in cost due to the best available emission control system was calculated as 26% for the investment cost and 6.5% for the operational cost. However, high costs might be compensated for the increased fuel and energy prices, the increased land taxes, and increased land values. The MSW production in EU countries varies between 0.7 and 1.3 kg/person/day with an average value of 1 kg/person/day [15]. The present study focuses on evaluating the incineration of municipal solid waste with energy recovery and environmental safety in Greece. Besides being an effective means of reduction of the volume of MSW, incineration is also a source of energy recovery. Incineration is a feasible solution, but the high investment and operating costs create barriers to its implementation. Nevertheless, one has to consider that these barriers are temporary and could be overcome if combined with material recovery programs, resulting in the restraint of undesirable fractions of the combustible waste and a decreasing of emissions needed for high-cost cleaning systems.

Close to two-thirds of Chinese cities are experiencing "waste siege". China's municipal solid waste generation has reached 215 million tons, and it is projected to increase to 480 million tons by 2030. Over the last decades, municipal solid waste incineration has increased dramatically due to its ability to reduce the volume of waste. According to a report from the National Bureau of Statistics of China, from 2005 to 2014, around 7.9 million and 53 million tons of waste were incinerated. Anaerobic digestion technology is regarded as the best for management of organic fraction of municipal solid waste (especially, food waste). This is because it helps to recover high-quality biogas for energy generation and biofertilizer for agriculture purposes. Anaerobic digestion technology has gained popularity in Europe, with over 17,376 biogas plants and 459 biomethane plants registration in 2016. There are over 500 anaerobic plants in Germany and 140 in the United Kingdom and Italy.

Anaerobic digestion technology has been trusted as a reliable technology for the treatment of an organic fraction of municipal solid waste. However, challenges such as the presence of wood (lignin-rich) waste, big particles, high solid components, and slow biodegradable content could be a hindrance to its smooth process. In China, some studies have been conducted on the treatment of municipal solid waste through waste-to-energy technologies. Liu et al. [16] evaluated the environmental performance of different municipal solid waste management scenarios in China. Reduction of GHG emissions from electricity generation using municipal solid waste through incineration in Beijing has been investigated by Yao et al. [17]. Life cycle assessment of incineration for electricity generation from municipal solid waste and sewage sludge was carried out under four scenarios to evaluate its environmental impact, energy potential, and economic viability by Chen et al. [18]. Under the clean development mechanism, Wang et al. [19] conducted a cost-benefit analysis of GHG emissions reduction of two waste-to-energy projects (Incineration with combined heat and power- ICHP and landfill disposal with landfill gas utilization GU). Landfill gas to energy and anaerobic digestion technologies both require an organic fraction of municipal solid waste for electricity generation. However, for effective electricity generation potential, different components of organic fraction of municipal solid waste should be utilized in each technology. In this study, food waste, which is referred to as putrescible, was utilized in anaerobic technology. This is because another organic waste such as wood is not good to be fed in the digester because of its high lignin content. Electricity generation potential of landfill gas to energy technology depends mainly on the captured volume of methane generated from the landfill. Biogas which produced from the organic fraction of municipal solid waste using anaerobic technology consists of methane and carbon dioxide. Electricity generation potential of anaerobic digestion technology depends largely on the amount of methane produced from the food waste (feedstock) fed to the digester. Electricity generation potential of landfill gas to energy technology depends on the amount of captured methane from the organic part of municipal solid waste in the landfill. Methane produced from putrescible (food waste) in the digester determines the electricity generation potential of the anaerobic digestion technology.

With the growth of population and rising standards of living over the world, the usage of products, resources, and energy is on the rise. On the one hand, consumption increases the generation of waste. For instance, the average amount of municipal solid waste (thereafter MSW) generated by each of about 512 million inhabitants of the European Union was accounted as 477 kg per year in 2015. [20,21] Taking into consideration an estimated density of MSW (about 200e400 kg/m3), after one year of generation, the EU municipal solid waste would cover Malta (316 km2) with a layer almost 2 m high! That sounds alarming.

The solutions of MSW management should be not only environmentally sustainable but also cost-efficient and socially acceptable. Several factors are influencing this complex process, which are largely intertwined. First of all, there is a need for political will, a willingness to pursue changes. While the EU sets a direction (i.e. a shift towards the circular economy), waste management is implemented at the national level. The most recent broadest (in scope) study was conducted by the European Environment Agency "Assessment of waste incineration capacity and waste shipments in Europe" in 2017 [22], with the previous study on incineration overcapacity and waste shipping in Europe commissioned by the Global Alliance for Incinerator Alternatives in 2013. [23] These studies observed uneven distribution of WtE capacity across Europe with the six countries e Germany, France, the Netherlands, Italy, the United Kingdom, and Sweden - accounting for almost three-quarters of Europe's incineration capacity and with the other countries heavily relying on the landfill for MSW disposal. The duration of EU membership does not seem to correlate with the states' waste management performance, as it depends on different visions, strategies, and priorities of waste management. Yet, historical data of some Member States (for instance, the Baltic states) are not available due to different classifications of waste streams before joining the EU. Although Norway has large resources of oil and gas, it is also a country with high renewable energy resources. This particularly regards hydropower, since for example, in the year 2013, production of Norwegian hydroelectric power corresponded to around 40% of the total for the then EU-27 block. [24] As laid out in the Norwegian national bioenergy plan, Norway has a target to double bioenergy production (including contributions from both biomass and MSW), from 14 to 28 TWh, between 2008 and 2020. [25] In 2016, 20.5 TWh, or around 1% of the total energy products supplied in Norway, originated from biofuels (solid or liquid), biogas, and waste (renewable and non-renewable). [26] Around 25% of this was waste, amounting to a total quantity of 1415 kt. [27] The main strategies for the management of waste are the increasing material recovery (MR), which can significantly reduce the landfill disposal, the enhancement of energy recovery (ER) from waste and reduces the environmental impact. These two last objectives can be attained by introducing a breakthrough technology for waste treatment based on a plasma torch gasification system integrated with a high-efficiency energy conversion system, such as combined cycle power plant or high-temperature fuel cells. Integrated Plasma Gasification/Fuel Cell(IPGFC) system is able to generate a net power of 4.2 MW per kg of RDF with an electric efficiency of about 33%. This efficiency is high in comparison with those reached by conventional technologies based on RDF incineration (20%). Conventional technologies for energy recovery from waste are based on the incineration process and pyrolysis or gasification processes. [28] While both pyrolysis and gasification are feasible technologies to handle municipal waste, commercial applications of these technologies have been limited. Recently, an innovative technology, based on the plasma torch gasification, seems to be the most effective and environmentally friendly method for biomass/solid waste treatment and energy utilization. The plasma gasification process works at very high temperatures in an oxygen-starved environment and decomposes the input waste material completely into very simple molecules. The organic compounds are thermally decomposed into their constituent elements and converted into a synthesis gas, which mainly consists of hydrogen and carbon monoxide, while the inorganic materials are melted and converted into a dense, inert, non-leachable vitrified slag.

