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MASTER THESIS

Cost estimation and procedure to set up 1 MW waste-to-energy gasification plant in India

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Energy technology, 15 credits

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Dedicated to Swachh Bharat Abhiyan (Clean India Campaign)

Abstract:

With an increasing demand for electrical energy, it is certain that the production will also increase, especially in rapid developing countries like India. Rapid industrialization is carving for more electrical energy, investment and suitable space for its infrastructure. But this development has to be sustainable keeping in mind the increasing global temperature due to pollution.

India is the second largest population in the world and hence produces a lot of waste daily. As of now, most of the waste goes to the landfills and gets burnt there or decomposed, either way releasing greenhouse gases in the process and degrading the environment. The municipal waste management is a challenging process in developing countries because of non-availability of proper infrastructure. There are some methods to manage this waste, such as scientific landfills, Incineration, Biomethanation, Gasification, Pyrolysis and Plasma Arc Gasification. By gasification the solid waste is converted into synthesis gas which can be used for chemical industries, power generation, transportation and industrial heating etc. This process shrinks the solid waste to slag or ash which can either be used to manufacture eco bricks or can be disposed of on landfill. Thus saving a lot of place from land filling and if used for power generation it does not release any considerable harmful gases into the environment making it a sustainable process and partially renewable source of energy.

This project will estimate the capital requirement and procedure to setup a 1 MW gasification plant in Indian state of Telangana. In the study, the generation, composition, treatment and energy potential of solid waste have been studied. The technologies for waste-to-energy conversion have also been studied and the feasibility comparison of two leading technologies has been done.

Keywords: Municipal Solid Waste, Gasification, Plasma Arc Gasification, Waste-to-Energy

Sammanfattning:

Med ökande efterfrågan på elektrisk energi, är det rimligt att anta att produktionen också kommer att öka, särskilt i länder med snabb utvecklingstakt som Indien. Den snabba industrialiseringen ger ett ökat behov av elektrisk energi, investeringar och även landareal för ny infrastruktur. Men denna utveckling måste vara hållbar med tanke på den ökande globala temperaturen på grund av våra utsläpp.

Indien har den näst största befolkningen i världen och producerar därmed stora mängder avfall dagligen. I nuläget går de mesta av avfallet till deponier och blir där förbrända eller bryts ned, vilket i båda fallen gör att växthusgaser frigörs i processen och miljön försämras. Den kommunala avfallshanteringen är en utmaning i utvecklingsländerna på grund av bristande tillgång till ordentlig infrastruktur. Det finns ett antal metoder för att hantera detta avfall från kommuner, såsom avancerade deponier, förbränning och förgasning och några till.

Genom förgasning omvandlas det fasta avfallet till syntesgas som kan användas för kemisk industri, elproduktion, transport och industriell uppvärmning etc. Denna process reducerar det fasta avfall till slagg eller aska som antingen kan användas för tillverkning av miljötegel eller kan läggas på deponi. Detta sparar en hel del plats vad gäller deponering och när de producerade betydande gaserna används för kraftgenerering släpps inga skadliga gaser ut i miljön, vilket gör detta till en hållbar process och delvis förnybar energikälla.

Detta projekt kommer att uppskatta kapitalbehov och procedur för att sätta upp en 1 MW förgasningsanläggning i den indiska delstaten Telangana. Studien belyser hur fast avfall genereras, dess sammansättning, hur det behandlas samt dess energipotential. Tekniker för energiproduktion från avfall har också studerats och en jämförelse presenteras av två ledande tekniker.

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I would like to thank my parents, sisters and friends for their constant support.

Thank you!

Nomenclature:

1) MSW – Municipal Solid Waste
2) WTE – Waste-to-energy
3) WTP – Waste to Product
4) RCC - Reinforced Cement Concrete
5) NGO – Non Governmental Organization
6) CH_4 – Methane
7) CO – Carbon Monoxide
8) SO_2 – Sulfur Dioxide
9) CO_2 – Carbon Dioxide
10) HC – Hydrocarbons
11) PM – Particulate Matter
12) NO_x – Nitrogen Oxide
13) SO_x – Sulfur Oxide
14) H_2O - Steam
15) TEQ – Toxic equivalency factor
16) RDF - Refuse Derived Fuel
17) CFB – Circulating Fluidized Bed
18) BFB – Bubbling Fluidized Bed
19) SIA - Secretariat for Industrial Assistance
20) CBDT - Central Board of Direct Taxes
21) CBEC - Central Board of Excise and Customs
22) FEMA - Foreign Exchange Management Act
23) GHMC – Greater Hyderabad Municipal Corporation
24) NSWAI – National Solid Waste Association Of India
25) MNES – Ministry Of New And Renewable Energy
26) MW – Mega Watt
27) kW – kilo Watt
28) WHO – World Health Organization
29) INR – Indian Rupee

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1. Introduction

The world population has crossed 7 billion by the end of year 2012 [1]. And out of these 7 billion people over 1.25 billion people are living in India within an area of 3.288 million km^2 [7]. It is evident that every person generates waste. As of 2001, 27.8% of the total Indian population lives in urban areas, and the urban population of India is expected to increase by 33.4% by 2026 [3]. This rapid increasing population will surely generate a massive amount of Municipal Solid Waste MSW which has to be handled effectively. According to (Singh, R.P. et al., 2011) the urban population of India is expected to generate 440,460 t d^{-1} of MSW by the year 2026 [3]. To recycle, reduce, reuse or dispose this amount of MSW, huge and sustainable infrastructure is required, which at present is lacking in India. According to (Agarwal, D. et al., 2012), most of the MSW in India goes to either identified disposals or unidentified dumping sites [6], which keep on heaping up due to unavailability of the infrastructure to contain it and dispose it. This causes major concerns of an outbreak of epidemics.

There are mostly two types of waste from municipalities, solid waste and liquid waste. The liquid waste is generally black water, which is fecal matter and urine and the greywater is wastewater from bathing, kitchen and laundry. According to (Winrock International India 2007), 80% of this waste flows into water bodies untreated due to lack of infrastructure [2].

Figure 1 Pond affected by untreated water flow, Hyderabad, India

By definition municipal solid waste (MSW) is non-hazardous and non-industrial waste [5]. MSW consists of all kinds of waste such as paper, plastic, food leftovers, electronic waste, glass and crockery etc. This waste altogether is called municipal solid waste (MSW). As of now most of the bio-hazardous waste from nursing homes and hospitals is treated as MSW in India, but as per legal regulations it should be treated separately [6].The composition of MSW varies depending on a multitude of factors such as culture, customs, traditions, economic factors, food habits, climatic conditions and demographics etc. [4].

1.1 Municipal Solid Waste (MSW) Composition

Typically, the MSW in the developed countries consists predominantly of waste with high content of recyclable material such as paper and plastic (40-50%) and less biodegradable waste, such as food leftovers (30-40%) and very little inert waste such as waste from building destruction, fine earth and ash. But in developing countries the composition of MSW is different as it mostly contains biodegradable waste such as food leftovers (40-60%) and less inert waste (30-40%) and very little recyclable waste such as, paper and plastic (3-6%) which are mostly used for packing and wrapping of food [10]. The composition of MSW also varies depending on the size of the population and depends on whether the population is urban or rural.

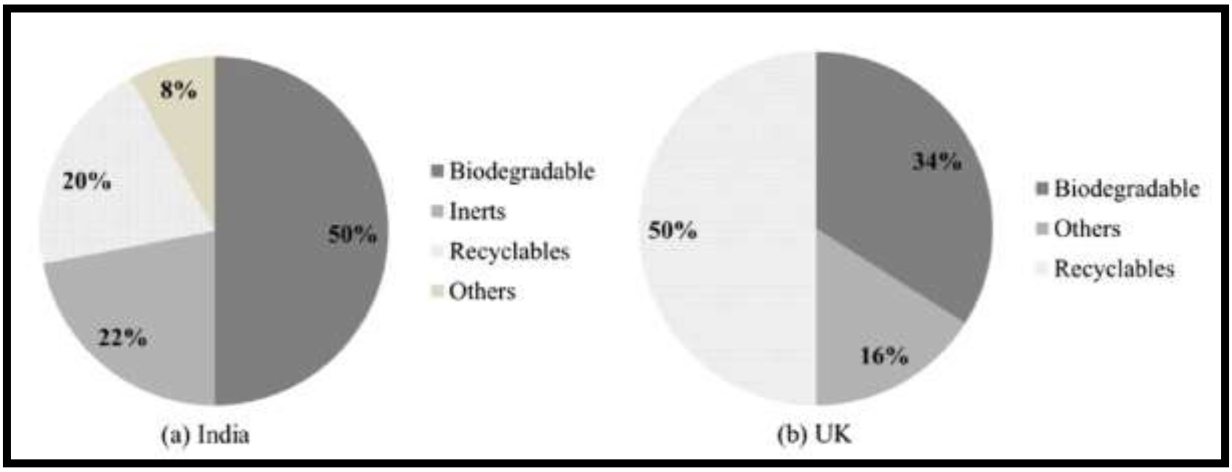

Figure 2 (a) & (b) Comparison of average MSW composition in (a) India and (b) United Kingdom [10]

1.2 MSW Collection Scheme

In India mostly MSW management, i.e. its collection, transportation, segregation and disposal, is done by the municipal agencies who work under the state government as per MSW management and handling rules, 2000 which is under the Environment Protection Act, 1986 [9]. And in some urban areas it is handled by the private agencies as well, such as non-governmental organizations (NGO's). But the management process is almost same, which is unscientific and chaotic as stated by (Chattopadhyay, S. et al., 2009) [4].

