Integrated Municipal Solid Waste Management Framework for Indian Cities:

Case Study of Kolkata

Integrated Municipal Solid Waste Management Framework for Indian Cities: Case Study of Kolkata

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Glossary

°C	degree centigrade (unit for temperature)
ABT	Availability Based Tariff
AEB	Annual Energy Baseline
ASSOCHAM	The Associated Chambers of Commerce and Industry of India
BAU	Business As Usual
BOP	Balance of Plant
C/N	Carbon to Nitrogen ratio
$Ca(OH)_2$	Calcium Hydroxide
CDM	Clean Development Mechanism
CER	Certified Emissions Reduction
CESC	Calcutta Electricity Supply Corporation
CPCB	Central Pollution Control Board
CPHEEO	Central Public Health and Environmental Engineering Organization
cr.	crore (unit for money) 1 cr. = Rs. 107
CSTEP	Center for study of Science, Technology & Policy
FAO	Food and Agriculture Organization
FGTS	Flue Gas Treatment System
GHG	Greenhouse gas
GWP	Global Warming Potential
H_2S	Hydrogen Sulphide
HCl	Hydrochloric acid
HGC	Hot gas clean up
HHV	higher heating value (kJ/kg or kcal/kg)
HP	High pressure
HRSG	Heat recovery steam generator
HTW	High-temperature Winkler
HV	High Voltage
IAD	Institutional Analysis and Development
IC	Internal Combustion
IEA	International Energy Agency
IFC	International Finance Corporation
IGCC	Integrated Gasification Combined Cycle
IGES	Institute for Global Environmental Strategies
IMF	International Monetary Fund
IPP	Independent Power Producer
IREDA	Indian Renewable Energy Development Agency Limited
IRR	Internal Rate of Return (%)
kcal/kg	kilo-calories per kilogram (unit for energy content)
KEIP	Kolkata Environmental Improvement Project
kg	kilogram (unit for weight)
kg/s	kilograms per second (unit for flow rate)
$kgCO_2/kWh$	kilograms of carbon di-oxide per kilo-watt hour of electricity
kJ/kg	kilo-joules per kilogram (unit for energy content)
kWh_{el}	kilo-watt hour electrical (unit for electrical energy)
kWh_{th}	kilo-watt hour thermal (unit for thermal energy)
KMC	Kolkata Municipal Corporation

kV	kilo-volt (unit for electrical voltage)
kWh	kilowatt hour (unit for electricity)
LHV	lower heating value (kJ/kg or kcal/kg)
LP	Low Pressure
LPG	Liquified Petroleum Gas
m^3	cubic meters (unit for volume)
MCR	maximum continuous rating
MJ/kg	Mega-joules per kilogram (unit for energy content)
mm	milli-meter (unit for length)
MNRE	The Ministry of New and Renewable Energy
MoU	Memorandum of Understanding
MRQ	Main Research Question
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
MT	metric tons (unit of weight)
MVA	Mega volt ampere (unit for electrical power rating)
MW	mega watt (unit of electrical power)
MWh	Mega watt hour (unit for electricity)
NDA	National Designated Authority
NEERI	National Environmental Engineering Research Institute
NGI	Next Generation Infrastructures
NGO	Non governmental organization
NO_x	Nitrous oxides
NPV	Net Present Value
PAH	polyaromatic hydrocarbons
PCB	polychlorinated biphenyls
PCDD/F	polychlorinated dibenzo-p-dioxine/-furans
PDD	Project Design Document
PLF	Plant Load Factor
PRB	Population Reference Bureau
PW	Pre-processed waste
R & D	Research and Development
RDF	Refuse Derived Fuel
RES	Renewable Energy Systems
RPA	Reject Processing Area
Rs.	Indian National Rupee (unit for Indian money) 1 Euro = Rs. 61
SA	Stakeholder Analysis
SDA	Spray Drying Absorption
SWOT	strengths – weaknesses – opportunities – threats
tpd	tons per day
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UPS	Uninterrupted Power Supply
WBERC	West Bengal Electricity Regulatory Commission
WGT	Waste Gas Technology
WTE	Waste to Energy
WWF	World Wildlife Fund
WWTP	Waste Water Treatment Plant

Summary

The city of Kolkata in West Bengal, India, has a population of around 15 million (resident and floating) and the amount of MSW collected is around 4000 tpd. Owing to the rapid saturation rate of the dump site at Dhapa and the financial difficulties faced by the compost plant, KMC are looking at ways to alleviate the problem. One of the options is to convert the MSW to electricity. Kolkata has a shortage of around 275 MW during peak hours and summer. IPP's like Astonfield and monopolist CESC have tried in the past to explore this option but their feasibility reports to KMC have not convinced the latter to go ahead with such a project.

This study looks at the problem from a systems perspective and identifies the system to be a complex socio-technical one influenced by the role of institutions and environmental effects. It sets up a framework for carrying out a feasibility study for conversion of MSW to electricity in densely populated cities. It exemplifies the framework by taking Kolkata as a case study for this study.

The study research starts by asking for depth and insight into the actors involved in the MSWM scheme of Kolkata and what are their roles, interactions, power and attitude towards improving the scheme and how the scheme will impact them. A strategic stakeholder analysis based on the Institutional Analysis and Development (IAD) framework has been made to identify the stakeholder interactions and the space within which the stakeholders make their decisions in this socio-technical-ecological system. The problem owner is identified to be *KMC* and the other actors directly impacted by a change in the MSWM infrastructure are the *ragpickers and scavengers* at Dhapa and the opposition party. The containing system has the *garbage farmers, waste collectors, population of Kolkata, industries* and *CESC*. To improve the situation, all these stakeholders must collaborate with each other. CESC's monopoly in the electricity market means that they need to participate in the project as well. The attitude of the population, ragpickers and scavengers, and the garbage farmers need to be transformed into a more positive one towards change. Interviews have been conducted to obtain information about the actors in this research.

An analysis of the existent MSWM scheme is then made to be able to understand the shortcomings and the possible scenarios for the future of MSWM in Kolkata. The KMC employs personnel to collect waste from households and markets and industries and transfers this MSW to the dumping site at Dhapa. Inefficient handling of intermediate storage in community bins leads to problems of overflowing bins and public nuisance. To be able to alleviate the problem the following barriers and constraints need to be addressed by KMC:

- Shortage of land
- Lack of finances
- Bounded rationality about technologies and MSW characteristics
- Rehabilitation of ragpickers and scavengers
- Dealing with the opposition party
- Environmental control standards

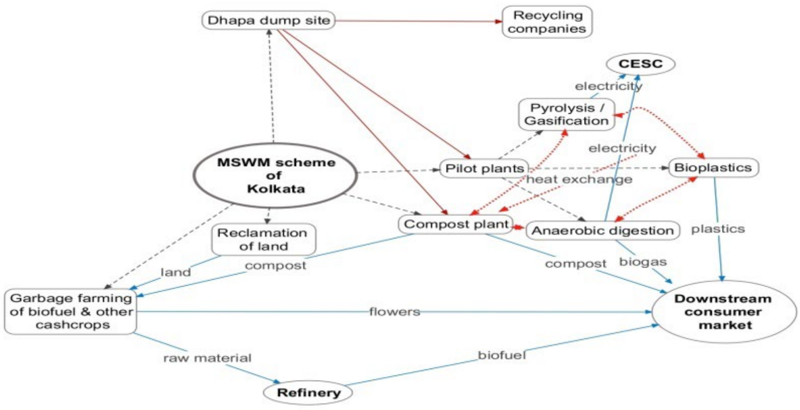
The barriers and constraints that lie in the path of actors who want to set up a power plant to convert MSW to electricity in Kolkata are:

- Unproven technology
- Low calorific value of MSW
- Financial constraints (CESC demands tipping fee of Rs. 300-400/ton; Astonfield Rs. 700-800/ton of MSW treated)
- Monopoly of CESC

The study then shifts focus into the technical aspects of the system. The characteristics of Kolkata's MSW are analysed and the change in composition over time shows the increase in consumption of society and economic growth. The moisture content however is always on a higher side (50%) and this leads to the low calorific value of the MSW (1000-1100 kcal/kg). This shows the need for pre-treatment or drying of the MSW before conversion to electricity. From the technology superstructure, the relevant technologies of direct combustion, PYROPLEQ process (pyrolysis), WGT process and Kruppe-Uhde PreCon process (gasification) are analysed for electricity production using industry data and Cycle-Tempo simulations. The economics of each technology (including CDM aspects) are analysed in terms of NPV, IRR and payback period. Then the technologies are then compared in terms of energy efficiency and economic performance over their lifetimes.