Four technologies are investigated which produce energy from municipal solid waste (MSW): incineration, gasification, generation of biogas and utilization in a combined heat and power (CHP) plant, generation of biogas and conversion to transport fuel. Typically, the residual component of MSW (non-recyclable, non-organic) is incinerated producing electricity at an efficiency of about 20% and thermal product at an efficiency of about 55%. Gasification produces electricity at an efficiency of about 34%; this would suggest that gasification of the residual component of MSW is more advantageous than incineration where a market for the thermal product does not exist. Gasification produces more electricity than incineration, requires a smaller gate fee than incineration and when thermal product is not utilized generates less greenhouse gas per kWh than incineration. Gasification of MSW (a non-homogenous fuel) is, however, not proven at commercial scale. Thermal conversion and anaerobic digestion are components of a number of the integrated waste management solutions proposed in the various strategies. This paper evaluates the technologies, which allow energy production from various components of MSW. Typically, the organic fraction may be digested and the biogas may be utilized either for CHP or as a transport fuel. The non-recycled non-organic fraction may be either incinerated or gasified; this residual fraction is a non-homogenous fuel comprising of plastic, textiles, combustible composites and metals. A waste management infrastructure is about to be created in Ireland and it needs to be done properly. Biogas cost is low, then the gasification and incineration cost is the highest. Among all, gasification produces moderate energy and low cost, but incineration gives higher energy but the cost is also higher. Electricity generation was one of the most environmental beneficial factors for PG process.

Chapter 3

Methodology

After conducting our literature reviews, we analyze the processes of Incineration, Gasification, Pyrolysis, and Plasma Gasification to select the best possible approach from Bangladesh's perspective. We gather municipal solid waste sample data and use Ultimate analysis to get chemical composition and Proximate analysis to get the samples' physical properties. We had to use data from DNCC as we couldn't collect primary data under the current situation of conducting our thesis. From the data, we calculate the energy content of the MSW using Dulong Formula. Finding the contribution of each component of the waste towards the energy, we can get the calorific value of the MSW we're working with and the amount of electricity produced. We've designed also designed a prototype that was too costly for us to manufacture.

Chapter 4

WTE Conventional Process

4.1 Incineration

Incineration is a waste treatment process that involves the combustion of organic substances in waste materials [29]. The waste materials are converted into heat, ash and flue gas. The heat can be used to generate electric power. This may be implemented without the recovery of energy and materials. The environmental effects of Incinerators are a major concern for experts in several countries. In Incinerators, the solid mass of the waste is reduced by over 80% and its volume by over 90% depending on the composition of the waste [30]. This reduces the amount of waste needed for landfilling by a significant amount. It is particularly good for treating clinical and hazardous wastes as it destroys the pathogens and toxins at higher temperatures. Waste combustion is popular in countries such as Singapore, Japan and the Netherlands, where land is a scarce resource. Denmark and Sweden have been leaders by using the energy generated from incineration for more than a century [31].

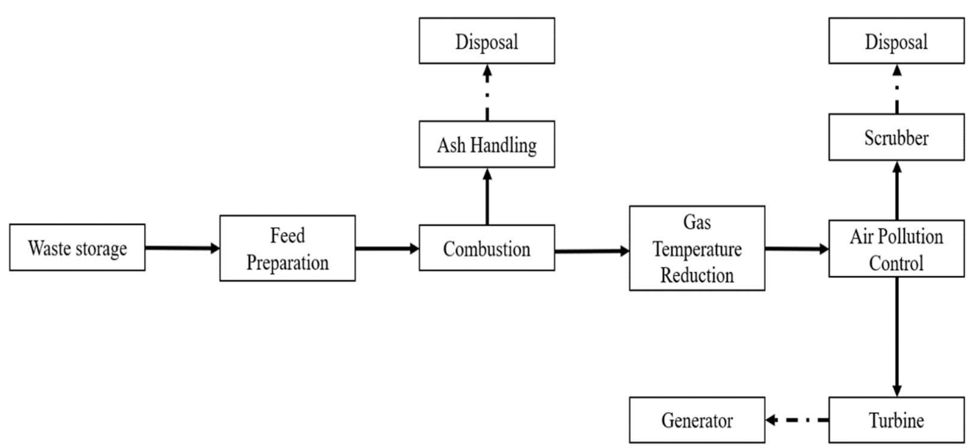

Figure 6: Flowchart of Incineration process

Advantages:

1. Decreases quantity of waste.
2. Efficient waste management.
3. Production of heat and power.
4. Reduction of pollution.
5. Incinerators have filters for trapping pollutants.
6. Saves on transportation of waste.
7. Provides better control over odor and noise.
8. Prevents the production of methane gas.
9. Eliminates harmful germs and chemicals.
10. Incinerators operate in any weather.
11. Effective metal recycling.
12. It has a computerized monitoring system.
13. Uses of ash.
14. Occupies relatively small space.
15. Uncontaminated groundwater.

Disadvantages:

1. It is expensive.
2. Pollutes the environment.
3. Damaging public health.
4. The possibility of long-term problems.
5. Ash waste can potentially harm people and the environment.
6. Environmental racism.

4.2 Gasification

Gasification is a process that converts fossil fuel- or biomass-based carbon compounds into carbon monoxide, carbon dioxide and hydrogen. To achieve the material is reacted with a controlled amount of oxygen and/or steam at high temperatures, without combustion. The resulting gas is a fuel called syngas or producer gas [32] [33] [34]. Gasification of fossil fuels is currently widely used on industrial scales to generate electricity [35].

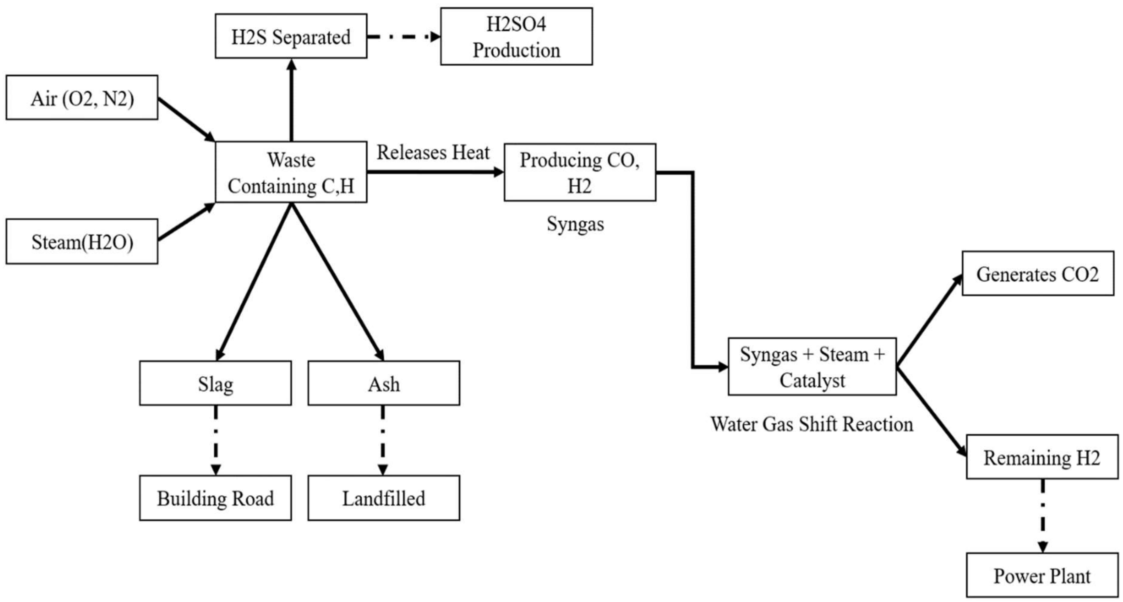

Figure 7: Flowchart of Gasification process

Advantages:

1. It takes place in a low oxygen environment that limits the formation of dioxins and of large quantities of SOx and NOx.
2. requires just a fraction of the stoichiometric amount of oxygen necessary for combustion.
3. he volume of process gas is low, requiring smaller and less expensive gas cleaning equipment.
4. generates a fuel gas that can be integrated with combined cycle turbines, reciprocating engines and, potentially, with fuel cells that convert fuel energy to electricity more efficiently than conventional steam boilers.

Disadvantages

1. Contains various tars, particulates, halogens, heavy metals and alkaline compounds.
2. Agglomeration in the gasification vessel.

4.3 Pyrolysis

Pyrolysis focuses on the change of chemical composition among materials by thermally decomposing them at an elevated temperature in an inert atmosphere. This method is most commonly used in the treatment of organic materials and largely in the chemical industry. For example, to produce ethylene, many forms of carbon, and other chemicals from coal, petroleum, and even wood, to produce coke from coal. Aspirational applications of pyrolysis would convert biomass into syngas and biochar, waste plastics back into usable oil, or waste into safely disposable substances. In general, the pyrolysis of organic substances produces volatile products and leaves a solid residue enriched in carbon, char [36].

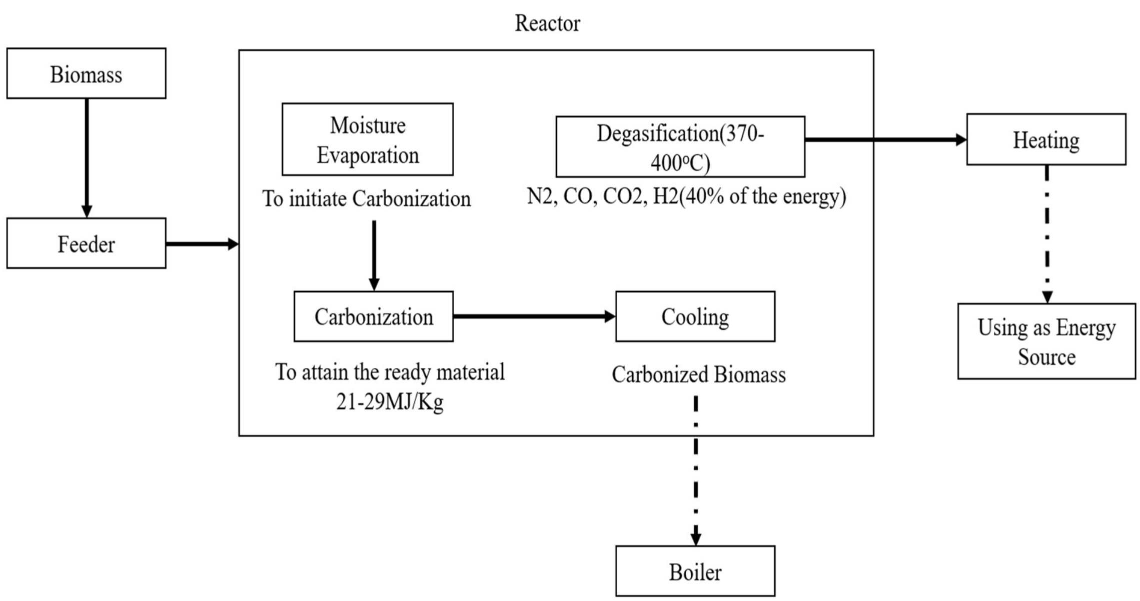

Figure 8: Flowchart of Pyrolysis process

Advantages:

1. High efficiency.
2. High profit.

Disadvantages:

1. Environmental problem
2. Project permit.

4.4 Plasma gasification

Plasma Gasification is an extreme thermal process using plasma converting organic matter into syngas that primarily contains hydrogen and carbon monoxide [37]. It is used commercially as a form of waste treatment and has been tested for gasification, biomass, industrial waste, hazardous waste, and solid hydrocarbons [38].

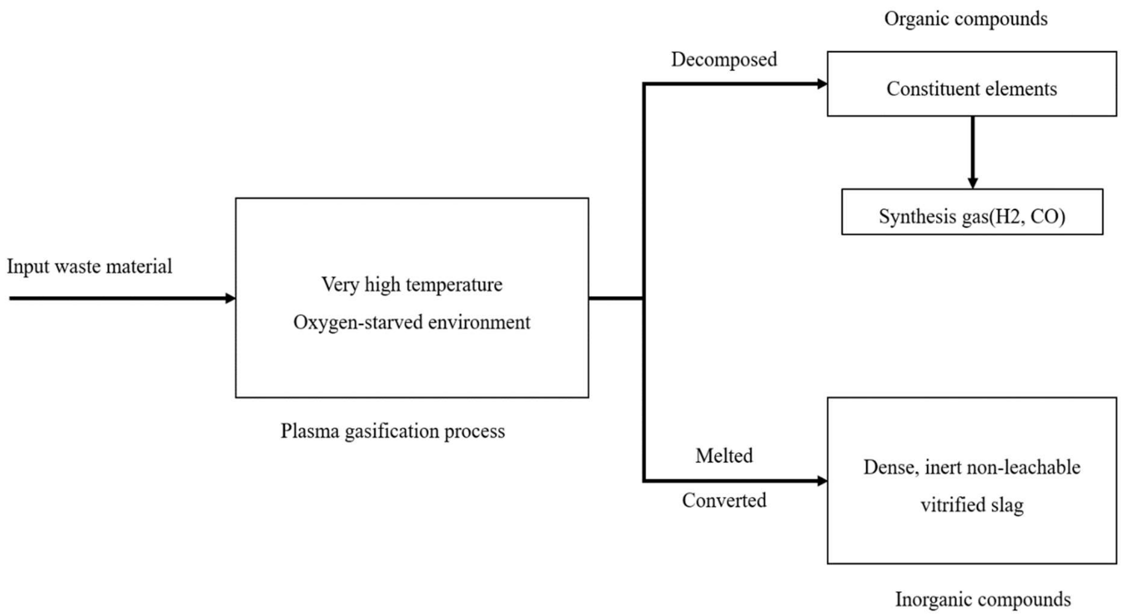

Figure 9: Flowchart of Plasma Gasification process

Advantages:

1. It unlocks the greatest amount of energy from waste.
2. Feedstock can be mixed, such as municipal solid waste, biomass, tires, hazardous waste, and auto shredder waste.
3. It does not generate methane, a potent greenhouse gas.
4. It is not incineration and therefore doesn't produce leachable bottom ash or fly ash.
5. It reduces the need for landfilling of waste.
6. It produces syngas, which can be combusted in a gas turbine or reciprocating engines to produce electricity or further processed into chemicals, fertilizers, or transportation fuels.
7. It has low environmental emissions.
8. Preventing hazardous waste from reaching landfills.
9. Some processes are designed to recover fly ash, bottom ash, and most other particulates, for 95% or better diversion from landfills, and no harmful emissions of toxic waste.