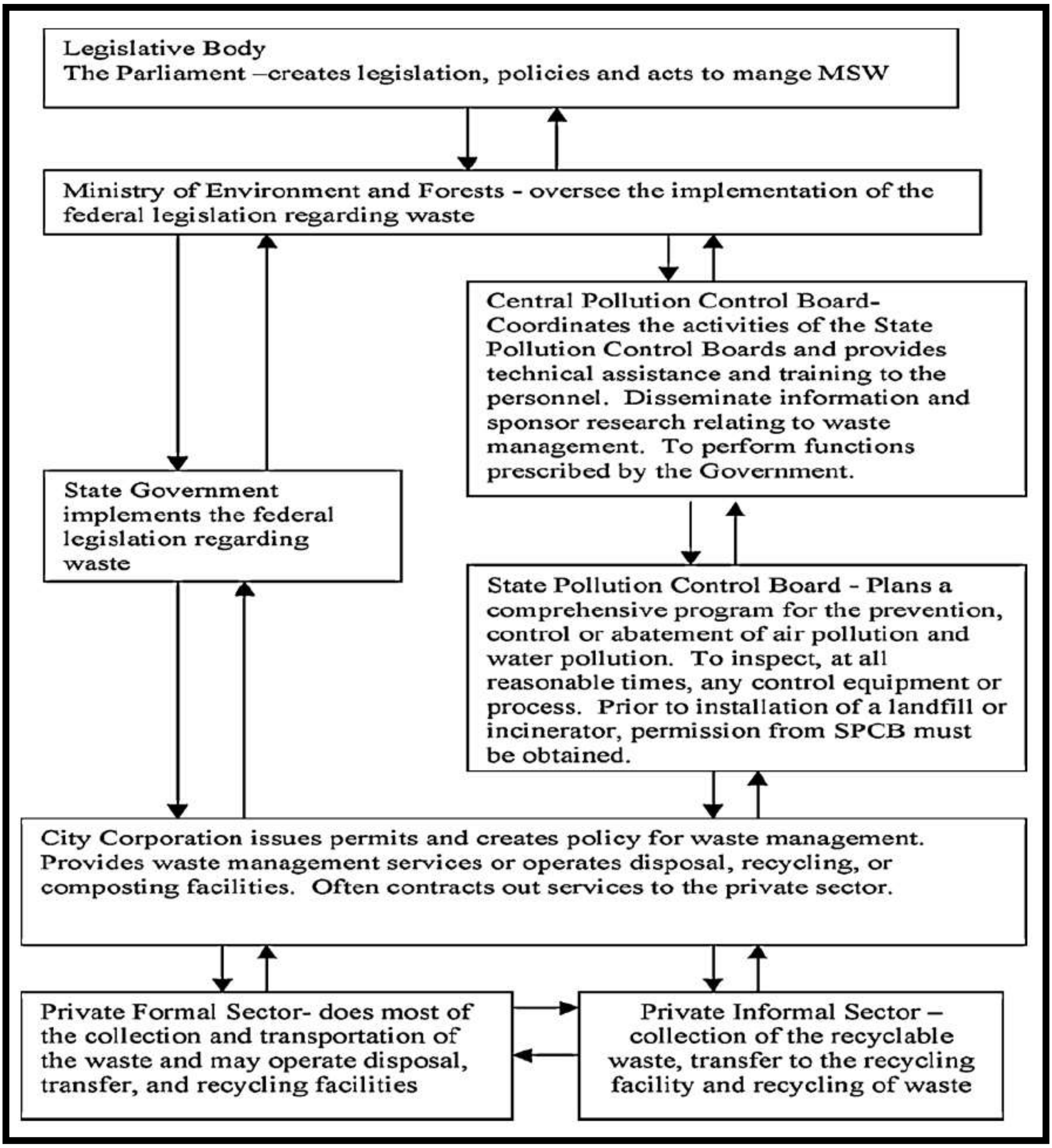

Figure 3 Municipal Solid Waste Management (MSWM) system in India [3]

Every day the work of the municipal field staff starts at 5:00 am with the sweeping and cleaning of the streets and pavements and is completed till 7:30 am. All the sand and garbage is collected in a small hand cart and is disposed of in the nearest reinforced cement concrete (RCC) bin or metallic container.

Figure 4 Greater Hyderabad Municipal Corporation (GHMC) Field staff sweeping roads

After cleaning roads and pavements field staff goes on to door-to-door collection of garbage from houses and commercial office buildings.

Figure 5 GHMC door-to-door waste collecting vehicle

This work is completed till 10:30 am and all the garbage is disposed into the nearest RCC bin or metallic container which is later emptied or picked up by the vehicle and transported to the nearest disposal ground if it is a metallic container. Large hotels, restaurants, shopping malls and theaters transport the waste by their own bins to the nearest dumping yard or to the nearest recycling unit facility (if available) as a free service. Organic waste from the vegetable market is dumped into the nearest bins by individual shop owners and the ground is cleaned by the municipal field staff daily and the fine earth and organic leftovers are dumped into the same nearest bins. Small scale industries and unauthorized road markets dispose their waste into the nearest RCC bin or metallic container and the leftovers are cleaned by the municipal field staff just like it is done at the vegetable markets [4] [8].

Figure 6 Greater Hyderabad Municipal Corporation's (GHMC's) Metallic Bin

1.3 MSW Disposal Scheme

The waste from the RCC bin or metallic container is collected into the garbage trucks and then the municipal waste is dumped in identified landfill or unidentified dump sites.

Figure 7 GHMC's MSW dumping truck

Some of the metallic containers are directly carried off and emptied at the dumping site itself [7]. Most of these dumping sites are usually at the low lying outskirt areas of the cities. As per (Sharholy, M. et al., 2008) the collection efficiency of MSW from Indian cities and states is about 70% [8]. Since these disposal sites are mostly in the low lying areas, whenever there is a downpour of rain some of the waste gets carried away by the water and wind to even further low lying area, polluting the land and water. Some of the waste is also carried over and spread by the birds and other wild animals further deteriorating the condition of surrounding areas. Only 10% – 30% of this waste goes for further treatment or reduction process and 70% - 90% of it remains at the unattended dumping site [3][9].Such unscientific dumping has resulted in heavy metals seep into the coastal waters as well. According to (Singh, R.P. et al., 2011) based on the MSW generation in 1997, the land required for the landfill by 2047 will be 1400 km^2.

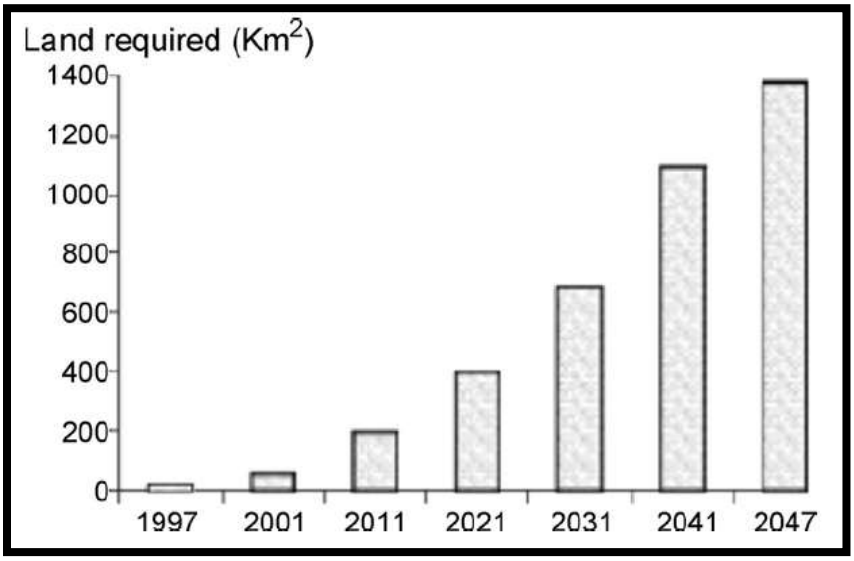

Figure 8: Cumulative of land required for MSW disposal [3]

The disposal grounds near most of the Indian cities are overflowing and need an urgent solution for this problem.

1.4 MSW Segregation

As most of the MSW, nearly 40% - 60%, is composed of organic matter [8], it starts decomposing releasing harmful and toxic gases into the atmosphere. In India the process of segregation of solid waste is not carried out in the homes or offices or by any agency, even though sometimes bins are provided by the municipal authorities for source segregation of waste.

Figure 9 Bins Provided by GHMC to every house

Only in some urban areas it is carried out by some companies and also by some Non-Governmental Organizations (NGO's) working for the cause of safe MSW disposal.

Figure 10 Separate slots for organic and recyclable waste in GHMC's door-to-door collection vehicle

Segregation is however carried out by the waste scavengers / rag pickers who collect plastics, glass, metals or any other recyclable material from the dumping yard and sell it to the dealers who then sell it to the recycling companies in bulk. In this way, the scavengers are unknowingly contributing to the environment by helping in the process of recycling lots of materials.

Figure 11 Rag pickers segregating the recyclable waste, Hyderabad, India

1.5 Problems Associated

Most of the Indian population lives in the rural areas, but as the industrial revolution gained its pace in India and as the population increased, people started migrating to the urban areas in search of jobs and better standards of living. This Industrial revolution in India was quick and the migration was rampant, which resulted in the urban areas becoming more densely populated. The per capita income of individual has also increased which has further increased the standard of living of people. But the infrastructure of the urban areas was not yet ready to sustain such a rapid increase in the urban population. When the industries, population and standard of living increased, the MSW generation also increased but the infrastructure to process the generated solid waste was not ready yet, which resulted in the buildup of heaps of MSW on the land.

The plastic in the MSW is carried away by the wind, water, animals and birds which end up in water bodies and water channels and resulting in blocking and choking of drains and also degrading the state of the waterbodies.