	Direct combustion	PYROPLEQ	WGT	PreCon
Capacity of plant	54 MW	9 MW	10 MW	29 MW
Electrical η %	~40%	~43%	~40%	~40%
Initial investment	Rs. 622 cr.	Rs. 153 cr.	Rs. 150 cr.	Rs. 351.6 cr.
IRR (without CDM)	8 %	8 %	12 %	16 %
(with CDM)	13 %	9 %	12 %	19 %
Payback period		Tipping fee needed		
(without CDM)	12 yrs	13 yrs	9 yrs	8 yrs
(with CDM)	10 yrs	12 yrs	9 yrs	7 yrs

The comparison shows that the most suitable technology in Kolkata's context is the WGT process pilot plant since the PreCon process has not been proven on such a scale yet. This WGT technology is incorporated in the conceptual system design, which explains the change in the new feasible MSWM scheme and the roles that actors need to play in order to bring about this change. The social, institutional, technical, environmental and economic feasibility criteria are met by this system. This system design is derived from the generic framework that has evolved from this study research to carry out feasibility studies.



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1. INTRODUCTION

India is a country with a population of over a billion people today and is expected to become the world's most populous country by the year 2030 [PRB (2006)][1]. Kolkata (22°34'11''N 88°22'11''E), the capital city of the state of West Bengal, officially had a population of around 14.04 million in the year 2011 [Census 2011 India][2]. Projected population figures, taking 2010 as the base year, show that today around 15.5 million people spend an active part of their daily life in Kolkata, and this figure rises to around 16.93 million in 2031 and 17.72 million in 2041 [Dey et al., 2021][3].

1.1 Problem Description

Taking into account that the municipal waste (MSW) generation rate is around 470 g per capita per day (gpcd) for the resident population and about 250 gpcd for the floating population [Chattopadhyay et al., 2007][4], the total MSW generated today in Kolkata is around 4,500 MT[5]. According to recent reports of the **Kolkata Municipal Corporation (KMC)** – the **problem owner** responsible for handling the municipal solid waste management (MSWM) service – the amount of MSW collected in the city of Kolkata has risen from 3,000 metric tons (MT) per day in 2004-05 to around 4,000 MT in 2009 [KMC, 2009][6]. So potentially 1,500 MT of MSW is left unattended in Kolkata every day, and this leads to environmental pollution and nuisance.

The MSWM scheme as employed by the KMC today, is to collect the waste generated from different points within the municipality area and transfer it to an open landfill facility and a compost plant in a locality in the eastern fringes of Kolkata called Dhapa (Figure 1). This site has been used for dumping the MSW of Kolkata for generations. A major portion of the landfill site is saturated and has become part of the landscape at present. Basing their opinions upon the rate at which the area reached saturation, the current rate of generation of MSW in the city and the predicted usage of the landfill area for landfill purposes only, local experts say that the land will be totally exhausted in 8-10 years [Appendix I – Interviews with stakeholders]. Land reclamation would be necessary to continue this practice of dumping a major portion of the city's collected MSW in a landfill site. This would mean encroaching upon the land occupied by the farmers and the water bodies in the vicinity of the present site.

To alleviate this problem KMC entered into a joint venture with M/S Eastern Organic Fertilizers (India) Private Limited to set up a mechanized compost plant in April, 2000. This plant is designed to treat a portion of the collected MSW and convert it into usable compost for agricultural purposes. The plant has been set up within the perimeter of the landfill site. The capacity of the plant is around 700 tons/day. Due to the advent of technology, consumers are showing preferences for artificial fertilizers over compost. Owing to the loss of sales of their product in the downstream market, this compost plant has been showing signs of failing financially. The plant became non-functional in 2003 [7]. The problem entails the operation of this plant throughout its expected lifetime.

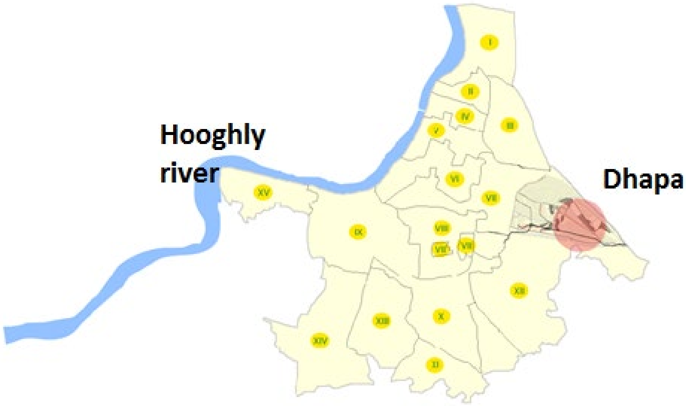

Figure 1 Location of Dhapa Landfill Site in Kolkata

Another option that is available to KMC is the conversion of MSW to electrical power. Kolkata had a daily peak power demand of around 2337 megawatt (MW) in 2019-20. The Calcutta Electric Supply Corporation Ltd. (CESC) is the body responsible for the distribution of power in the city of Kolkata. With their current resources they can supply only around 1255 MW per day leaving a shortage of around 1082 MW during peak hours [CESC 2019-2020][8]. This leads to frequent power cuts all over the city especially during summers.

A scope arises to link the two sub-systems viz. MSWM and electricity supply systems of Kolkata. The shortage in the electricity supply can be met partially by utilizing the MSW stream of Kolkata as feedstock for a power plant. There are mature as well as innovative technologies being implemented all over the world to convert MSW and other waste streams into energy for society.

Since 2007, Astonfield Renewable Resources (a multi-modal renewable energy company) has been trying to push KMC into letting them construct a direct combustion power in the Dhapa region in order to generate electricity from Kolkata's MSW and other waste streams. They have faced difficulties in obtaining the land required from the government and also have not signed any Memorandum of Understanding (MoU) with the KMC. Their proposal of setting up a 54 MW capacity powerplant is still stuck in the pipeline and recent press releases claim that they might discard the project plan [Astonfield, 2010][9]. CESC and other companies are also looking at options to utilize the waste streams of the city in terms of electricity production. However, no power generation plants have been incorporated in the future plans of KMC with respect to MSWM.

One of the reasons behind KMC not seeing sense in a power plant is the lack of a coherent feasibility study proving that such a plant can stay operational over its lifetime. So far KMC has not received a formal feasibility study report that analyzes MSWM as a component of a complex socio-technical system and assures that a power generation plant is technically, socially and financially viable in the context of Kolkata's MSWM service. This leads this study to form its main research question (MRQ).

How can a feasibility study be developed for a MSW to power plant in Kolkata taking into account the social, technical, economic and institutional factors that govern the MSWM practice in the city?

The mindmap for the research to be carried out in this report of setting up a feasibility study for MSW conversion to energy in Kolkata is depicted in Figure 2.