10. Potential production of vitrified slag which could be used as construction material.
11. Processing of biomass waste into combustible syngas for electric power and thermal energy.
12. Production of value-added products (metals) from slag.
13. Safe means to destroy both medical [45] and many other hazardous wastes.
14. Gasification with starved combustion and rapid quenching of syngas from elevated temperatures can avoid the production of dioxins and furans that are common to incinerators.
15. Air emissions can be cleaner than landfills and similar to that of incinerators.
16.

Disadvantages:

1. Large initial investment costs relative to that of alternatives, including landfill and incineration.
2. Operational costs are high relative to that of incineration.
3. Little or even negative net energy production.
4. Wet feed stock results in less syngas production and higher energy consumption.
5. Frequent maintenance and limited plant availability.

4.5 Comparison

	Incineration	**Pyrolysis**	**Gasification**	**Plasma Gasification**
Process	Combustion of raw MSW, moisture less than 50%	Thermal degradation of organic materials through use of indirect, external source of heat	Can be seen as between pyrolysis and combustion (incineration) as it involves partial oxidation	Use of electricity passed through graphite or carbon electrodes, with steam and/or oxygen / air injection to produce electrically conducting gas (plasma)
Temperature	Between of 1000 to 1200oC	Between 300 to 850oC	Above 650oC	Above 3000oC

Product	Waste is converted into CO_2 and water concern about toxics (dioxin, furans).	Product is char, oil and syngas composed primarily of O_2, CO, CO_2, CH_4 and complex hydrocarbons.	Main product is syngas. residue of non-combustible materials (ash).	Organic materials are converted to syngas composed of H_2, CO. Inorganic materials are converted to solid slag.
Amount of air injected	Need enough oxygen. Large diameter pipes	Anaerobic / hypoxic. Small pipe diameter	Occurs in absence of Oxygen preventing Combustion	
Equipment volume	Large size	Small size	Large size	Large size
Reaction type	Oxidation under aerobic conditions	Reduction reaction under oxygen-free conditions	Dehydration, Pyrolysis, Gasification.	Thermal chemical conversion
Equipment structure	Open structure	Closed structure	Closed structure	Closed Structure
Secondary pollution	Dioxin / Heavy metal	No dioxin / Heavy metals are fixed by residues		
Investment scale	High cost	Low cost	Very High Cost	Very High Cost
Maintenance cost	High cost / More labor required	Low cost / Only need 2-3 labor		
Working Environment	Harsh working environment	Good working environment	Good working environment	
Area	Large	Small	Medium	Medium

Table 1: Comparison among MSW to energy generation method

4.6 Selection of the most suitable process

From our literature review and process analysis, we come to the following conclusions:

- Developed countries have gained much success in managing MSW through Incineration. As a developing country, we have to follow their ideals in order to succeed.
- Heterogeneous wastes can be easily fed into the plant without any need for separation. Separation of wastes needs a huge change in infrastructure and a lot of time. We are planning for the immediate future.
- Incineration decreases the harmful effect of landfill by 30% as well as decreasing need and space for landfilling.
- Production of electricity is going to help us to import less electricity for the country and saving money in the process.
- Though the initial investment scale of Incineration is high, it is not as much as that of Plasma Gasification, but it has a better payoff than the ones with lower investment cost like Gasification and Pyrolysis.

Due to these reasons, we opted to go for Incineration for Bangladesh.

Chapter 5

Experimental Setup, Calculation & Result

Proximate analysis is done to find the physical properties and Ultimate analysis done to get the chemical properties. We use Dulong Formula to find the energy content from the MSW. Then we find the contribution from each of the component in the final calorific value. Using an average Incineration plant efficiency, we get an estimate of how much electricity can be produced, in other words, how much electricity Bangladesh is missing out on.

		Food	Plastic	Paper	Grass and straw	Glass and ceramics	Metals	Textiles	Others
Physical properties	Wet weight fraction (%)	80	2	8	2	1	1	-	6
	Moisture content (%)	71.34	.53	3.2	38.21	0	0	-	8.67
	Dry weight fraction (%)	22.13	1.99	7.74	1.24	1	1	-	5.48
Chemical properties	Carbon (%)	48	60	43.50	47.8	0.50	4.5	55	24.3
	Ash (%)	5	10	6	4.50	98.90	.46	2.50	68
	Sulphur (%)	2.60	0	.4	3.40	.10	0	90.50	0.2
	Nitrogen (%)	.40	0.10	.2	0.30	0	0	.10	0.5
	Oxygen (%)	37.60	7.20	45	38	0.40	4.30	31.20	4
	Hydrogen (%)	6.40	22.80	7	6	0.10	0.60	6.60	3

Table 2: Physical and chemical properties of MSW

Source: Dhaka North City Corporation

Dulong Formula for Determining the Energy Content

Energy Content (kJ/kg) = $338.2C + 1430\left(H - \frac{1}{8}O\right) + 95.4S$

Here,

C = percentage of carbon existing in a substance

H = percentage of hydrogen existing in a substance

O = percentage of oxygen existing in a substance

S = percentage of carbon existing in a substance

Food Waste

Energy Content = 338.2C + 1430 $\left(H - \frac{1}{8}O\right)$ + 95.4S

= (338.2 X 48) + 1430 $\left(6.40 - \frac{1}{8}X\ 37.60\right)$ + (95.4 X 2.60) kJ/ kg

= 18912.64 kJ/ kg

= 18. 913 MJ/kg

Plastic Waste

Energy Content = 338.2C + 1430 $\left(H - \frac{1}{8}O\right)$ + 95.4S

= (338.2 X 60) + 1430 $\left(22.80 - \frac{1}{8}X\ 7.20\right)$ + (95.4 X 2.60) kJ/ kg

= 51609 kJ/ kg

= 51.609 MJ/kg

Paper Waste

Energy Content = 338.2C + 1430 $\left(H - \frac{1}{8}O\right)$ + 95.4S

= (338.2 X 43.50) + 1430 $\left(6 - \frac{1}{8}X\ 44\right)$ + (95.4 X .30) kJ/ kg