Figure 12 Water body near MSW dumping site in detreating condition, Hyderabad, India

The plastic waste does not decompose easily and it breaks down into micro plastics which affect the life of aquatic animals. It has been also observed that the cattle grazing at the landfills or near the dump yards consumes the plastic materials and suffers serious health impacts. This decomposition of garbage at the landfill releases Methane (CH_4) gas, which is, apart from carbon dioxide, the largest contributor of the greenhouse gases [4]. According to (Singh, R.P. et al., 2011), approximate emission of Methane (CH_4) by the MSW all over India in the year 2001 was

4612.69 MT d^{-1}, as calculated by National Solid Waste Association Of India (NSWAI) [3]. The conditions at the dumping yard also takes a toll on the health of the rag pickers because of the release of harmful gases by decomposing matter and also by medical waste, which is often, ends up mixed with other MSW. As also mentioned by (Singh, R.P. et al., 2011), “Infectious waste from the hospitals normally finds its way to the disposal site” [3]. Currently the landfills or dumping yards in India are out of their capacity and are overflowing, forcing the authorities to burn the waste directly on the ground to make space for the coming lots. This practice is resulting in the release of high polluting gases into the atmosphere which include pollutants like Carbon Monoxide (CO), Sulfur Dioxide (SO2), Hydrocarbons (HC), Particulate Matter (PM) and Nitrogen Oxides (NOx) plus an estimated 10,000 toxic equivalency factor (TEQ) grams of dioxins/furans. As the burning of the waste occurs at the ground level, the smoke originating from it causes grave air quality in the locality nearby.

Figure 13 Solid waste being burnet near the locality metallic bin, Hyderabad, India

It is very difficult to get a land for dumping MSW in India near the urban centers. Therefore, most of the dumping grounds are located at the outskirts of the cities, which add to the transportation cost of the MSW. This reduces the budget which can be spent on the disposal of the MSW. As found out in the study of MSW management in Kolkata in India by (Chattopadhyay, S. et al., 2009), 70-75% of the total budget of municipality for MSW management is spent on the collection of solid waste, 25-30% of the total available budget is spent on the transportation of the MSW, and at the end only 5% of the budget is left for the disposal arrangement. With lacking infrastructure and unavailability of funds and huge generation of waste by the rapidly increasing population and standard of living, Indian cities are left with only one option which is the cheapest of all and that is unscientific landfilling and burning the waste to ground.

But with growing global temperatures, pollution levels and the urge of India to become an active player in the sustainable development, there is pressure on the government to lead the country towards sustainable developments, including sustainable treatment of the MSW.

1.6 Treatment

There are many ways to treat the MSW such anaerobic digestion (Biomethanation), Pyrolysis, Incineration, Refuse derived fuel (RDF), Gasification, Landfilling, Composting and Vermicomposting, and some of them are even implemented in India. But the feasibility of the process depends on factors such as composition of waste and climatic conditions. As mentioned earlier MSW in India contains around 50% biodegradable waste such as food leftovers, which makes it unfeasible for incineration. According to (Chattopadhyay, S. et al., 2009), the MSW from Indian cities has low energy value of 3,350-4,200 kJ kg^{-1}, with high moisture content and the inert content is also high. Of the two leading mechanisms of waste disposal adopted by the India are Aerobic composting and Vermicomposting. Waste-to-energy (WTE) plants which are adopted by the India are Incineration, Palletization, Biomethanation and gasification. However, as the infrastructure is not yet matured and fully developed, most of the waste is still going on the landfills. Below, some of the most relevant waste-to-energy technologies are described.

1.6.1 Biochemical conversion

This process uses enzymes of bacteria and other microorganisms to breakdown organic matter. Biochemical conversion includes processes like anaerobic digestion, anaerobic composting and Biomethanation.

Figure 14Biomethanation plant in Chennai, India [12]

Biochemical processes are some of the processes which provide environment friendly procedures to treat organic fraction of waste and convert it into biogas and compost in the form of liquid residual. Biogas can be used to generate power or can also be used as fuel. The liquid residual is used as fertilizer. Biochemical processes require feedstock to be source separated or the segregation of organic waste is needed before it can be introduced into the process chambers, as certain contaminants in the feed can upset the process. Lack of source separation in India makes it difficult for large scale biochemical processes to be feasible. And the inorganic content in the waste has to be treated by incineration or gasification whatsoever.

1.6.2 Incineration

Incineration is the process in which the organic waste is thermally treated by combustion to convert it into ash, flue gas and heat. The operating temperature of the incineration reactor is between 750 – 1000 $^{\circ}$C. Incineration process is capable of reducing the mass of the waste by over 70% and its volume by around 90% [3]. The sterile ash is mainly due to the presence of inorganics in the waste, which cannot be combusted but can be used in the construction industry. The heat gained in the process can be utilized to generate electricity and also for district heating applications. As said earlier the methane gas emitted by the decomposing organic waste is a major contributor to the global warming and incineration is one of the best ways to eliminate the methane gas emission. Waste incineration is one of the methods which can be considered as the substitute for fossil fuel combustion. Waste incineration is suitable, where landfilling is not an option or very far away from the waste generating place which increases the transportation cost in waste management. Incineration plant needs very expensive machinery and skilled people to operate it, making the waste management process by incineration quiet expensive [13]. For the incineration process to be feasible and efficient, the quality of the waste is an important criterion. The moisture content in the waste should be small and the calorific value of the waste should be high.

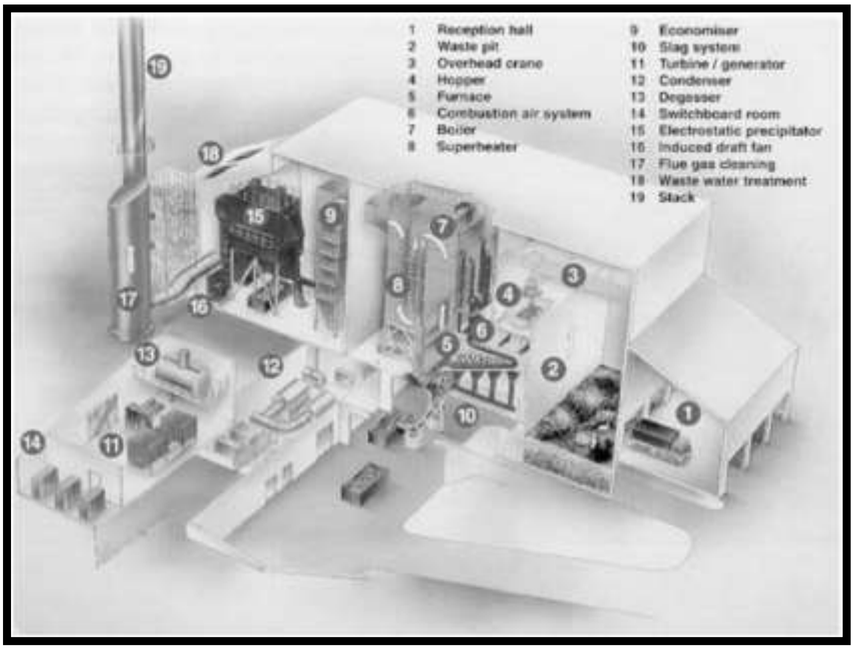

Figure 15 Exploded view of Incineration Plant [24]

The first incineration plant in India was at Timarpur, New Delhi in 1987 by Ministry Of New And Renewable Energy (MNES) but it failed and was shut down after six months of operation because the MSW in India has high moisture content in it with a low energy value of around 3.35 - 4.2 MJ kg^{-1},where the required for incineration is around 7 MJ kg^{-1} and the energy value of the MSW shall never fall below 6 MJ kg^{-1} if the incineration is considered [13], so the project was no longer feasible. And there were also concerns with the emitted pollutants from incineration plants so there was a lot of opposition from the local population. However, at present WTE plants in different Indian cities such as are being tested on their feasibility, but their performance is rather poor [3].

1.6.3 Refuse Derived Fuel (RDF)

The purpose of the waste to RDF facilities is to produce improved solid fuel or pellets from waste which can be used for energy production by thermal combustion of RDF or as a cheap and efficient fuel in Industries and it can also be fired along with the conventional fuels such as coal. RDF facilities can relieve the pressure on the landfills [8]. But operation of such thermal treatment systems involves higher cost and expertise [9]. High metal concentration in the RDF is a major problem which is encountered, which makes it essential to pretreat the waste. The RDF generation involves dehydration, shredding and palletization, which require a separate site, increasing the operational cost of the RDF facility.

Figure 16 RDF machinery [12]

India has experience with the RDF facilities, like the RDF facility installed in Hyderabad, Jaipur, Rajkot, Vijayawada and Chandigarh. All these five facilities experienced severe problems and public opposition which resulted in the closure of these facilities. But nevertheless, attempts to setup RDF plants in India are still going on. And there are already some other RDF plants which are in operation.

1.6.3 Pyrolysis

Pyrolysis is an innovative technology which thermally degrades the MSW in absence of oxygen and the output of this procedure comes in the form of charcoal, liquid and gaseous products, which can be further utilized. This process generally requires pretreatment of MSW [17]. There are many advantages from pyrolysis process such as significant reduction in volume of the waste (50-90%). Once the process is started it is self-sustaining. According to (Potdar, A. et al., 2015), fast pyrolysis of MSW not only decreases the requirement of landfills but also decreases the risk of environmental pollution. But several hundreds of compounds are produced during MSW pyrolysis and many of them are not yet identified. It is important to identify and study almost of those compounds before naming MSW pyrolysis as sustainable [17].

1.6.4 Gasification

Gasification is a process in which the feedstock is partially combusted in a closed reactor to produce gas and char at the first stage and subsequent reduction of the product gases, chiefly CO_2 and H_2O by charcoal into CO and H_2. Gasification is one of the best alternatives for WTE treatments, especially if the dramatic reduction in the volume of the waste is required [9]. Depending upon the reactor technology used and composition of waste, gasification can reduce the volume of waste by over 95% even without any pretreatment of the waste [10]. Basically gasification is a thermochemical conversion of solid or liquid carbon based waste into combustible gases by the supply of gasification agent such as steam, air or oxygen. A gasification system is the combination of three fundamental elements such as: (1) The gasifier (2) The gas cleanup system (3) The energy recovery system. So gasification of MSW provides a future alternative to waste incineration as the flue gas cleanup is less intense in gasification process and CO2 emissions are also lower than produced by incinerator plants and dramatic reduction in the volume of MSW [10].