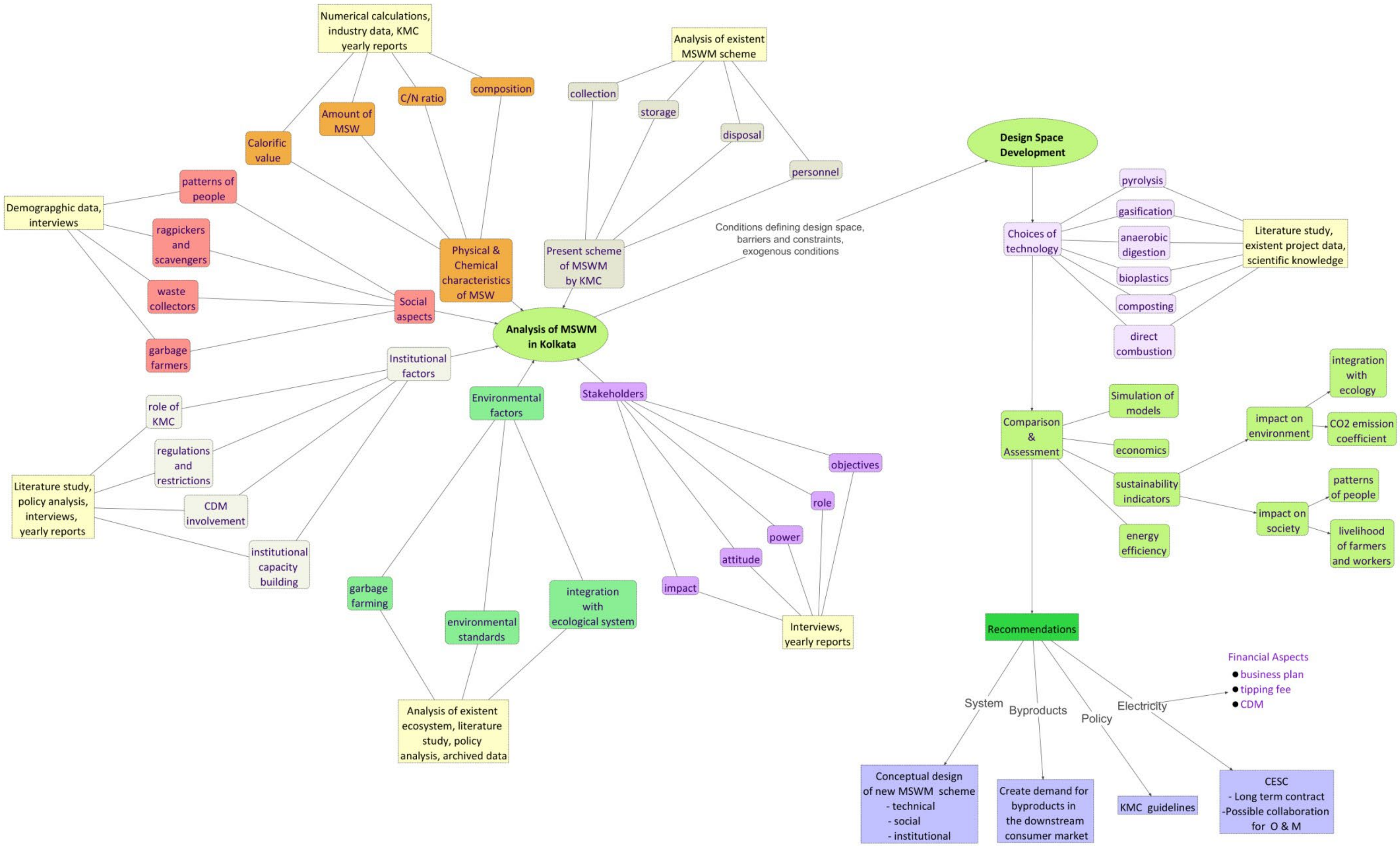

Figure 2 Kolkata's MSWM research mindmap

1.2 Relevance

Academia

The research for this study involves looking at the problem of MSWM in Kolkata from the perspective of systems engineering which is a research area of the section of Energy and Industry at TU Delft, Faculty of Technology, Policy and Management. The research will result in the evolution of a framework for carrying out feasbility studies of MSW to energy conversion systems in densely populated cities. The results and insights obtained from this case study of Kolkata's MSWM scheme, can be extrapolated into designing the variables in the framework. This framework can be applied to systems like Kolkata, in other regions of the country. This framework will enable researchers to follow certain generic steps to make feasibility studies in terms of municipal waste management and sustainable urban development. Implementing the resulting framework in other systemic projects of sustainable urban development related toMSWM will lead to the formation of innovation networks and the fabrication of innovative technology policies to promote waste to power production in the future.

The feasibility study for the case studied in this study (Kolkata) will add to the knowledge base that exists for options for waste management programs in India and contribute to innovations in the field of waste utilization.

Industry

This study evolves over the experiences of companies which have tried to enter the MSWM sector of Kolkata and explores the barriers and constraints that have prevented the industry from stepping in till date. It looks at the possibilities to overcome these obstacles and design a solution which allows industrial participation in the scheme of MSWM in Kolkata.

Technology

MSW is often looked upon as a nuisance rather than a resource in society. Hence, the attention devoted to research in this field in India in the past was not exemplary. This led to simple technologies such as recycling, composting and landfill to take over the regime of MSWM in society. However, in the recent past, there has been research and innovation in the technologies that are associated with MSWM. The primary driver behind this research has been to recover energy from MSW thereby treating it as a valuable resource.

This study identifies the innovative processes of pyrolysis and gasification as major research drivers and analyzes the potential of these technologies to fit into the context of Kolkata's MSWM scheme. It also identifies other relevant technologies that are applicable in this scheme and attempts to integrate them into the system design.

Society

The pillars of any MSWM infrastructure are built on the behavioural patterns of society. Consumption and disposal patterns specific to the culture and habits prevalent in society define the scheme employed for MSWM. This study studies the social aspects within the MSWM scheme of Kolkata and and searches for ways to influence them in order to facilitate a more sustainable MSWM scheme.

There have been a lot of efforts from NGOs and local bodies to increase the standard of living of the population below the poverty line. However, Kolkata still has countless beggars and some scavengers. Some of the slum dwellings do not have electricity. The personnel involved in the scheme of MSWM are exposed to health hazards and form one of the poorest sections of society in Kolkata. This study aims at involving the ragpickers and scavengers as grass-roots level stakeholders in the scheme of waste management, thereby leading to sustainable development and increase in income in this section of society.

Environment

MSWM practices irrefutably have impacts on the local environment. Inefficient MSW collection schemes lead to MSW being left unattended and causing environmental pollution. Landfilling leads to emissions of methane and other high global warming potential (GWP) gases into the atmosphere [Manfredi, 2009][10]. Leachates affect soil fertility and underground water quality and enters the food chain of society if the soil is used for agricultural purposes [Saha et. al., 2003][11].

This study looks at how the MSWM scheme of Kolkata is integrated with the local ecology and environment. It attempts to come up with a solution that has the least detrimental impacts on the environment. The research includes an analysis of the environmental standards prevalent in Kolkata and how the proposed technologies can adhere to these standards in terms of emissions into the local atmosphere and integration into the ecological balance.

Political Institutions

MSWM is usually the responsbility of the municipality authorities. In the case of Kolkata, the KMC is the problem owner and the solid waste management department is responsible for the collection and disposal of MSW. They are however having issues keeping up with the MSW generation rate and the rapid saturation of the Dhapa landfill site.

This study analyzes the existent MSWM scheme employed by the KMC and identifies the shortcomings as well as the scope for improvement. The research is intended to result in strategies to induce institutional capacity building in the KMC by involving financial instruments like the Clean Development Mechanism (CDM) and exploring the possibilities of collaboration with the industry and other institutions for a more suitable MSWM scheme.

1.3 Background

India, being a densely populated country, produces a huge amount of solid waste. The annual figure rose from 6 million MT in 1947 to around 48 million MT in 1997 with an annual growth rate of 4.25% and is predicted to grow to 300 million MT by 2047 [CPCB, 2004][12]. MSW management is a complicated problem for most of the municipalities in India because it requires substantial investments and is not given much importance in a social context [Bhide et al., 1983][13]. Since this system involves complex interactions between political, legal, socio-cultural, environmental and economic factors, as well as available resources, the technologies of converting waste to electrical power have not received much attention in India. Current prevalent practices are to dump MSW and other waste streams in open spaces and then leave the dump to compost under natural process conditions. This has led to environmental hazards causing ecological imbalances with respect to land, water and air pollution over the years [Kansal et al., 1998][14]. However, due to a lack of finances and technical knowledge, there has been no major push towards dealing with MSW in ways other than composting and landfills.