= 15455.32 kJ/ kg

= 15.455 MJ/kg

Grass & Straw Waste

Energy Content = 338.2C + 1430 $\left(H - \frac{1}{8}O\right)$ + 95.4S

= (338.2 X 47.8) + 1430 $\left(6 - \frac{1}{8}X\ 38\right)$ + (95.4 X 3.40) kJ/ kg

= 18277.82 kJ/ kg

= 18.278 MJ/kg

Glass & Ceramics Waste

Energy Content = 338.2C + 1430 $\left(H - \frac{1}{8}O\right)$ + 95.4S

= (338.2 X .50) + 1430 $\left(.10 - \frac{1}{8}X\ .40\right)$ + (95.4 X .10) kJ/ kg

= 250.14 kJ/ kg

= 0.250 MJ/kg

Metals Waste

Energy Content = 338.2C + 1430 $\left(H - \frac{1}{8}O\right)$ + 95.4S

= (338.2 X 4.50) + 1430 $\left(.60 - \frac{1}{8}X\ 4.30\right)$ + (95.4 X .0) kJ/ kg

= 1611.275 kJ/ kg

= 1.611 MJ/kg

Textiles

Energy Content = 338.2C + 1430 $\left(H - \frac{1}{8}O\right)$ + 95.4S

= (338.2 X 55) + 1430 $\left(6.60 - \frac{1}{8}X\ 31.20\right)$ + (95.4 X 9.50) kJ/ kg

= 31095.7 kJ/ kg

= 31.096 MJ/kg

Others

Energy Content = 338.2C + 1430 $\left(H - \frac{1}{8}O\right)$ + 95.4S

= (338.2 X 24.3) + 1430 $\left(3 - \frac{1}{8}X\ 4\right)$ + (95.4 X 0.2) kJ/ kg

= 11812.34 kJ/ kg

= 11.812 MJ/kg

Physical Composition of waste in Dhaka City,

Food waste = {22.13/(22.13+1.99+7.74+1.24+1+1+5.48)}X100 = 54.53%

Similarly,

Plastic waste = 4.90 %

Paper waste = 19.07%

Grass & straw waste = 3.06%

Glass & ceramic waste = 2.46%

Metal's waste = 2.46%

Others = 13.50%

Textile = 0% (Almost)

Calorific value of waste generation in the Dhaka City,

= { (18.913 X .5433) + (51.609 X .0490) + (15.455 X .1907) + (18.278 X .0306) + (0.250 X 0.0246) + (1.611 X 0.0246) + (11.812 X 0.1350) } MJ/kg

= 17.99 MJ/kg

= 17990 MJ/ton

= 17990000 KJ/ton

= (17990000 / 3600) kWh/ton

= 4997.222 kWh/ton

Electricity generation efficiency of incineration plant is around 30%

Therefore, specific electricity output = (4997.222 X .3) kWh/ton

= 1499.1666 kWh/ton

So, the total calorific value of the MSW is 4997.222 kWh/ton and we get 1499.1666 kWh of electricity per ton MSW produced in Dhaka alone.

Chapter 6

Prototype Design

Based on the decisions have been taken we have designed a prototype portable incineration plant. This plant burns solid wastes and turn them into ashes, then cleans up the particulate materials from the exhaust gas and finally releases the purified air into the environment. That purified air can be used to rotate turbines which can drive generator to produce electricity. [39] But this we have not added this portion wo our design. Then we analyzed the capacity and cost of this prototype. We have used SolidWorks 2021.SP2.0 version to design our prototype.

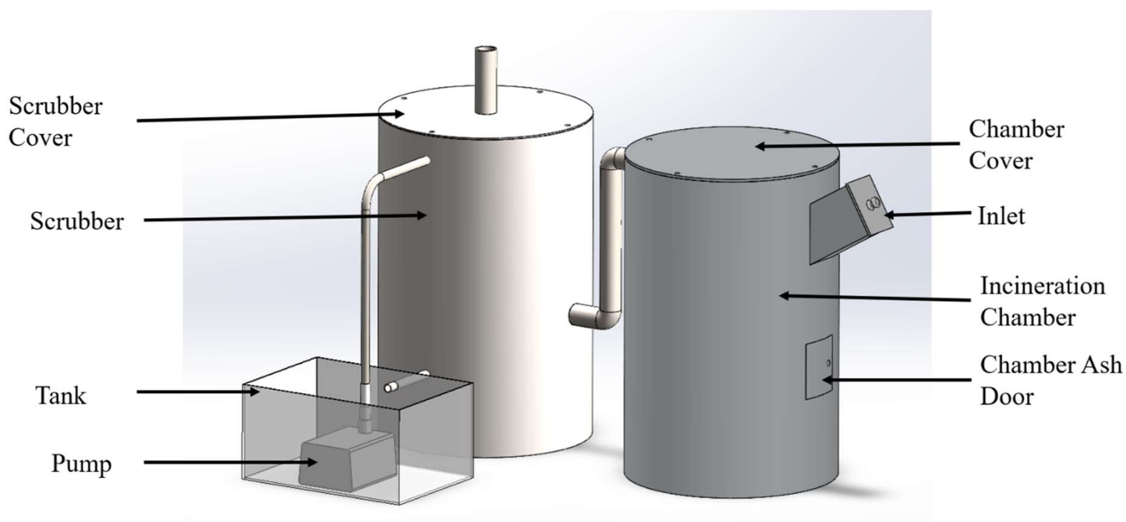

Figure 10: Portable Incinerator

6.1 Components

Cylinders: We have used two cylinders where one of these is considered as the incineration chamber and the other one is considered as a scrubber.

Chamber Cover: It is used for cleaning up the stacked wastes from the chamber.

Inlet: Solid wastes are fed through the inlet. The cover is removed when waste is being fed, during the incineration the cover is attached to the inlet.

Chamber Ash Door: It is used for cleaning up the ashes occasionally. Ashes are formed by burning up the wastes.

Scrubber: Particulate materials are cleaned up in this chamber by water treatment.

Tank: The water for cleaning up the particulate materials are stored there.

Pump: It is used to pump the water over the scrubber.

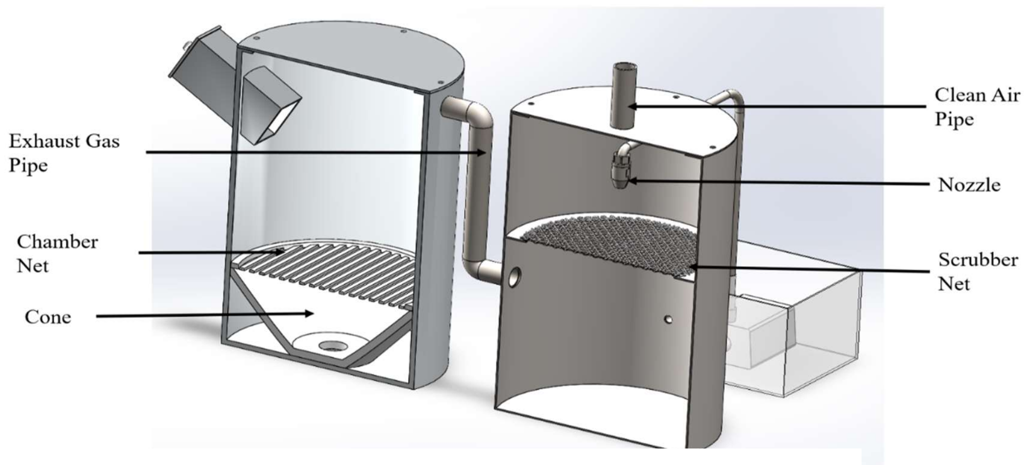

Figure 11: Portable Incinerator (Sectional View)

Nozzle: It is used for spraying the water.