1.7 Municipal solid waste-to-energy potential in India

Generation of municipal waste in the rural parts of India is not so significant and the quantitative data of this generation is not available hence the quantitative data of only urban India is considered. As mentioned earlier the urban population of India generated 114,576t d^{-1} of MSW in the year 1996 and is predicted to generate around 440,460t d^{-1} of MSW by 2026 [3]. As 70-90% of it remains at the disposal site unattended due to lack of Infrastructure for treatment, it will be emitting a huge amount of methane gas (CH_4) which is a great threat for the environment as it is escaping into the atmosphere. However, if trapped and utilized properly methane has a very good WTE or WTP conversion potential. But the disposal at the landfills in India is unsymmetrical and random, hence trapping it and channeling it for utilization is impossible [3]. The only way to stop it is by introducing the WTE or WTP plants. The 10 major cities in India produced around 10 Mt of municipal solid waste annually as per 1991 census. This amount of waste has the 4612.69 Mt d^{-1} of CH_4 emission capability. As mentioned by (Singh, R.P. et al., 2011), about the feasibility study conducted by Indira Gandhi Institute of Development Research (IGIDR) in the Mumbai city found that for the population of around 10 million producing 1.82 MT of MSW per year has the net CH_4 producing capacity of around 8.5 GJ [3]. The main advantage of introducing a WTE plant is that it can reduce the volume of waste by 60 – 90% and hence cutting the need of landfills, which in turn cuts not only CH_4 emissions but also helping in less maintenance cost of the nearby areas and also decreasing the cost of transportation of MSW besides generating electricity. The 11th Planning commission estimated the MSW to energy potential from urban cities in India as follows in Table 1below:

Period	Projected MSW generation (TPD)	Potential for power generation (MWe)
2007	148,000	2550
2012	215,000	3650
2017	304,000	5200

Table 1: Potential power estimation from MSW generated by the urban cities in India [3]

Telangana is one of the major states in Southern India with a population of 35.19 million by 2011 Census. The capital city Hyderabad has a population of around 3.637 million according to 2001 Census. The quantity and quality of the waste generated by the Hyderabad city is shown in the Table 2 below:

	Physical characteristics (in % composition)					
Total MSW (T/day)	**Biodegradable / Compostable**	**Recyclables**	**Inert, ash, debris**	**Calorific value (kcal/kg)**	**C/N Ratio**	**Moisture (%)**
2187	40	10	50	1969	25.9	46

Table 2: Quantity and quality of MSW generated by Hyderabad city [3]

The MSW and Energy generation in Andhra Pradesh (before the division of state) is given in the Table 3 below:

State/ Union Territory	**Total MSW (T/day) (2011)p**	**Total MSE(T/day) (2015)p**	**Total MSW (T/day) (2020)p**	**Energy Potential 2011 (p) (MW)**	**Energy Potential 2015 (p) (MW)**	**Energy Potential 2020 (p) (MW)**
Andhra Pradesh	9998.97	10344.37	10732.24	198.98	205.85	224.30

Table 3: MSW and Energy generation in Andhra Pradesh over the years [3]

The MSW and energy generation table above is from the data collected by National Environmental Engineering Research Institute (NEERI), National Solid Waste Association of India (NSWAI) and Census, 2011 collected by (Singh, R.P. et al., 2011). The data shows significant power generation capacity available by waste. Based on the similar data from all over India, (Singh, R.P. et al., 2011) has calculated the generation potential by the available technologies, as shown in the Table 4 below:

S.No.	Technology	MSW (TPD)	Energy generating potential (MW)
1	Biomethanation	100	1.9
2	Incineration	100	1.2
3	RDF	100	3
4	Gasification and Pyrolysis	100	2
5	Plasma Arc Gasification	100	4.5

Table 4: Power generation capacity by different technologies [3]

The data above shows the Plasma gasification technology has the best generating capacity for 100 tons of waste per day.

The URS Corporation, U.S has determined the thermal efficiencies for each technologies used for the WTE process. The thermal efficiencies are as shown in Table 5 below:

Type of Thermal Process Technology	Net energy production to grid	Net energy capacity to grid (calculated)
Incineration	544 kWh/ton MSW	2.267 MW / 100 ton MSW
Pyrolysis	571 kWh/ton MSW	2.379 MW / 100 ton MSW
Conventional Gasification	685 kWh/ton MSW	2.854 MW / 100 ton MSW
Plasma Arc Gasification	816 kWh/ton MSW	3.40 MW / 100 ton MSW

Table 5: Thermal process technologies and net energy to the grid [3]

(Singh, R.P. et al., 2011), has estimated a potential of over 3000 MW from MSW by 2020 in India. The prediction scenarios of different technologies are shown in the Table 6 below:

Scenario for 2011 & 2015	50% Bio + 20% Mass burn + 20% RDF + 5% from Gasification + 5% Pyrolysis
Scenario for 2020	35% Bio + 25% Mass burn + 20% RDF + 8% Gasification + 7% Pyrolysis + 5% Plasma Arc Gasification

Table 6: Prediction of combination of technologies for WTE generation [3]

The present plants and future predictions show a great potential to generate power from MSW.

1.8 Objective

The aim of this master's thesis is to find out the cost and the bureaucratic procedures to setup a 1MW Gasification plant in India. This thesis will also include the feasibility comparisons between the two prominent technologies used in WTE power plants. At the end following will be discussed:

a) Suitable technology for WTE conversion in Indian scenario.
b) Capital cost to setup a WTE plant in India.
c) Comments on the Licenses and approvals needed from the government of India and State government of Telangana.

1.9 Expected result from the study

The study will result in an information and analysis report on the WTE prospects in India and will discuss the reasons for failure of MSW management systems. Suitable technology for WTE conversion will be suggested at the end.

1.10 Methodology

This project is a literature study targeting a feasibility analysis of MSW gasification plant in an Indian scenario. Lot of scientific articles were collected and studied, to come up with a technical, economical and legal feasibility study. The procedure to setup such plants was also studied and summarized in this project.

2. Gasification

This data is combinedly collected by literature study of various sources [14], [15], [16], [17], [18], [19], [23].

Gasification is a thermochemical process which involves the reaction of carbon-containing feedstock material with a reagent containing oxygen. The reagent is usually oxygen, air, steam or carbon dioxide. This reaction usually takes place in temperatures in excess of 800 ˚C to 5000 ˚C. The temperature buildup depends on the technology used.

The gasification process involves partial oxidation of the feedstock which implies that the oxygen is added to the process as said earlier, but the amount of oxygen added is not enough to allow the complete oxidation or full combustion of the feedstock in the gasifier chamber. The gasification process is an exothermic process, but some heat is still required to initiate and sustain the gasification process. The feedstock is heated to high temperatures, producing gases which undergo chemical reactions to form a synthesis gas.

The synthesis gas or syngas is a mixture of hydrogen, carbon monoxide and methane with a calorific value of about 4-10 MJ / Nm^3. This syngas can be utilized to generate power, to produce a range of chemicals or to make liquid or gaseous transport fluid.

The byproduct of the gasification process is solid char and ash. Solid char can further react, when the gasifier's temperature is high enough and further breakdown into smaller particles resulting in even lesser remnants. Ash is noncombustible material with low carbon value. It can be utilized to make Eco bricks or can be disposed of onto the landfills.

Gasification process consists of the following thermochemical steps:

1) **Drying**: It usually occurs at about 100 ˚C, at this stage the feedstock is generally drained out of moisture content in it.

2) **Pyrolysis:** Subjecting the feedstock to heat in absence of air, to break it down to charcoal, liquid and various tar gases is known as pyrolysis. It is actually the process of charring.

When the temperature in the gasifier furnace reaches above 240 °C the feedstock begins to decompose quickly and breakdown into a combination of solid, liquid and gases. The solid which remained is charcoal and the liquid and gases which remained are called tars.

When the pyrolysis process is at beginning stage at lower temperatures some gases and liquids are produced. These liquids and gases are fragments of the feedstock that breaks off with heat. These fragments of the feedstock are molecules of hydrogen (H), carbon (C) and oxygen (O) which are collectively known as volatiles. These volatiles are highly reactive in nature. Or to put in another words less strongly bonded with the feedstock than the fixed carbon. These volatiles in the feedstock are evaporated into tar gases and the fixed carbon to carbon molecules remain. These carbon to carbon molecules are known as charcoal.

3) **Controlled combustion and cracking:** Cracking is the process in which the larger tar molecules are broken down into the smaller ones (lighter gases), by exposing them to heat. Cracking is an important process to produce clean gas. This clean gas is compatible with an internal combustion engine, as opposed to the tar gases which, when they start condensing, condense into a sticky tar which will rapidly foul the valves of the engine.

Cracking is a necessary process, as it ensures proper combustion – complete combustion only takes place when the combustible gases get thoroughly mixed with oxygen.

When the combustion process is undergoing, the high temperatures in the gasifier furnace makes sure the larger tar molecules which pass through the combustion zone gets decomposed.

5) **Reduction:** Reduction of oxygen atoms off combustion products of hydrocarbon (HC) molecules, so as to return the molecules to forms, which can burn again. We can say reduction is the reverse process of combustion.

Combustion is when the combustible gases mix with oxygen to release heat and produce water vapor (H_2O) and carbon dioxide (CO_2) as byproducts. Whereas reduction is the process in which the oxygen (O) is removed from these byproducts at high temperatures to produce combustible gases. One can say that the combustion and reduction are equal and opposite reactions.

Reduction in a gasifier furnace is achieved by passing carbon dioxide (CO_2) and water vapor (H_2O) over a bed of red hot charcoal (C).

The carbon in the hot charcoal is extremely reactive with oxygen; it has so high affinity with oxygen that it strips the oxygen (O) off carbon dioxide (CO_2) and water vapor (H_2O) and redistributes it to as many single bond sites as possible.