In recent years, municipalities have started looking at ways to handle MSWM in more sustainable ways as industrialization and economic growth have started to affect the consumption and disposal patterns of society. This has allowed innovation to play its part in the emergence of other schemes for waste management now in India. Centralized power generation options using local MSW resources are being proposed in different urban locations in the country. Studies have shown that India has a potential of generating 5690 MW from waste streams [MNRE][15]. However, reports show that India has realised only 2% of its waste-to-energy potential till date [Projects Monitor, 2010][16]. The main reason behind this low realisation is that the initial investments of setting up waste-to-power plants are far greater than similar capacity thermal or hydel power plants. Also, the Indian Renewable Energy Development Agency Limited (IREDA) does not finance projects which do not meet their eligibility criterion, so private investors cannot rely on governmental subsidies when setting up plants of capacities over 6 MW [IREDA, 2010][17]. Many experts also believe that the MSW generated in the country is unsuitable for power generation. When new technologies are brought into the system of waste management, these barriers and constraints restrict their growth.

Not only do most cities in India have considerable amounts of waste generation, but implementing waste to power generation projects to provide electricity to the cities also brings about sustainable development in the poorer sectors of society and contributes to reducing emissions on a local scale and thereby reduces the city's carbon footprint by a considerable amount. This is in line with the statement made in the World Energy Outlook of 2007 – "*The challenge for all countries is to put in motion a transition to a more secure, lower-carbon energy system, without undermining economic and social development"* [IEA (2007)][18].

Kolkata is a city which already has a waste collection, storage and disposal scheme. The KMC has an allocated landfill and composting site at Dhapa. However, due to increasing population levels, rapid economic growth and rise in community living standards, the MSW generation rate has increased and the site is overburdened. Also farmers in the region of Dhapa are encouraged to grow vegetables in the vicinity of the dumping ground premises. Recently, due to pressures from industrial ecologists, it has been deemed hazardous to health if these vegetables are consumed beyond a certain limit. Since the farmers have a strong union, the government has not gotten involved in the complications that may arise if these farmers are prohibited from growing vegetables that are not of good quality. This study aims to prove that setting up a waste to power generation plant will not only alleviate the problems of waste management in Kolkata but will also open up jobs for the farmers who would otherwise have been stripped of their livelihood. This can thus qualify to be a CDM project as it meets the additionality requirements of the mechanism.

This study research is also an attempt by the section of Energy and Industry at TU Delft to facilitate knowledge and technology transfer in the field of solid waste management from the Netherlands to Kolkata, India.

1.4 The client– KMC

This research involved undertaking an internship at KMC in Kolkata. The role was to analyze the existent MSWM scheme, identify the areas of improvement, compare technological options for MSW to power generation and present a conceptual design for a more sustainable MSWM scheme that can be used by the client in its future plans.

This section aims to briefly clarify the preliminary goals of KMCwith respect to this internship, to be able to present how my understanding of the client's objectives led to the formulation of research sub-questions that need to be answered in order to answer the MRQ. The scope of this project from the perspectives of KMC and TU Delft can be formulated here. For now it is important to note that the following factors were considered in the scope of this study when defining the research sub-questions:

- This study concentrates on the technologies involved in this conversion of waste to electrical power only. It looks at other options of waste management but does not analyze them. Since Kolkata has a tropical climate, district heating or space heating is not required. So thermal energy recovery is not part of the research.

- This research is limited to a pilot project at one location, viz. Kolkata, India. Nonetheless, the insights gained from this pilot can be valuable when considering other cities in the future.

- The economics of only the pilot plant for electricity generation will be analyzed in this research but the economics of a cash crop regime to replace the vegetables grown in the area and the other pilot plants will not be looked into.

- This pilot plants in the MSWM scheme can broaden the scope by involving CDM activity and hence generate CERs due to displacement of coal-based electricity as well as biofuel production for consumption in downstream markets. The social sustainability indicators will also be identified. Economics of the biofuel production will not form a part of the research in terms of CDM.

- In a later stage of the feasibility study, the scope arises to construct a framework which explores the possibilities of designing conceptual MSWM schemes for a more generic system depending upon the local exogenous conditions such as climate, population, economics and demands of the consumers.

1.5 Research Sub-Questions

In order to develop a feasibility study to convert MSW to electricity, this research needs information and data regarding the socio-technical, economic, institutional and environmental aspects. Although research has shown that there is potential for MSW to power conversion to displace a certain percentage of coal-based electricity in urban areas with large populations and waste streams [Ruth, 1998][19], there is limited direct knowledge regarding applicability of waste to energy conversion technologies in these areas and how centralized energy infrastructures can be implemented in order to provide electricity and aid urban development. Combining this with the focus on Kolkata led to the formulation of the sub-questions (1-6) which will yield answers and information that together address the MRQ.

1. *Who are the stakeholders in the MSWM scheme and what are their roles and interactions?*

2. *What is the situation of MSW management in Kolkata today and what are the barriers and constraints that define the necessary conditions which need to be satisfied in order to implement a sustainable MSWM scheme?*

3. *What are the physical and chemical characteristics of the waste stream of Kolkata and is there a need for separation and pre-treatment of waste streams in order to increase conversion efficiencies from MSW to electricity?*

4. *What are the different technology options that can be used to convert MSW to electrical energy and which are viable in the case of Kolkata?*

5. *How can an extended business case evolve from this feasibility study and how can CDM be used as an instrument to aid profitability?*

6. *What is the total system design going to be involving all the elements of the system and how does this system evolve over time?*

1.6 Expected results and deliverables

The project can be looked at from a systemic perspective. “A system is a collection of different things which when integrated appropriately produce results unachievable by the elements alone” [Maier et al. (2002)][20].

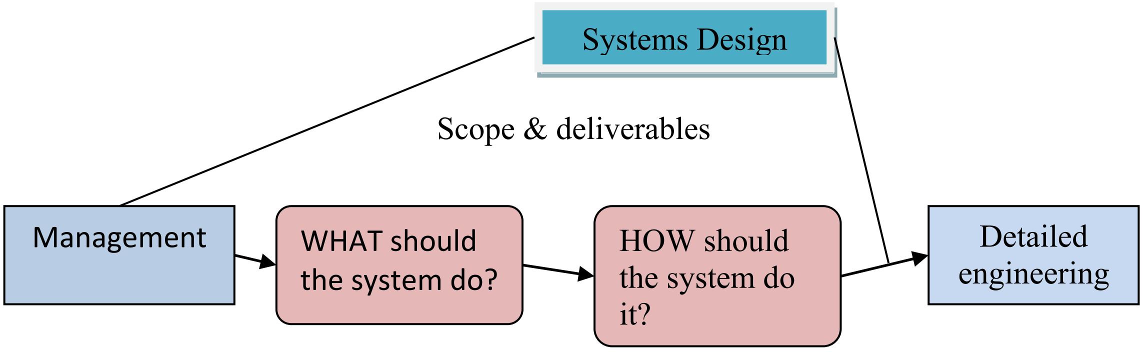

Figure 3 Systems design

In this particular project, the system boundaries are restricted to the city of Kolkata. The system defines its goals as better MSW management options with a focus on waste to electrical energy conversion to partially solve Kolkata's electricity shortage problems. This is the translation of "what" the system should do. To get the system to realise its goals, the research aims to describe the steps taken in the designing of the entire system to show "how" the system plans to implement itself in the future (Figure 3). This report aims to present a detailed conceptual system design based on a waste to power generation plant to solve the problems of MSWM and electricity shortage in Kolkata. This research will result in the design of a system which includes the following components:

- Waste to power generation used to supply reliable electricity to the citizens of Kolkata. The choice of technology will be made after exploring the options available and opting for the ones that best fit the objectives of the stakeholders.
- Recommendations on the selection of main system components in terms of electricity generation.
- Recommendations on how to integrate the new technology in the current electricity and MSWM regime.
- Prediction of performance of the power plant in terms of economics (the business plan) and social development in terms of employment opportunities and increase in standards of living.
- Recommendations on the implementation of these pilot plants in Kolkata.
- Recommendations regarding other elements of the MSWM scheme.

In addition the research will lead to the formulation of a high level generic framework for other MSW to electricity generation and sustainable urban development projects based on:

- Local demands in terms of energy and economic development
- Local climatic, environmental and economic conditions
- Local waste stream characteristics and quantity
- Local waste management services in practice & scope for improvement
- Local stakeholders
- Barriers and constraints
- Sustainability indicators of options

These results and the information that will be gathered over the course of this project will be transferred to the client i.e. KMC and to CSTEP via a Public Report and a set of Appendices. Also digital files containing calculations and software models used in this research will be made available.