Clean Air Pipe: The purified air is released into the environment through this.

Exhaust gas pipe: It is the link between the incineration chamber and the scrubber. The exhaust gas by burning of the solid wastes is travelled through the pipe.

Chamber Net: It carries all the wastes that is dumped into the chamber.

Cone: The cone shaped holder is used so that the ashes can easily slides through small hole below the chamber.

6.2 Working Principle

It follows the basic working principle of an incineration plant. At first, solid wastes are fed into the chamber with necessary fuel like kerosene or diesel oil. Then the wastes are ignited and starts to burn. After combustion the ashes will slides through the small hole below the chamber and exhaust gas will produce resulting the combustion.

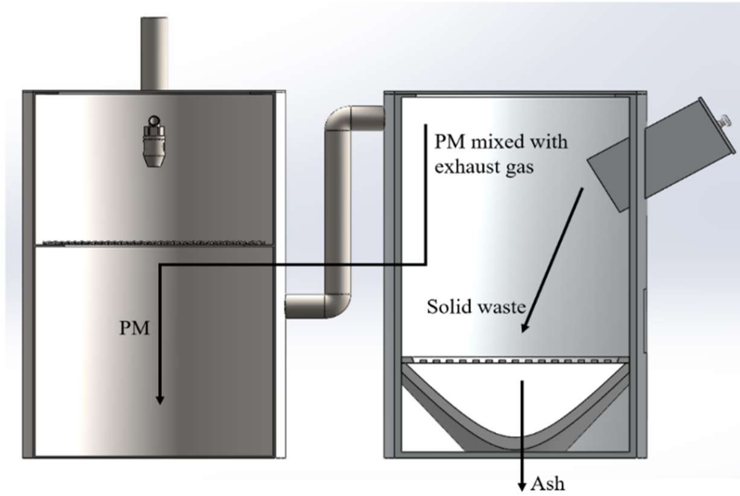

Figure 12: Waste Flow

The exhaust gas is mixed with particulate materials of different waste components. Through the exhaust gas pipe, it will reach the scrubber. The nozzle will then spray water to clean up the particulate materials from the gas and the water mixed with exhaust materials will be stored below the scrubber. Then, the purified air will be released to the environment through the clean air pipe (Fig: Gas Flow). In the economic sector, this air is used for rotating turbines. The turbines will then drive a generator which will produce electricity.

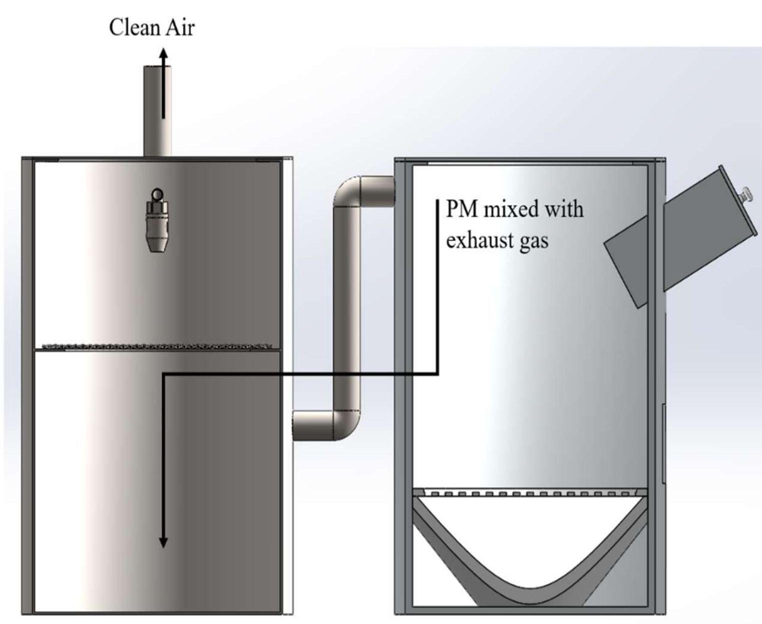

Figure 13: Gas Flow

The water mixed with exhaust materials will then travels to the tank through the connecting pipe for reusing (Fig: Water Flow).

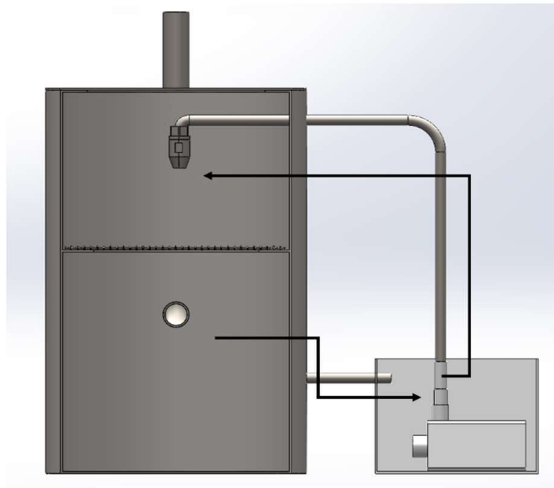

Figure 14: Water Flow

6.3 Measurements

Some measurements of the designed cylinders are mentioned here:

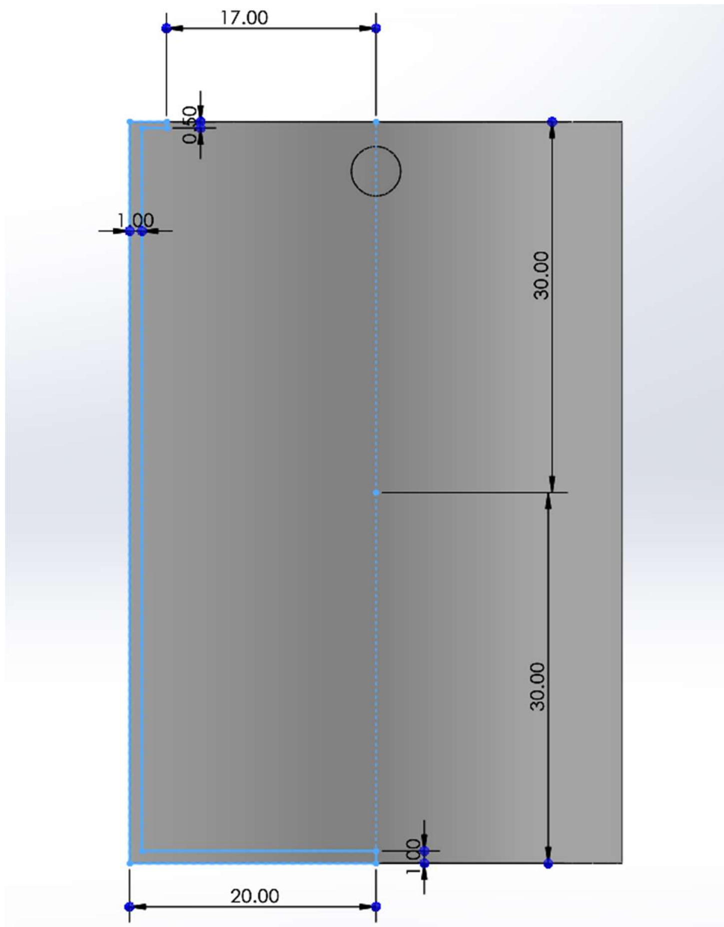

Figure 15: Incineration Chamber (Measurements)

Height: 60cm

Inner Diameter: 18cm

Outer Diameter: 20cm

Thickness: 1cm

6.4 Capacity

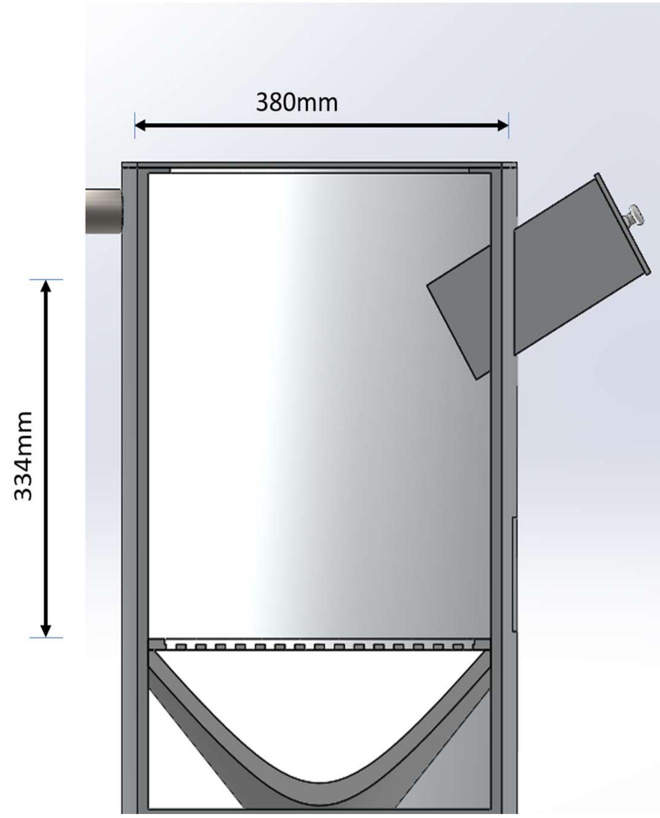

Figure 16: Incineration Chamber (Waste Capacity)

Maximum height from the chamber net is kept 334mm. The rest is kept for safety factor and exhaust gas flow.

Total Waste Capacity = π x (Inner Diameter)2 x Effective Height

= π x (380/2 mm)2 x 334 mm

= 37,879,439.26 mm3

= **37,879.439 cm3**

6.5 Material

For incineration a high temperature environment is required. It requires to reach 850°C in 2 seconds in order to proper breakdown of the wastes [40]. So, we need materials with lower thermal conductivity as they are good for high temperature environment [41].

Table 3: Thermal conductivity Common metals

Metal	Thermal Conductivity [BTU/(hr·ft·°F)]
Copper	223
Aluminum	118
Brass	64
Steel	17
Bronze	15

Thermal conductivity of bronze is lower than most of the steels. But, for being an alloy it is more expensive than steel [42]. So, we selected **mild steel** as our principal material for being cheaper and having better availability in our country.

6.6 Cost Analysis

Cost for individual components of the prototype is determined here. At first, we analyzed the volume of each component by the SolidWorks function 'Mass Properties'. Then we searched for the available materials properties and price in market. Then we compared between the required value and the available value to determine the price of individual components.

Table 4: Cost Analysis

Component Name	Available Properties	Available Price	Required Properties	Determined Price
Cylinders x2	4ft x 3ft x 4mm	3800 Tk [43]	8800 x 2 cm3	14,998 Tk
Chamber Net			407 cm3	346.84 Tk
Cone			2210 cm3	1883.38 Tk
Scrubber Cover			372.28 cm3	317.26 Tk
Chamber Cover			626.75 cm3	534.18 Tk
Exhaust Pipe Clean Air Pipe	Thickness: 3.68 mm Diameter: 50.8 mm Length: 6M	325 Tk [44]	Thickness: 3 mm Diameter: 40 mm Length: 510 mm	325 Tk
Nozzle	2.5 in	1129 Tk [45]	63.5 mm	1129 Tk
			Total:	**19,533 Tk**

Also, additional costs will be applied for:

- Pump
- Mini water tank
- Pipes for water supply
- Metal net
- Machining

Chapter 7

CONCLUSION & RECOMMENDATIONS

7.1 Conclusion:

In this paper, we proposed an approach to manage the current MSW of Bangladesh in the form of Incineration. In the proposed approach, the dependence on Landfilling will decrease as well as its impact on the environment. Furthermore, we will be able to produce an amount of electricity that will save our costs in case of importing electricity. Incineration is the first choice for MSW management as many countries, especially developed ones, have gained much success from it.

7.2 Recommendations:

- Shift to Incineration as soon as possible to decrease pressure on landfill and production of electricity.
- Waste disposal at designated places to help make waste management easier on the responsible management.
- Plan on separating different types of waste at the source in the long run to further diversify efficient waste management.

References

[1] Nonhazardous waste Archived 2010-11-20 at the Wayback Machine U.S. Energy Information Administration.

[2] “System Overview > Solid Waste - GSA Sustainable Facilities Tool". sftool.gov.

[3] US EPA, OSWER (22 September 2015). "Advancing Sustainable Materials Management: Facts and Figures". US EPA.

[4] Wolsink, M. "Entanglement of interests and motives: Assumptions behind the NIMBY-theory on Facility Siting." Urban Studies 31.6 (1994): 851-866.