The oxygen molecule is more likely to bond with the carbon than to itself. Hence no free oxygen molecule can survive in its usual diatomic O_2 form. All the available oxygen (O) will readily bond with the available (C) sites as individual (O) until all the oxygen is bonded. When all the available oxygen is redistributed as a single atom, reduction process stops.

Through this process, the carbon dioxide (CO_2) is reduced by carbon (C) to produce two carbon monoxide (CO) molecules and water vapor (H_2O) is reduced by carbon to produce hydrogen (H_2) and carbon monoxide (CO). Both hydrogen and carbon monoxide are desirable combustible fuel gases. The H_2 and CO can be piped to the desired location. This mixture of H_2 & CO is called synthesis gas or syngas.

N°	Reaction name	Chemical reaction	Reaction enthalpy ΔH [1]
(1)	$C_nH_mO_k$ partial oxidation	$C_nH_m + {}^{n}/_{2}\,O_2 \leftrightarrow {}^{m}/_{2}\,H_2 + n\,CO$	Exothermic
(2)	Steam reforming	$C_nH_m + n\,H_2O \leftrightarrow (n + {}^{m}/_{2})\,H_2 + n\,CO$	Endothermic
(3)	Dry reforming	$C_nH_m + n\,CO_2 \leftrightarrow {}^{m}/_{2}\,H_2 + 2n\,CO$	Endothermic
(4)	Carbon oxidation	$C + O_2 \rightarrow CO_2$	$-393.65\ kJ.mol^{-1}$
(5)	Carbon Partial oxidation	$C + \frac{1}{2}\,O_2 \rightarrow CO$	$-110.56\ kJ.mol^{-1}$
(6)	Water-gas reaction	$C + H_2O \leftrightarrow CO + H_2$	$+131.2\ kJ.mol^{-1}$
(7)	Boudouard reaction	$C + CO_2 \leftrightarrow 2\,CO$	$+172.52\ kJ.mol^{-1}$
(8)	Hydrogasification	$C + 2\,H_2 \leftrightarrow CH_4$	$-74.87\ kJ.mol^{-1}$
(9)	Carbon monoxide oxidation	$CO + \frac{1}{2}\,O_2 \rightarrow CO_2$	$-283.01\ kJ.mol^{-1}$
(10)	Hydrogen oxidation	$H_2 + \frac{1}{2}\,O_2 \rightarrow H_2O$	$-241.09\ kJ.mol^{-1}$
(11)	Water-gas shift reaction	$CO + H_2O \leftrightarrow CO_2 + H_2$	$-41.18\ kJ.mol^{-1}$
(12)	Methanation	$CO + 3\,H_2 \leftrightarrow CH_4 + H_2O$	$-206.23\ kJ.mol^{-1}$

[1] T = 298 K, P = 1.013 10^5 Pa, carbon as solid and water in vapor form

Figure 17 Main chemical reactions of Gasification [19]

2.1 Types of gasification technologies available

There are several different types of gasification technologies that have been demonstrated or developed. The selection of the gasifier type depends in a multitude of factors, such as:

a) Feedstock type
b) Feedstock quality
c) Feedstock availability
d) Capacity of plant
e) Gas quality conditions

Since there is an interaction between gasifying agent and feedstock in the gasifier furnace, they are classified according to the way air or oxygen is injected into the gasifier furnace. The principle types of gasifiers are:

A. Fixed bed gasifier
   a) Updraft fixed bed gasifier
   b) Downdraft fixed bed gasifier
B. Entrained flow
C. Fluidized bed gasifier
   a) Bubbling fluidized bed gasifier
   b) Circulating fluidized bed gasifier
D. Plasma gasifier

A) **Fixed bed gasifier**: It is the simplest type of gasifier consisting of a usually cylindrical furnace for fuel and gasifying media. In the fixed bed gasifier the fuel moves slowly downwards into the reactor as the gasification process occurs. The fixed bed gasifier has a bed of solid fuel through which the gasifying media or gas moves in either up or down direction. The two primary types of fixed bed gasifiers are updraft gasifier and downdraft gasifier

a. Updraft fixed bed gasifier: The feedstock is dumped into the gasifier furnace from the top and steam, air or oxygen is supplied from the bottom of the furnace, making feedstock and gasifying agent to travel in opposite directions with respect to each other. As the feedstock travels downwards through the vessel it dries, pyrolyzes, gasifies, combusts and finally the residual ash or slag is all what remains, which is collected from the bottom. Some of the char also burns up providing some heat for the process. The syngas gas leaves the gasifier from the top at relatively low temperature. The process has high thermal efficiency and as a result MSW containing moisture around 50% can be gasified without any need of pre-drying it. But the tar content in the syngas produced is around 10-20%, making it infeasible to use for electricity production [19].

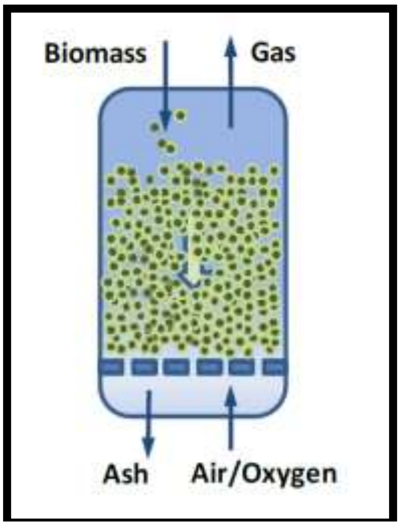

Figure 18 Updraft Fixed bed gasifier [15]

b. **Downdraft fixed bed gasifier**: In downdraft gasifier the feedstock is introduced from the top, like in updraft gasifier and the gasifying agent which is either steam, air or oxygen is introduced from the middle or top of the furnace. The feedstock and the gasifying agent both flows in the same direction i.e. downwards, hence it got the name co-current configuration. The gasifying agent and the feedstock enters the reaction zone from above and travels down, decomposing the combustion gases and burning most of the tars all along. The syngas is piped out from just above the ash collecting chamber at the bottom of the gasifier furnace. As the downdraft furnace generally produces low particulates and tar levels which is around 0.1% [19], it is well suited for small scale energy applications 80-500 kWe [19]. Downdraft gasifier is not well suited for waste treatment as it typically requires a low ash fuel such as wood to avoid clogging and also the residence time of fuel in the reactor of about 1-3 hours ads to its disadvantage [19].

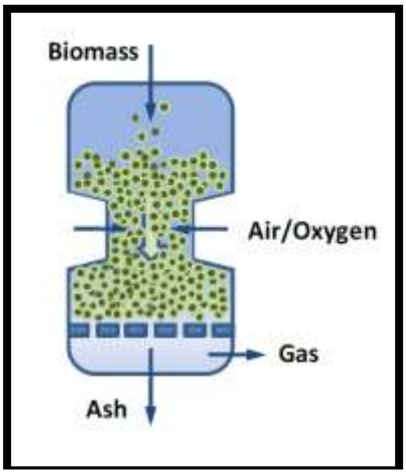

Figure 19 Downdraft fixed bed gasifier [15]

B. Entrained flow gasifier: In entrained flow gasifier the powdered feedstock is introduced into the gasifier furnace form the top and pressurized steam, air or oxygen is also introduced into the furnace from the top. Flame from the top of the furnace provides major share of the heat and burns some of the feedstock at temperature (1200-1500 ˚C), enabling fast conversion of feedstock into high quality syngas. Ash melts into the gasifier furnace walls and gets discharged as a molten slag.

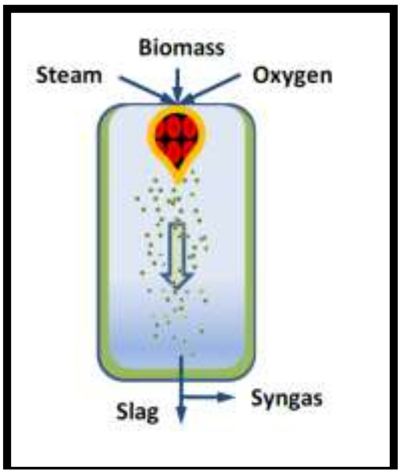

Figure 20 Entrained flow gasifier [15]

C. Fluidized bed gasifier: In a fluidized bed reactor, steam, air or oxygen is forced in upward through a bed of solid feedstock. By the introduction of forced gasifying agent from below the reactor the solid fuel exhibits a fluid like behavior, hence the name fluidized bed reactor. The gasifying agent acts as the fluidizing medium and also contributes the oxidant for combustion and tar cracking. The feedstock is introduced from the top of the reactor or into the bed through an auger. The fluidized beds have extremely good mixing and high heat transfer capability, eventually resulting in very uniform bed conditions and efficient reactions and ease of temperature control gives an advantage to use the fluidized bed over fixed bed gasifiers. The fluidized bed gasifiers enable an excellent gas-particle contact (L.M. Armstrong, 2011). The tar content in the syngas produced by this method is between 1-5% [19]. These gasifiers are suitable for many kinds of feedstock. Because of the low operation temperature (700-900˚C), the bed ash in the gasifier does not form an agglomeration, making ash removal simple and affordable.

Types of fluidized bed gasifiers:

a. **Bubbling Fluidized bed gasifier (BFB)**: Fine and even particles of the feedstock are fed into the bubbling gasifier from the side of the reactor. Pressurized gasifying agent such as steam, air or oxygen is forced into the reactor from the bottom at a constant rate (1-3 m/s) to constantly agitate the feedstock. The bubbling fluidized bed gasifier comes with a cylindrical or rectangular shaped reactor so that the contacts between the gas and the solid feedstock facilitates in drying and size reduction of the constantly introduced feedstock particles and also aids with the pyrolytical vaporization of the organic material and its partial combustion in the bed. Ultimately the syngas is collected from the top of the reactor. The reactor operates at or below 900 ˚C to avoid ash melting and sticking.