This study is a starting point in the sustainable development of Kolkata. MSW management is one of the major problems faced by the KMC but it is not the only one contributing to pollution in the city as well as increased emissions. To become more sustainable and to reduce its emissions, Kolkata will need to bring about change in other sectors too.

2.RESEARCH APPROACH & METHODOLOGY

As mentioned in the previous chapter of this report, the basis for analyzing the feasibility of a new MSWM scheme, which involves the conversion of the waste streams into electricity, is to treat the problem as a part of a complex socio-technical system which is influenced by the roles of institutions and environmental effects.

2.1 Systems approach – Socio-technical system

The MSWM infrastructure of Kolkata is considered to be the primary system taken into consideration. The sub-systems associated with the primary system are the electricty infrastructure of Kolkata and the man-made ecological waste water treatment infrastructure. Looking at it from the perspective of cognitive systems engineering, it can be seen that these systems evolve over a socio-technical context and the complex interactions of these systems with each other in terms of soceital, industrial, technical, institutional and environmental aspects can be better understood.

2.2 System definition

Primary system of MSWM of Kolkata

The existent MSWM infrastructure present in Kolkata forms the main system under consideration in this research. The main elements of this system are:

- MSWM scheme of Kolkata
- The role of KMC – institutional and regulatory
- The role of ragpickers and scavengers in Dhapa
- Consumption and behavioural patterns of society
- Boundary and exogenous conditions of Kolkata
- Characteristics of the MSW of Kolkata
- Linkages to other infrastructures/systems/industries

These elements will be explored in detail and the relationships between them will be identified in the course of this research.

Sub systems associated with the primary system

There are two sub systems which are also part of this study research:

Electricity infrastructure

The electricity system of Kolkata will need to import the electricity generated from the MSWM scheme that will result from this study. The aspects that need to be looked at to enable this import of electricity feasible are:

- Demand for electricity in Kolkata
- Electricity company in Kolkata – CESC
- State of grid infrastructure

Ecological waste water treatment system

The local wetlands in the region are a part of the complext man-made ecological waste water treatment infrastructure. This study research looks at how this system is integrated with the primary system of MSWM and explores the following details:

- Impact on environment and system because of MSWM scheme
- Impact on garbage farming because of toxicity of wetlands
- Sustainable schemes to restore quality of ecological system

The system boundaries are drawn over these three systems and taking the city of Kolkata to be the system scope and the whole system is defined in Figure 5.

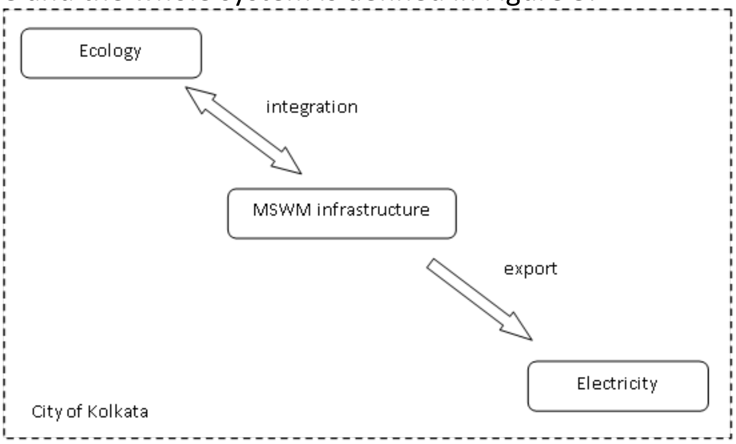

Figure 4 System definition

2.3 Methodology

This study can be divided into two main parts: formulating a regime description and system design.

The first three research sub-questions describe the regime of waste management in Kolkata taking into account the institutional, technological, social, environmental and economic factors. The institutional factors give an insight into what exactly the municipality wants to do with the problems related to MSWM. Interviews with people in the MSWM sector will reveal the bottlenecks faced by them in their efforts to improve the situation. The willingness of the KMC, to shift from a regime of waste collection and storage to one of waste utilization into electricity, can be gauged by analysing the responses of these people. The technological factors show the kind of technology that is available to the KMC at present and if there is any scope for improvement in that field. It also sheds some light over the existing electricity regime in Kolkata and helps in determining where can a generation source fit in and how much can the grid import from a new power plant. The social aspects will show how society is integrated within the MSWM infrastructure. The consumption patterns of the residents of Kolkata and their MSW handling habits along with the conditions of the section of society involved as personnel in the MSWM scheme define the social research needed to be carried out. The impact that the existing regime has on the environment is also going to be analyzed to help in developing the design space. The financial conditions of the farmers in the Dhapa region as well as the waste collectors in the city will reveal if this project can help them benefit financially in terms of agriculture and other industries prevalent in the region.

The last three sub-questions will yield answers that lead to the total system design taking into account the constraints and objectives of the project and the design variables formed in the previous part. The present grid infrastructure in the region and its ability to import power from a waste to power plant, the proposed technology choices and the quantity of daily MSW generation will determine the capacity of the power plant. Agricultural patterns will get altered based upon the introduction of a cash crop. The business plan for the entire system along with the involvement of CER generation will emerge after analysing the market prices of the system components and the revenue generation from the power plant. The economics involved with the cash crop in the future are not within the scope of this project.

The division between regime description and system design and the segmentation of the sub-questions fall into place within the framework for meta-model of design developed by Herder & Stikkelman (2004)[21]. The meta-model framework presents a structured view on the design process. The framework which has been used to carry out this feasibility study blends the components of the meta-model framework and the framework for developing a conceptual design by Dijkema (2004)[22]. Designing is often an iterative process and the model must not be seen as a step by step guideline, it rather depicts the various design activities that need to be performed and how they relate to each other. The adapted framework will be used to structure both the research itself as well as this report. Some aspects of this model will be incorporated in the evolutionary framework for the set up of a feasibility study for MSW to energy conversion.

The following section of the report shows how the research sub-questions will be answered and what information and data can be extrapolated in order to develop the feasibility study and come up with a conceptual design of a new MSWM scheme in Kolkata.

Stakeholder analysis

The first sub-research question in this study research asks for depth and insight into the actors involved in the MSWM scheme of Kolkata and what are their roles, interactions, power and attitude towards improving the scheme and how the scheme will impact them. A strategic stakeholder analysis based on the Institutional Analysis and Development (IAD) framework [Ostrom et. al., 1994][23] will be made to identify the stakeholder interactions and the space within which the stakeholders make their decisions in this socio-technical-ecological system. The willingness of the farmers of Dhapa to move onto a regime of a cash crop will show the success of such a project being implemented. It also has to be seen whether the KMC and the opposition party will agree to allow a private company to participate in the waste management process of Kolkata and hence interviews and meetings need to be held to discuss the possibilities of a joint venture. Social outlook towards renewable energy systems (RES) and sustainable development can be improved through these interactions. This is how the first sub question will be answered with respect to the role of KMC and how it interacts with the other stakeholders in the system. Interview results and data collection from the various stakeholders will formulate the goals and objectives of the project along with defining the power and attitude of the stakeholders and how changes in the MSWM scheme are likely to impact them. Chapter three of this report deals with this question.

Existent MSWM scheme: potential barriers & constraints

An analysis of the existent MSWM scheme will need to be performed to be able to understand the shortcomings and the possible scenarios for the future of MSWM in Kolkata. Analysing the existent technology policies with respect to waste management schemes and air quality in Kolkata will be the starting point of the second question. To understand why Astonfield and CESC have not yet succeeded in obtaining the land required for this project and why the government is tentative towards signing a MoU, it has to be analyzed where and why do the interests of Astonfield, CESC and the KMC lead to conflicts. Information regarding this aspect can be gained by interacting with KMC officials and obtaining data from the feasibility study carried out by Astonfield. The social, technical and financial barriers that Astonfield and CESC failed to overcome can be understood from this analysis. This analysis will also show the present schemes for waste management in Kolkata as implemented by the KMC and how they will change if the industry intervenes with a waste to power plant project. Moreover, interviews with CESC officials and retrieving data from them will show how much power can be imported by the grid in the location of Dhapa. The permissible limits of emissions into the atmosphere will also determine which technologies can be explored in the design space. The boundary conditions and the barriers and constraints will be determined based on this analysis. This section answers the second sub question and is covered in chapter four.