[5] Kirschbaum, Miko U.F. (2000-01-01). "Will changes in soil organic carbon act as a positive or negative feedback on global warming?". Biogeochemistry. 48(1): 21–51. doi:10.1023/A:1006238902976. ISSN 1573-515X. S2CID 97491270

[6] “International Waste Activities.” 2003. U.S. Environmental Protection Agency. 12 Oct 2009. epa.gov Archived 2009-10-16 at the Wayback Machine

[7] Ferronato, Navarro; Torretta, Vincenzo (2019). "Waste Mismanagement in Developing Countries: A Review of Global Issues". International Journal of Environmental Research and Public Health. **16** (6): 1060. doi:10.3390/ijerph16061060. PMC 6466021. PMID 30909625

[8] Annepu RK. “Sustainable Solid Waste Management in India,” (2012)

[9] Singh RP, Tyagi VV, Allen T, Ibrahim MH, Kothari R, “An overview for exploring the possibilities of energy generation from municipal solid waste (MSW) in Indian scenario.”

[10] E.D. Anomanyo, Integration of municipal solid waste management in Accra (Ghana): bioreactor treatment technology as an integral part of the management process. MSc thesis, Lund University, Sweden, 2004.

[11] N. Obirih-Opareh, Institutional arrangements and stakeholders perspectives for solid waste collection in Accra, A Report Presented to the Netherlands Israel Development Research Programme (NIRP), 2000.

[12] Wen-Tien Tsai , Kuan-Chi Ku, “ An analysis of power generation from municipal solid waste (MSW) incinerationplants in Taiwan”

[13] Institute of Engineers Malaysia (IEM/ICE). Conference on Solid Waste Management System. Institute of Engineers, Kuala Lumpur, Malaysia; 1994.

[14] Ministry of Housing and Local Government. Annual report, Section 4—Local government technical section. Local Government Division, Ministry ofHousing and Local Government, Kuala Lumpur, Malaysia; 1999.

[15] A. Zabaniotou & N. Giannoulidis, “Incineration of Municipal Solid Waste with Electricity Production and Environmental Safety: The Case of a Small Capacity Unit in Greece.”

[16] Y. Liu, P. Xing, J. Liu, Environmental performance evaluation of different municipal solid waste management scenarios in China, Resour. Conserv. Recycl. 125 (2017) (2017) 98–106.

[17] X. Yao, Z. Guo, Y. Liu, J. Li, W. Feng, H. Lei, Y. Gao, Reduction potential of GHG emissions from municipal solid waste incineration for power generation in Beijing, J. Clean. Prod. 241 (2019) 118283.

[18] G. Chen, X. Wang, J. Li, B. Yan, Y. Wang, X. Wu, R. Velichkova, Z. Cheng, W. Ma, Environmental, energy, and economic analysis of integrated treatment of municipal solid waste and sewage sludge: a case study in China, Sci. Total Environ. 647 (2019) 1433.

[19] Y. Wang, R. Zhang, R. Saravanan, Asian pollution climatically modulates mid-latitude cyclones following hierarchical modelling and observational analysis, Nat. Commun. 5 (2014) 3098.

[20] Eurostat. 477 kg of municipal waste generated per person in the EU n.d. http://ec.europa.eu/eurostat/en/web/products-eurostat-news/-/DDN20170130-1 (accessed November 13, 2017).

[21] Eurostat. 477 kg of municipal waste generated per person in the EU n.d. http://ec.europa.eu/eurostat/en/web/products-eurostat-news/-/DDN20170130-1 (accessed November 13, 2017).

[22] Wilts H, Galinski L, Marin G, Paleari S. Assessment of waste incineration capacity and waste shipments in Europe. 2017. p. 1e66.

[23] Jofra M, Ventosa I. Incineration overcapacity and waste shipping in Europe: the end of the proximity principle? 2013. p. 23.

[24] Eurostat. Municipal waste treatment in EU-27 by type of treatment, (kg per capita), 1995-2015. n.d.

[25] Trømborg E. IEA Bioenergy task 40 e country report 2013 for Norway. Innovation. 2015. p. 1e20.

[26] SSB. Production and consumption of energy, energy account [Online]. Stat Norw. 2017. http://www.ssb.no/en/energiregnskap (accessed July 14, 2017).

[27] SSB. Production and consumption of energy, energy balance. Table10950. 2017. 1, https://www.ssb.no/en/energi-og-industri/statistikker/ energibalanse/aar-endelige/2015-10-08 (accessed July 14, 2017).

[28] G. Galeno, M. Minutillo, A. Perna, From waste to electricity through integrated plasma

gasification/fuel cell (IPGFC) system, https://doi.org/10.1016/j.ijhydene.2010.11.008.

[29] Knox, Andrew (February 2005). "An Overview of Incineration and EFW Technology as Applied to the Management of Municipal Solid Waste (MSW)" (PDF). University of Western Ontario. Archived from the original(PDF) on 5 December 2008.

[30] “Waste to Energy in Denmark". Ramboll. 2006.

[31] Kleis, Heron; Dalager, Søren (2004). 100 Years of Waste Incineration in Denmark (PDF).

[32] National Non-Food Crops Centre. "Review of Technologies for Gasification of Biomass and Wastes, NNFCC project 09/008" (PDF). Archived (PDF)from the original on 2017-08-10. Retrieved 2011-06-24.

[33] The Clean and Renewable Energy Source, biomass.uk.com, accessed 16.05.11 Archived 2011-09-10 at the Wayback Machine

[34] Thermal Gasification of Biomass, International Energy Agency Task 33Archived 2011-05-09 at the Wayback Machine, http://www.gastechnology.org, accessed 16.05.11

[35] Giddey, S.; Badwal, S.P.S.; Kulkarni, A.; Munnings, C. (June 2012). "A comprehensive review of direct carbon fuel cell technology". Progress in Energy and Combustion Science. 38 (3): 360–399. doi:10.1016/j.pecs.2012.01.003

[36] BASF. "BASF researchers working on fundamentally new, low-carbon production processes, Methane Pyrolysis". United States Sustainability. BASF. Retrieved 19 October 2020.

[37] Moustakasa, K.; Fattab, D.; Malamisa, S.; Haralambousa, K.; et al. (2005-08-31). "Demonstration plasma gasification/vitrification system for effective hazardous waste treatment". Journal of Hazardous Materials. **123** (1–3): 120–126. doi:10.1016/j.jhazmat.2005.03.038. PMID 15878635.

[38] Kalinenko, R. A.; Kuznetsov, A. P.; Levitsky, A. A.; Messerle, V. E.; et al. (1993). "Pulverized coal plasma gasification". Plasma Chemistry and Plasma Processing. 13 (1): 141–167. doi:10.1007/BF01447176.

[39] https://www.eia.gov/energyexplained/biomass/waste-to-energy-in-depth.php

[40]https://en.wikipedia.org/wiki/Incineration#:~:text=According%20to%20the%20European%20Waste,breakdown%20of%20toxic%20organic%20substances

[41] https://www.metalsupermarkets.co.uk/which-metals-conduct-heat-best/

[42] https://www.thomasnet.com/articles/metals-metal-products/types-of-bronze/

[43] https://www.thomasnet.com/articles/metals-metal-products/types-of-bronze/

[44] https://sindabad.com/ms-seamless-pipe-schedule-40-2-thickness-3-91-mm.html

[45] https://sindabad.com/hosepipe-nozzle-2-5-inch.html