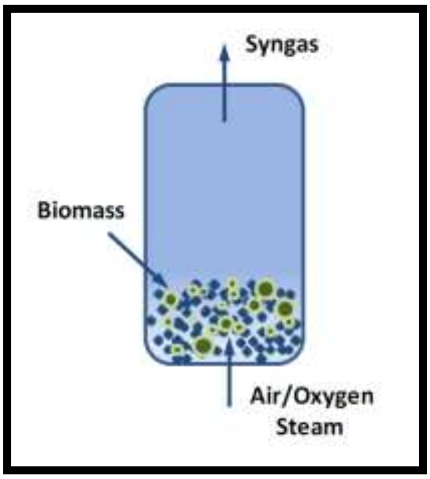

Figure 21 Bubbling fluidized bed gasifier [15]

b. **Circulating fluidized bed (CFB):** Pressurized gasifying agent (5-10 m/s) is forced into the reactor from the bottom, to suspend the feedstock material throughout the gasifier. Crushed feedstock is introduced into the gasifier from the side of the gasifier. The circulating fluidized gasifier operates at much higher gas velocities than that of the minimum fluidization point which results in the entrainment of the particles in the gas stream. These entrained particles in the gas stream that reach the top of the reactor get caught in the cyclone and are again returned into the reactor bed. Syngas is piped out from the top of the cyclone. Same as the other fluidized bed gasifiers, this gasifier as well operates at temperatures below 900 ˚C to avoid ash melting and sticking to the reactor walls. The major advantage of using this gasifier is that various types of feedstocks with varying compositions and moisture contents can be introduced into the gasifier.

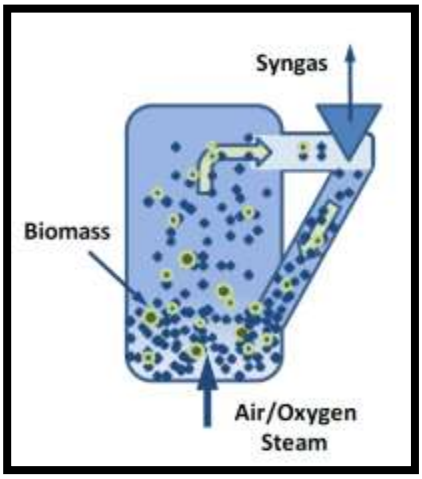

Figure 22 Circulating fluidized bed gasifier [15]

D. Plasma Gasification (PGP): In Plasma gasification untreated feedstock is introduced into the reactor containing electrically energized plasma torches which can generate temperatures up to 1500-5000 ˚C. The feedstock is subjected to oxygen starved environment where at high temperature it is decomposed into its basic molecular structure. The constant supply of electricity to the plasma torch ensures the extremely intense energy inside the reactor, powerful enough to disintegrate the feedstock into its component elements. The extreme high temperatures in the reactor produce very high quality syngas. The byproducts of the plasma gasification process are a glass like substance used in construction industry, as a raw material for asphalt or as homemade tiles. The metals in the feedstock become molten and inorganic materials such as silica, soil; concrete, glass etc. are vitrified and flown out of the reactor. There are no tars or ash formed as the byproduct which needs to be carried to the landfill after the gasification process.

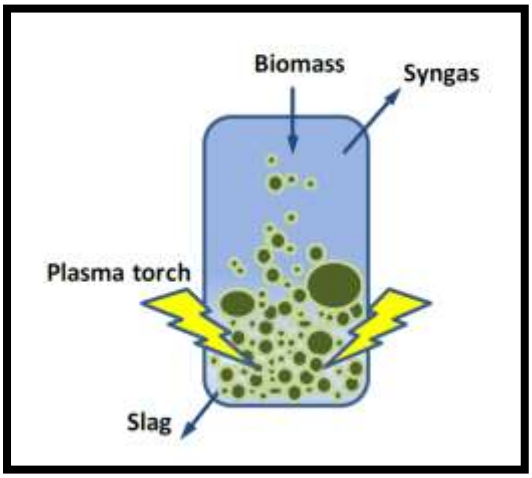

Figure 23 Plasma Arc gasifier [15]

2.2 Comparison among technologies

Description	Downdraft Fixed Bed	Updraft Fixed Bed	Entrained Flow	Bubbling Fluidized bed	Circulating Fluidized Bed	Plasma Gasification
Fuel requirements Particle size	Waste particle diameter up to 100 mm. Due to poor temperature control, there is risk of sintering.		Fine fuel particles (smaller than 1mm) are added to water to produce slurry (with solid concentration >60%) that is fed to the gasifier	Waste particles must not be larger than 150mm. Bed particle diameter is between 0.08 to 3mm. Attrition of bed particles (and their entrainment) may be severe.	Waste particles must not be larger than 150mm. Bed particle diameter is between 0.05 to 0.5mm	No Problem for size
Morphology	Uniform	Almost uniform	Uniform	Uniform	Uniform	No Problem
Moisture content	<20%	<50%	<15%	<55%	<55%	No Problem
Ash content	<5% db	<15% db	<20% db	<25% db	<25% db	No Problem
Ash melting point	>1250 °C	>1000 °C	<1250 °C	>1000 °C	>1000 °C	No Problem
Bulk density	>500 kg/m^3	>400 kg/m^3	>400 kg/m^3	>100 kg/m^3	>100 kg/m^3	>100 kg/m^3
Temperature profile	Large temperature gradients can occur. Frequent presence of hot spots	Large temperature gradients can occur. Frequent presence of hot spots. Relatively low gas exit temperatures.	The range is 1200-1500 °C, anyway above the ash melting temperature	Temperature is almost constant in vertical direction. Very small variation in radial direction. The range is 550–1000 °C	Small temperature gradients in the direction of solids flow can be limited by high solid flow rate circulation. The range is 900–1000 °C	Defined by the specific process, but usually very high, typically between 1,500 and 5,500 °C

Heat exchange and typical suspension to surface heat transfer coeff. (W/m2K)	Inefficient exchange. Necessity of large surface of heat exchanger. (20-100)		Poor exchange (dominated by radiation)	Very efficient exchange. Large heat transfer activated by solids circulation. (200-700)	Efficient exchange, particularly along longitudinal direction. (100-350)	Very high temperatures imply that heat exchange is dominated by radiation
Residence time	Particles stay in the bed until their discharge		Very short (few seconds)	Particles spend substantial time (minutes or hours) in the bed. Gas residence time depends on gas velocity that is below 2 m/s	Particles pass repeatedly trough the circulation loop: residence time for each circuit is few seconds. Gas velocity is from 3 to 15 m/s	–
Conversion	Very high conversion is possible with gas plug flow and adequate temperature control	High gasification efficiency	–	Mixing of solids and gas bypassing can determine performance poorer than that of other reactors	High conversion is possible	Conversion can be as high as 100%
Process flexibility	Very limited. Any change in process variables often needs a new reactor design		Very limited. Size and energy content of the waste must be in a narrow range. Pretreatment steps are usually adopted	Excellent. It can be used for low- and high-temperature pyrolysis and gasification, in presence or not of a catalyst. Different solid wastes can be treated	Excellent. Different gasifying agents can be add at different heights of the riser	Excellent

Scale-up problems	Can be scaled, taking carefully into account the temperature control.	The long design and operating experience in coal gasification processes allows very large gasifiers	They must be carefully considered. A pilot plant is often necessary	Some large projects are planned	The technology is offered in small scale identical modules. So there are no scale-up risks
Costs	The major advantage is the reactor simplicity and the relatively limited investment costs.	Very high investment and operating costs that impose large scale gasification plants.	Moderate. The possibility of small-scale plants makes wider the investment alternatives. Low costs of maintenance.	Capital costs higher than those for BFB. Generally convenient for large-scale plants.	Very high cost of investments and high operating cost. Electric energy consumptions can be relevant

Table 7 Comparison among different technologies [16]

2.3 Selection and Comparison

As described earlier in this report the major problems with the MSW in India are high moisture content, un-segregated waste (MSW, Medical waste and Hazardous waste), and high inert content in MSW (≈30%). All this makes the processing of MSW a challenge. Availability of efficient and sustainable technology is needed to safely process the Indian MSW and transform it into WTE or WTP (Waste to Product). As per many studies on MSW gasification among all gasifier technologies, circulating fluidized bed and plasma gasification are best for WTE conversion of MSW. Circulating fluidized bed is considered to have a best vessel design for MSW gasification and has the capability to process different types of feedstock with varying composition and moisture content [18].CFB is a proven technology especially in China where it is converting RDF into electricity. Plasma gasification is considered to be one of the best methods to obtain superior syngas by gasifying MSW without any need of pre segregation. And the byproduct of the process is vitrified slag which is used in construction industry [14]. So we'll perform feasibility study on both these technologies and suggest a best among them.