MSW characteristics in Kolkata

One of the most important aspects of realising waste to power generation is to characterize the waste steam available as input. The physical and chemical properties of the waste stream determine whether the waste generated in the city of Kolkata is suitable for conversion into electricity. Research has been carried out by National Environmental Engineering Research Institute (NEERI) to identify the characteristics of the MSW in Kolkata. The information and data retrieved from this research is available to KMC and CESC. These characteristics show the need for separation of waste streams into usable and non-usable flows and also indicate which technology options can be applied for the specific kind of MSW generated in the city of Kolkata. Some of the core concepts of evolutionary economics [Faber et al. (2005)][24] are embedded within the study research. In predicting MSW generation rates and characteristics and gathering information from the residents of Kolkata, the *bounded rationality* in this research takes shape. The concept of bounded rationality means that the researcher will never have complete and perfect information and hence not include all possibilities in order to perform any behavioural or economic act [Frör, 2008][25]. This research only has access to information gained from databases and interviews with residents in order to predict the MSW output in Kolkata. Since changes in the consumption and behavioural patterns of society are not within the scope of this research, the MSW characteristics are taken to be an exogenous condition in the ensuing research. Also the need for pre-treatment of the waste flow is proved from this data. This technical and statistical research will answer the third question and covers chapter five of this report.

Choices of technology for conversion of MSW to energy

A superstructure will be designed listing all the relevant technologies in the field of MSW conversion to energy. Based upon the quality and composition of the MSW flow in the city of Kolkata, the options in the design space can be narrowed down to the technologies that can be implemented in Kolkata. This establishes the concept of *diversity* in this research. Gasification, pyrolysis and direct combustion techniques are within the scope of this study and will be analyzed. Scientific simulation models based on softwares such as Cycle Tempo will be used to compare the performances of these options in the specific case of Kolkata thereby measuring the performance indicators obtained from the previous sections and comparing the test results based on these indicators. The capacity of the power plant is an important factor while running these simulations and it depends on the capacity of the local grid to import power. Based upon the *selection environment* formed by the exogenous conditions, objectives, constraints and site specific factors, the best choices will be made from all the options in terms of economics and sustainability. Based upon these technology choices, the way Kolkata deals with its waste can be altered so that the waste streams are used effectively and efficiently and in sync with the electricity supply thereby reducing the load on the existing landfill and composting site at Dhapa. The concept of *innovation* is exemplified in this section. This section is the transition of this research from the regime description part to the system design part to develop the design space and covers the sixth chapter of this report.

Economics of pilot plants for MSW to electricity conversion

The business plan for this waste to power generation project takes shape in the next section. The market price of the system components based upon the choice of technology for power generation is going to be derived from catalogues and personal enquiries to the respective companies that manufacture the components. The fixed and variable costs of the system will be determined by separating the initial investment and the operating and maintenance costs of the system. Based upon the lifetime of the power plant, the real price of power will be calculated. Interactions with financial intermediaries and other prospective investors will determine the debt to equity ratio in the initial investment and the interest rate on the debt. Based upon these, the need for waste disposal fees can be presented to the KMC (which it can pass to the consumer) as per present subsidy schemes. A dynamic cost calculation method – Cumulative Present Worth method – will be used to determine the present value of the system stated on a year to year basis throughout the lifetime of the system. This method takes into account the inflation rate and the depreciation rates offered by the government for RES. The internal rate of return (IRR) will be derived from these calculations. Payback periods and profitability follow from these figures. This section shows the *path dependency and lock-in* with the government based upon the subsidy structure. To alleviate the risk, another aspect of *innovation* is used here to involve CDM as a financial instrument to aid profitability. This calls for the definition of the Business As Usual (BAU) scenario based upon coal and hydel based energy demand. Also the annual energy baseline (AEB) will be calculated by interpreting data obtained from databases regarding energy consumption. The present CO_2-equivalent emissions are going to be calculated based on these figures. Then the predicted CO_2-equivalent emissions based on the technology choice for power generation will be calculated. The difference will give the number of CERs generated per year for the lifetime of the system. CER generation from afforestation/reforestation and the production and consumption of bio-fuels in the future will be ignored in this research. However, the scope of CER generation from this activity is not explored. This is again a result of *bounded rationality* because of lack of information that can only be obtained in the future. This extended business case will be dealt with in detail in chapter seven of this report.

Bringing the system into being

Finally, the whole system will be looked upon as one functional unit. A conceptual design will be presented that incorporates the technology option that is deemed feasible. The socio-technical feasibility is dependent upon the feasibility indicators which have been formulated based upon the following aspects:

Institutional aspects

The role of the local government and its policies govern the feasibility indicators. It is the government (in this case - KMC) that decides which stakeholder can play what role. If the system leads to institutional capacity building with respect to KMC, CDM involvement proving the additionality criterion, and complies with the policies and regulations of the KMC in terms of MSWM, then the institutional feasibility of the system will be proved.

Social aspects

Since MSWM involves every layer of society at different points and junctures of the infrastructure [Sembiring et. al. 2010][26], it is important to assume that the MSWM scheme expected to evolve from the research should include feasibility criteria that are influenced by how it impacts society at each intersection of society and MSWM. These criteria are dependent on standards of living, changes of roles and behavioural patterns, economic growth in poorer sections of society. If society benefits from the MSWM scheme in a sustainable way then the set of criteria will be considered to have been fulfilled.

Technical aspects

The options of technology that can be implemented in order to convert Kolkata's waste streams to electricity are presented in chapter five of this report. The technology is deemed to be feasible if the performances in terms of energy efficiency are competitive with prevalent technologies in terms of power generation, and if the demand for electricity and heat in the system is met to a certain extent.

Economic aspects

The regime of MSWM has never been a lucrative sector and private investors rarely show interest in the field because of low IRR on substantial initial investments [Wilson, 1978][27]. However, with the advent of technology in the field of MSWM, policies and strategies are being developed to make the economics of new technologies look more favourable for financial institutions and industry players [Kinnaman, 2009][28]. The IRR of new schemes applicable in the context of Kolkata's MSWM, financial mechanisms to meet initial investments, economics of technologies and the payback period of the pilot plants form the economic feasibility criteria for this project.

Environmental aspects

MSWM practices are bound to have impacts on the local environment. The case of Kolkata's existent MSWM scheme shows how it is integrated with the local ecological system. The impacts on this environment because of a new MSWM plan should be minimal and this forms a criteria for feasibility. Also the air pollution regulation standards applicable in terms of electricity generation should be considered as exogenous conditions while defining the set of environmental feasibility criteria along with the CO_2 emission co-efficient of the flue gases and the way by-products are processed.

These aspects have interactions amongst each other and there are dynamic relationships between the elements of the system which lead to the formation of all the feasibility indicators. Figure 6 depicts the feasibility indicators that form the basis for this research.