2.4 Technical Feasibility

Technical Feasibility with constant TPD			
Description	**Plasma Arc gasifier**	**CFB Gasifier**	
Fuel Acceptance	Any kind of waste, no preprocessing needed, no shredding needed	Heavy metal segregation needed, shredding needed	[15], [16],[17]
Conversion capacity	As high as 100%	High conversion up to 95%	[16], [10]
Power generation Capacity (MW/ton)	1MW/22.22 TPD	444.4 kW/22.22 TPD	[5], [20]
Level of Automation	High	Moderate	[5]
Plant Load Factor PLF (%)	90	90	[5]
Land Requirement (acres)	1.088/ MW	10/MW	[5]
Byproducts	Vitrified slag	ash, slag	[15], [16],[17]
Disposal at landfill needed	No	Yes	[15], [16],[17]
Dedicated waste pretreatment needed	No	Yes	[15], [16],[17]

Table 8 Technical Feasibility

2.5 Economic Feasibility

Economic feasibility			
Description	**Plasma Arc Gasifier**	**CFB Gasifier**	
Capital cost in million INR/ MW	82,3	10	[5]
Cost of power generation (INR/kWh)	4,11	3,5 (Assumed)	[5]
Unit rate in Telangana (INR/1 kWh)	6.15/Unit	6.15/Unit	[26]
Net power supplied to the grid (kWh/year)	7884000	3503965	Calculated
Money earned by power sale per year in million (INR)	23284176	2577917	Calculated
Payback period	4	4	Calculated
* Assumed 50% as maintenance charges from the amount left after deducting generation cost. * Calculation table in Appendix			

Table 9 Economic Feasibility

2.6 Legal Feasibility

Legal Feasibility					
Description	**Plasma Arc gasifier**	**Conventional Gasification**	**Open burning**	**Emission standards for waste incineration in India**	*All values in [mg/m³]
Particular Matter (PM)	12,8	8,2	50	50	[25], [14],[11]
Hydrochloric acid (HCL)	3,1	<1	16,17	50	[25], [14],[11]
Nitrous oxides (NO_x)	150	-	2,25	400	[25], [14],[11]
Sulphur oxide (SO_x)	26	15	0,375	200	[25], [14],[11]
Mercury (Hg)	0,0002	0,0006	-	0,05	[25], [14],[11]
Dioxins/furans (ng/N-M^3)	0,00925	0,01	27,77	0,1	[25], [14],[11]
* " - " Data not available					

Table 10 Legal Feasibility

2.7 Bureaucratic Procedures

The following data is collected from [12], [23], [25], [26], and [27]

To set up any industry or a company, an entrepreneur needs to acquire some licenses and certifications from the government or the regulatory agency. These licenses and certifications are issued on the public interest. These regulations display the policy framework of the governmental organization of the country. These regulations are introduced to protect the interests of the company, customer, public, government and environment and ensure that every company is working as per the judicial framework of the country.

The investor first needs to approach the regulatory agency working directly under the Government of India to get certifications and only after approval the investor shall move to the regulatory agency under the State government for further certifications and licenses. The Central government and the State government are the only two bodies which control and regulate the establishment procedure for any industry in India. The central and state regulations differ from each other. The central level regulations are the same for everybody but the state level regulations differ. There are two stages of clearances needed by the project,

1) **Pre-project clearances**: These are the clearances that are taken before the company starts making business. Under Pre-project clearance several clearances at central and state government fall such as:

Central Clearances: for central clearances and approvals the company should have:

- A registered office in India, it could be a foreign owned or a joint venture.
- Reserve Bank of India's approval and also a bank account in India

State Clearances: The Company can acquire the following clearances from the state regulatory agencies:

- Building plan approvals.
- Environmental clearance.
- Safety standards clearance such as fire, electricity, boilers etc.
- Labor department approvals.

2) **Post-project Clearances**: These are the clearances needed to be acquired by the company after it got approval to do the business. Main clearances which come under post-project

clearance are the tax registration, which has to be acquired from the center as well as from the state regulatory department.

Business Regulations enforced and controlled by the Government of India:

The Industrial Policy Resolution of 1956 and also the Statement of Industrial Policy of 1991 provides the basic framework for the overall Industries in India. With rapid liberalization and to boost the industrialization many licensing requirements are eliminated except in certain industries. And to ease the cash flow, laws related to Foreign Direct Investment have also been eased. Any industry which needs to obtain industrial license has to do so from Secretariat for Industrial Assistance (SIA), Government of India on the recommendation of a Licensing Committee. Once the company gets central approval it needs to approach the relevant state government for the land acquisition, permission to change land use, approval of building plan, release of water and electricity connection etc. Central Government only deals with issues of Industrial Licensing, Tax regulations and Foreign exchange regulations. This fractured regulation system is important to relieve the burden from the central government and also saves the time. The Central Board of Direct Taxes (CBDT) and the Central Board of Excise and Customs (CBEC) are both part of the department of Revenue under the Ministry of Finance, Government of India and deals with the matters relating to impose and collection of direct and indirect taxes respectively. The Reserve Bank of India administers the Foreign Exchange Management Act 1999 (FEMA).

Business Regulations enforced and controlled by the state government:

At the state level, the Directorate of Industries is the nodal agency for guiding new investors. It provides an interface between the investor and other agencies to assist the investor to get different approvals and clearances from various state level departments. Following are the business regulations enforced by the state government.

1) Land acquisition and building plan approved by local body.

2) Permission under Factories and Boilers Act from the Inspectorate of Factories and Boilers.

3) Permission from Inspectorate of Electricity for safety of power systems.

4) Permission from state pollution control board.

5) Approval from the Labor Department.

6) Power connection from the state electricity board.

7) Water supply connection from the local body.

3. Results

The results of the technical feasibility can be summarized as follows:

1) The fuel acceptance by the Plasma gasifier is very flexible, basically any kind of waste disregarding of its size and moisture content can be introduced into the plasma gasifier, whereas CFB gasifier needs the waste to be pre segregated of heavy metals and the waste should be shredded before its introduction into the gasifier.

2) The conversion capacity of the plasma gasifier can reach up to 100%, whereas for CFB gasifier also has high conversion capacity up to 95%.

3) There is a huge variation between the two technologies when it comes to power generation capacity. Plasma gasifier can generate a lot more power than CFB gasifier by utilizing same amount of MSW.

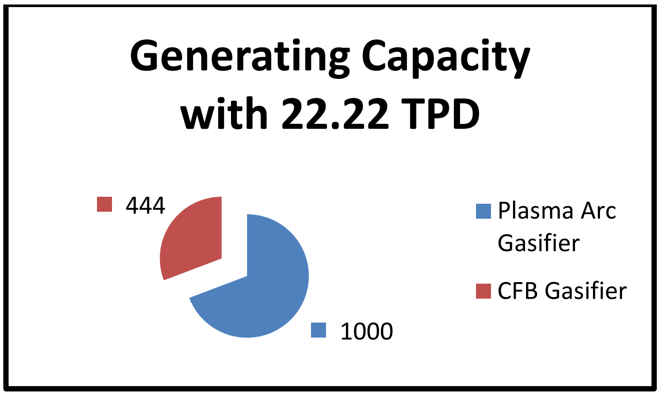

Figure 24 Generation capacity in kWh of both the technologies at constant TPD of waste

4) The level of automation in the plasma gasification is very high as its reactor can reach at 5000°C and required high level of temperature controllers and safety measures, whereas in CFB gasifier the level of automation is moderate.

5) The land requirements by both the technologies vary a lot. Where plasma gasification requires only 1.088 acres of land per MW, CFB gasifier requires around 10 acres of land for the same capacity.

6) The byproducts from the plasma gasifier are vitrified slag, which doesn't need to be treated and can be directly sold and used in the construction industry. The byproducts of the CFB gasifier are ash and slag which needs to be treated before its disposal into the landfills or before utilizing it in the construction industry.

The results of the Economic feasibility of both the technologies can be summarized as:

1) There is a huge variation in the capital costs of both the technologies, the cost to setup a WTE plant using plasma arc gasification technology is around 82.3 million INR. And the cost to setup the WTE plant using CFB gasification technology is around 10 million INR. The main reason for such a huge difference is the use of plasma torch technology, which is a comparatively new technology and costs more.

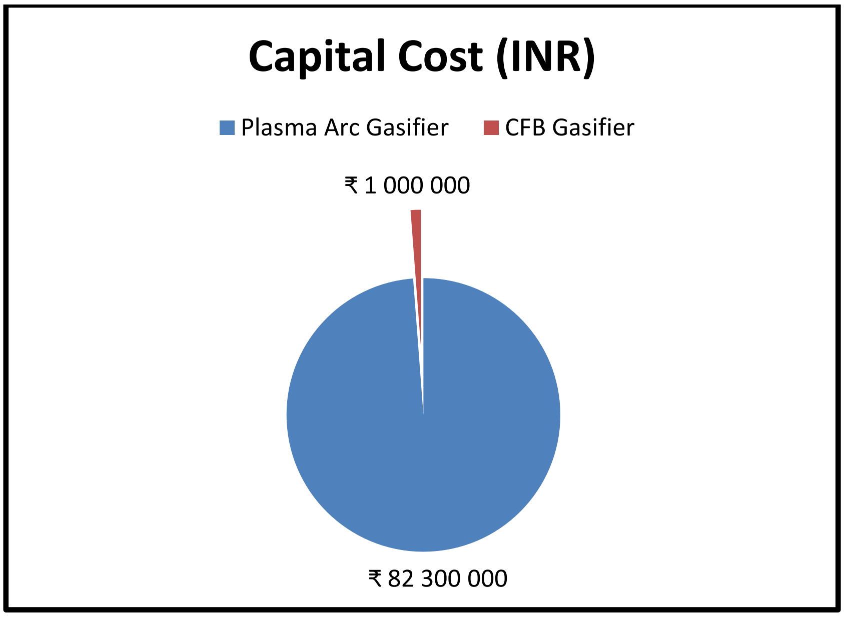

Figure 25 Variation in capital cost (INR) of the plasma and CFB gasification technologies

2) The cost of power generation using plasma gasification technology is significantly higher than the cost of power generation using CFB gasification technology, as the power consumption by the plasma torch itself is around 15-20% of the total generation.

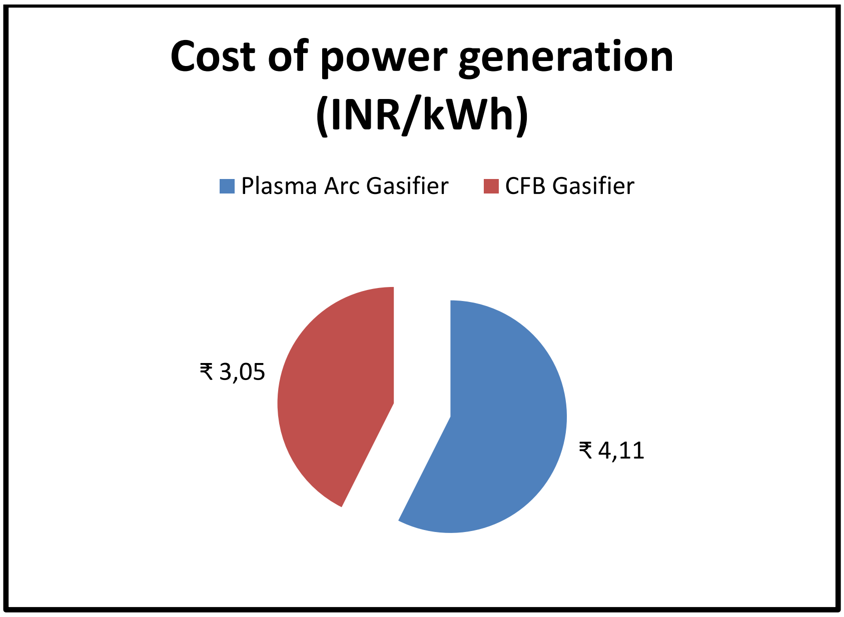

Figure 26 Variation between the costs (INR) of power generation of two technologies

3) The unit rate to sell the generated power is generally constant in the Indian state of Telangana, which is 6.15 INR/1 kWh, regardless of the technology used for WTE.