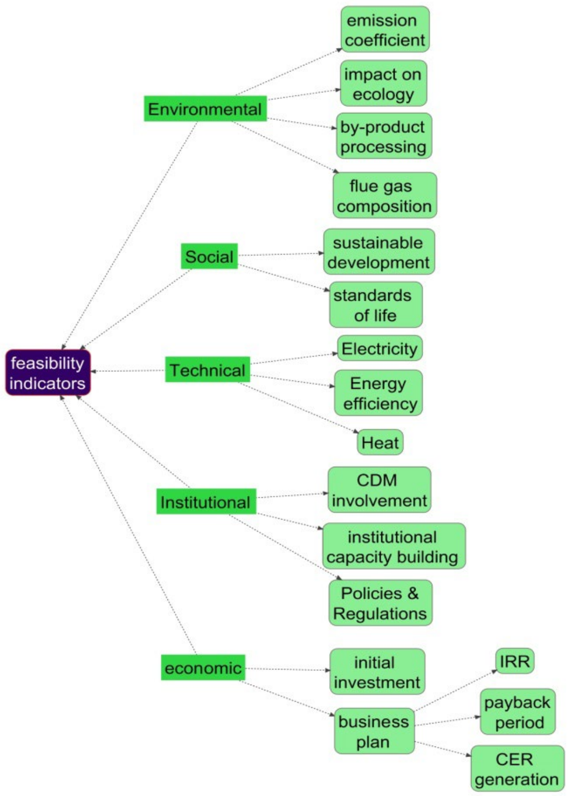

Figure 5 Feasibility indicators for research

Once the system has been proved to be feasible based upon the criterion, the research focusses on how to implement the system in a real life context in the city of Kolkata. The actors involved in the new MSWM scheme will be identified and their roles and interactions will be analyzed. The functioning of every unit in the system and how they are integrated over the lifetime of this project will be explained in this section. Starting from the articulation of demand of the farmers and ragpickers of the Dhapa region with respect to changing their farming patterns and source of livelihood, till the electricity demand of Kolkata being partially met in an environmentally sustainable manner which leads to sustainable development in terms of social and economic aspects – the whole process is to be formulated in this section to be able to bring the integrated system of MSWM, electricity and ecology into being. The concept of *innovation* plays a defining role in establishing this flow pattern of the process. Also the whole process shows the *co-evolution* of the waste to power generation regime with the economic and social development in the city of Kolkata. This section will form the starting point for KMC to decide if they want to plan a new MSWM scheme in Kolkata or not. This covers chapter eight of the report.

Generic framework

The case study of Kolkata's MSWM practices and challenges and how a feasibility study was developed for conversion of its MSWM into electricity will lead to the construction of a generic framework for other waste to power generation projects based upon other location specific exogenous conditions. This framework incorporates the various steps followed in the research for the case study of Kolkata and integrates itself to the meta-model framework developed by Herder et. al. and the conceptual design framework developed by Dijkema at TU Delft (Section of Energy & Industry, Faculty of TPM) as shown in Figure 7. This adaptive framework presents itself as a tool that a researcher or industry player can utilize in order to analyze the feasibility of MSWM schemes in chapter nine of the report.

Conclusions regarding the case study of Kolkata will be drawn in the last chapter of this study report. Recommendations regarding the policy and subsidy structure will be made which will guarantee the success of the scheme envisaged in this study.

As described in this chapter of the report, the research methodology involves starting with the analysis of the social and institutional aspects of the system followed by the technological and economic aspects that govern the design of the system. The study first focusses on identifying the actors and stakeholders in the MSWM scheme of Kolkata and analyzing their roles and interactions and attitude towards reform. This is dealt with in the next chapter.

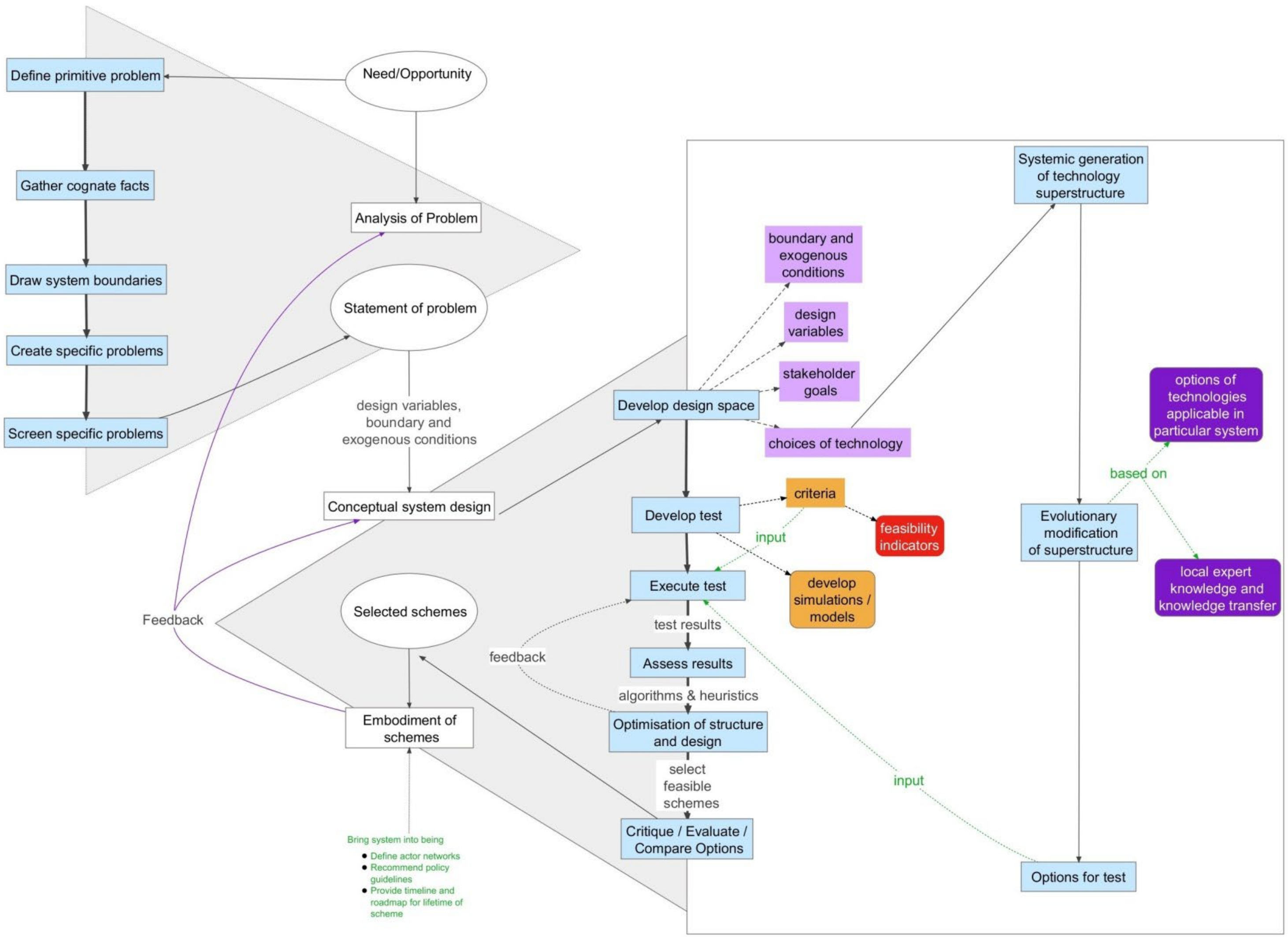

Figure 6 Adapted framework for set up of feasibility study[Dijkema, 2004

3.STAKEHOLDER ANALYSIS

This chapter of the report is dedicated to understanding the actors involved in the project of MSW to power generation in Kolkata. The roles, interactions and objectives of these actors have been analyzed here with the help of a Stakeholder Analysis. Stakeholder Analysis (SA) is a methodology used to facilitate institutional and policy reform processes by accounting for and often incorporating the needs of those actors who have a 'stake' or an interest in the reforms under consideration [World Bank, 2003][29]. Based upon the information collected about the interests, actions and interactions of the stakeholders, reform advocates can shape policies that are realistic and sustainable and acceptable to all the stakeholders. Current models of SA interpret quantitative and qualitative data to understand stakeholders, their positions, influence with other groups, and their levels of interest in a particular reform. Also the impact of the reform on social and political forces can be understood when SA is used because it shows how viewpoints of different groups may differ or coincide and how potential power struggles might evolve amongst groups and individuals. With the help of SA, negotiation strategies with opposing stakeholders can be shaped at early stages in the project so that bottlenecks are avoided in the future.