4) The net power supplied to the grid is larger while using plasma gasifier as the power generated per TPD is larger when compared to CFB and hence more money is also earned by selling the power.

5) The payback period according to the calculation done comes around 4 years for both the technologies, which is actually very good.

6) To encourage the WTE plants, the Government of India and the state governments provides incentives. (Discussed in Appendix)

The result of legal feasibility can be summarized as:

1) As per the data collected from different sources, the emission levels of different pollutants is far less in both the technologies than the emission standards set by the Indian government.

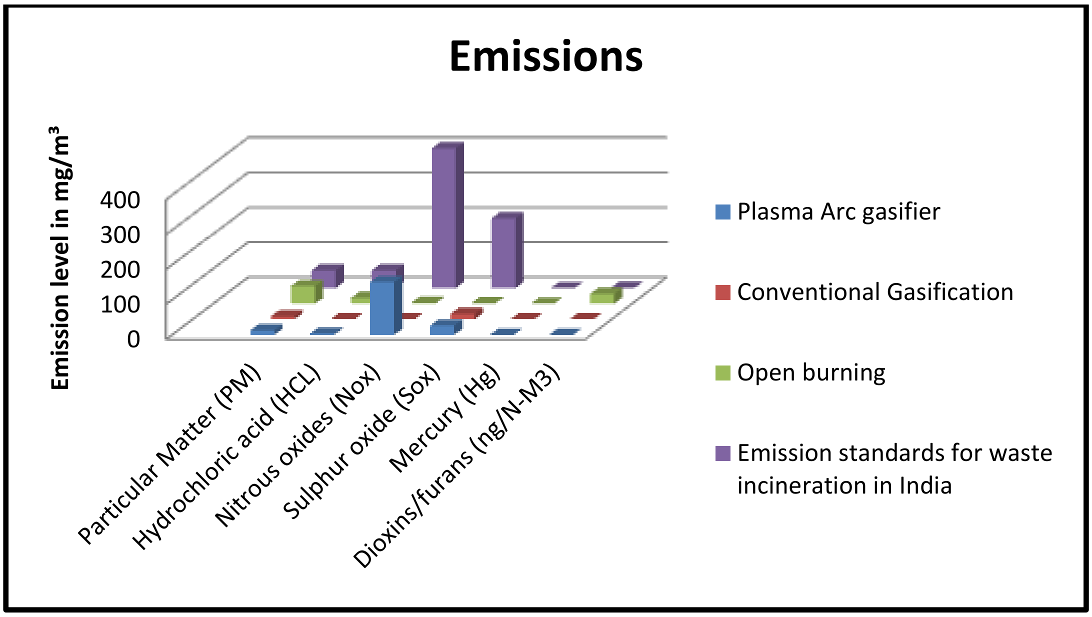

Figure 27 Emissions comparisons

4. Discussion

As discussed earlier, the decomposing MSW on the landfills is a major contributor to the global warming. Methane (CH_4) gas released by the decomposing organic fraction of the MSW on landfills has a major effect on the climate as it is 21 times more aggressive than CO_2. To minimize the threat of 2m sea level rise by 2050 as predicted by many scientists it is necessary to take immediate actions and control the emissions. And not only has it deteriorated the climatic conditions - the unscientific landfilling and open combusting also deteriorates the health of people living in nearby areas. According to the planning commission of India report May, 2014, the World Health Organization (WHO) has observed that 22 kinds of diseases can be prevented by improving the waste management system in India.

For sustainable treatment of the MSW operational feasibility of the process is necessary. The main criteria's to satisfy before choosing for a specific technology or process are:

a) Compatibility of the technology to treat the type and composition of waste available.
b) Type of conversion required from the waste, WTE or WTP.
c) The economic feasibility of the project.
d) The legal feasibility of the project.

Many technologies which can treat the Indian MSW and convert it into either WTE or WTP are discussed in the paper but not all are technically and economically or sometimes legally feasible enough. Incineration may be a very feasible process to convert waste to electricity and heat in the Europe and America, but it is not possible to combust the wastes which contain around 50-60% organic waste in India and generate electricity from it. Likewise the use of fixed bed gasifier and entertained flow gasifier were found not so feasible or mature enough for WTE projects. We have compared the feasibility of two mature technologies in WTE gasification sector. There are many plants treating MSW and generating electricity all over the world, especially in China. Even though the plasma gasification is new in the MSW gasification sector, it is a proven and mature technology. There are several pilot plants all over the world but Westinghouse plasma technology is far more superior to all others as found in many studies. India needs WTE power plants now more than ever as the country has the world's 2nd highest population and the majority of it is young. Apart from that, India is seeing a fast Industrial growth with ever growing need of power and hence increasing the waste emissions. For a sustainable growth India needs to take care of both of them. The WTE gasification has given a new hope to India but the uncertainty about the success rate is holding many entrepreneurs back from investing in this sector. There have not been many researches done on WTE sector with Indian scenario. This might be due to people having seen the failure of some big incineration and RDF plants in India, and also as the quality of waste was not suitable or the waste collection mechanism was not so efficient. But now the time is changing and with developing stats and some research done especially in RDF, and biochemical conversions, many small scale startups are opening up. It is estimated that the municipal solid waste-to-energy market could be growing at the rate of 9.7 % by the year 2013 [5]. There is even a hazardous waste-to-energy plant Pune, India which is processing 300 tons of hazardous waste per day and generating 3MW of energy since 2008. This shows that the WTE market is opening up in India. The power potential from MSW is estimated to be at 5,200 MW by 2017 [11]. There are even many plants which are under construction and by 2020 we can see a significant development in this sector. Like 12 waste-to-energy projects are being built across Andhra Pradesh, which would convert 77% of the municipal solid waste to electricity.

Some factors which were holding the investors back were long and complex bureaucratic procedures, high capital investment and non-participation or lack of proper awareness among the people about the technologies and its importance. As per (Karthik Ramakrishnan, 2014) there are around sixty five clearances required to set up a thermal power plant in India. But with the formation of new government in 2014, many procedures were trimmed short or simplified and there are many incentives related to land, infrastructure, capital investment or tax holiday schemes introduced by the government to encourage startups in waste-to-energy sector. Like 39 million per MW incentive is given by the Government of India for the companies generating power from MSW on gasification - Pyrolysis and Plasma arc gasification [28].

As per the literature study and feasibility study was done for this thesis, it has been found that the plasma gasification and circulating fluidized bed, both the technologies are feasible and reliable. Even though the capital cost for the plasma gasification is high, it can generate far more power than circulating fluidized bed with a specific amount of waste per hour or per day. The emissions by both the technologies are far below the emission standards set by the Indian government. But keeping in mind the urgent requirement to initiate such procedures to control the methane emission from the decomposing MSW on the open landfills, these technologies are urgently needed to attend the climate change situation.

India has already pledged under the Copenhagen Accord that it would decrease its CO_2 intensity (emissions per GDP) by 20 – 25% by 2020 compared to 2005 levels [29]. The Government of India has introduced campaigns like Swachh Bharat Abhiyan (Clean India Campaign) to encourage the public involvement. The Solid Waste Management Rules are also revised to tackle the problem more efficiently. Some of the initiatives under Solid Waste Management Rules, 2015 are: The schools are provided with 4 bins to segregate the solid waste. The rag pickers are recognized by the government and they are facilitated by the government for their work. To encourage the WTE plants, purchase of power from these plants is made mandatory. Co-marketing of city compost is made mandatory for the fertilizer marketing companies. With many similar steps taken, we can expect considerable change in coming years.

5. Conclusion

In this study it has been found that the WTE conversion plants are not just sustainable and economically feasible, but also urgently needed. There are many new startups in India opting to process the MSW and convert it into either WTE or WTP, which is a good but a massive expansion within this segment is needed in the near future. The Plasma gasification is found to be well suited for the Indian conditions and in the long run looks sustainable and economically feasible for WTE conversion. The payback period found in this study looks very viable, but the real-time payback could vary depending on many factors which were not considered in the calculations.

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7. Appendix

1) Calculation Table:

Calculation				
S. No	**Description**	**Plasma Arc Scenario**	**CFB Scenario**	**Formula**
1	Capital cost (INR)	82300000	10000000	
2	Power generating capacity in a year (Kwh)	8760000	3893294	kWh*(365)*(24)
3	Generated power (kwh) at 90% PLF in a year	7884000	3503965	0.9* S.No.(2)
4	Cost of power generation (INR)-O&M of Plant	1918248	1001133	S.No.(2) / Cost of power generation(INR)
5	Money earned by power sale (INR)	48486600	6156967	S.No.(3) / Unit rate in Telangana(INR/1kWh)
6	Remaining money after deducting gen. cost (INR)	46568352	5155834	S.No.(5) - S.No.(4)
7	Assuming 50% for maintenance charges	23284176	2577917	0.5 * S.No.(6)
8	Remaining profit by power sale (INR)	23284176	2577917	S.No.(6) - S.No.(7)
9	Payback period (years)	4	4	S.No.(1) / S.No.(8)

Table 11 Calculation table

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