A stakeholder in a system is "any entity with a declared or conceivable interest or stake"[World Bank, 2001][30] in the system. The range of stakeholders that are relevant for analysis varies according to the complexity of the reform area targeted and the type of reform proposed, and also the incentive to include stakeholders who are not organized in any way. Stakeholders can be of any form, size and capacity i.e. an individual or an organization or unorganized groups can be stakeholders in a project. In most cases, stakeholders fall into one or more of the following categories:

- International actors (e.g. donors)
- National or political actors (e.g. legislators, government)
- Public sector agencies (e.g. Media development authority)
- Interest groups (e.g. unions)
- Commercial/Private organizations for profit
- Non-profit organizations (e.g. NGOs)
- Civil society members
- Users/Consumers

Before the stakeholders for this MSW to power generation project in Kolkata are identified and analyzed, the following questions [IFC, 1998][31] were formulated to serve as guidelines in this stakeholder analysis:

- What are the interests of the various stakeholders and what influence do they have on the project?
- Which stakeholders will help to enhance the project design or reduce project costs?
- Which stakeholders can best assist with the early scoping of issues and impacts?
- At which stage of project development will stakeholders be most affected (e.g. procurement, construction, operations, decommissioning)?

- Who will be adversely affected by potential environmental and social impacts in the project's area of influence?
- Who are the most vulnerable among the potentially impacted, and are the special engagement efforts necessary?
- Who strongly supports or opposes the changes that the project will bring and why?
- Whose opposition could be detrimental to the success of the project?
- Who is it critical to engage with first, and why?

In the description of the stakeholders that will follow, the following attributes have been considered for the analysis:

- the stakeholders' position on the waste to power issue
- the level of influence (power) they hold
- the level of interest they have in the waste to power project
- the group/coalition to which they belong or can reasonably be associated with
- their role and their interactions
- their financial flows

The stakeholders that have been identified for this MSW to power generation project in Kolkata, India are:

- Kolkata Municipal Corporation (KMC) (local government)
- TU Delft (International research body for technology transfer)
- The Ministry of New and Renewable Energy (MNRE) (central government)
- United Nations Framework Convention on Climate Change (UNFCCC) (International regulatory authority for CDM)
- The Ministry of Environment and Forests (central government CDM authority)
- Center for Study of Science, Technology and Policy (CSTEP) (non-profit think tank as CDM regulatory authority)
- CESC Limited (Kolkata's electricity supply company)
- Population of Kolkata – residents and floating (users/consumers)
- Industries in Kolkata (users/consumers)
- Farmers in Dhapa region (grass-root level stakeholders)
- Waste collectors and scavengers (grass-root level stakeholders)
- NGOs in Kolkata interested in this project (non-profit social workers)

Some of these actors and stakeholders are directly connected to the system of MSWM in Kolkata, whereas the others are institutions indirectly associated with the improvement of the scheme. This is depicted in the onion model which has been adapted from Alexander [Alexander, 2005][32] in Figure 8.

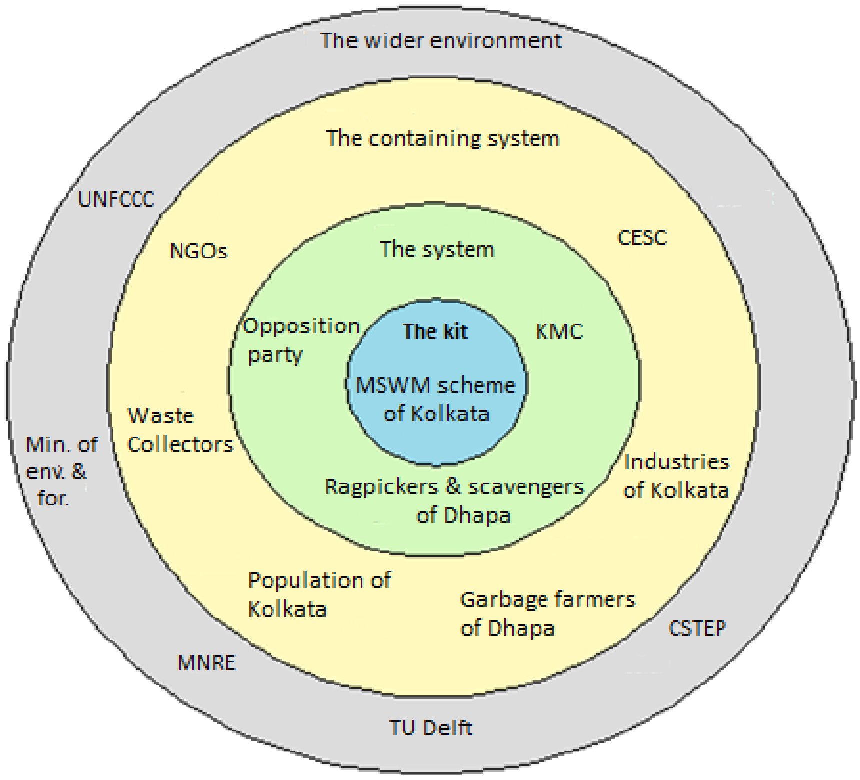

Figure 7 Onion model of stakeholders in Kolkata's MSWM scheme

3.1 Stakeholders: Roles & Interactions

The information presented here has been gathered from interviews [Appendix I – Interviews with stakeholders] with representatives of the respective stakeholders and with local experts who have first-hand knowledge of the system concerned. The suggestions and judgements made in this section are based upon the viewpoints of these representatives and experts and logical conclusions drawn from their comments. Also data regarding previous experiences of these stakeholders have been used to gather information about their roles and interactions.

KMC and the opposition

The Kolkata Municipal Corporation is responsible for MSW management and providing electricity to the city of Kolkata [KMC, 2010][33]. Presently, the MSW management scheme is to collect the waste from households and industries and take it to the landfill site at Dhapa and allow a part of it to turn into compost over time. The KMC is aware of the fact that this is not an efficient measure anymore considering the fact that the daily waste generation is increasing owing to the increase in population and change in consumption patterns in Kolkata over time. The previous government was hesitant in allowing Astonfield to take over the MSW management scheme of Kolkata because there had not been any MoU signed with respect to this and also there was no feasibility report. For this project to succeed, the KMC must exercise its power of governance in favour of private companies with sound technologies and allow them to lease the land or arrange technology transfers. For this purpose, they need to hold discussions with the opposition and address the grievances that will be made.

TU Delft and KMC will combine their research efforts and provide a feasibility report for this project. Also the KMC has to work with NGOs to rehabilitate the farmers of Dhapa who will be impacted by this project. The KMC has to actively participate in lobbying for a waste to power generation plant so that the population and industries of Kolkata accept the reform. It also has to collaborate with the MNRE and the IREDA in order to obtain central government subsidies for this kind of project. Also the co-operation of the opposition can help in reducing the time span of the project because interactions between stakeholders can progress at a faster rate once government approval has been obtained.

CESC

The Calcutta Electricity Supply Corporation is responsible for supplying electricity to the area under KMC as well as in a few districts such as Hooghly, Howrah, South and North 24 Parganas in the state of West Bengal. Currently, they still face a shortfall of around 1082 MW during peak hours. The proposed waste to power generation plant has the capacity to deliver base or peak load power at all times of the day. This potentially reduces the shortage to around 220 MW. CESC also has an obligation to incorporate renewables in their mix of electricity supplied to the city and they have also been carrying out research in the field of MSW to power generation in order to fulfil this obligation. Hence, CESC should be in favour of this project. However, interviews with personnel at CESC show that CESC have a dual nature in this MSWM scheme. Since CESC enjoys an absolute monopoly in the electricity generation and distribution regime of Kolkata, they use their market power to prevent any other IPPs from entering the market. This proved to be an obstacle for Astonfield when they made their proposal to set up a direct combustion plant to convert MSW to electricity. On the other hand, CESC want to enter the sector of converting MSW to electricity themselves and are involved in R & D efforts to achieve their goals. However, because of financial shortcomings in the business plans for MSW, their plans are shelved till date. This blockage exists because of the monopoly of CESC. It can be overcome if the role of CESC in this project is to be the connection between the independent power producer (IPP) and the end consumer. CESC has to be a stakeholder throughout the operational lifetime of the project as the entity which buys the electricity generated by the IPP and sells it to the consumers of Kolkata.

Population of Kolkata

The people of Kolkata play a major role in the social aspects of this project. They are the ones responsible for the generation of waste, and they are the first in the disposal chain. Social awareness about this project is essential for this reason. The fuel for the power plant in this case is MSW. The quality of the fuel is an important factor while considering design of the furnace or the technology to be used or the pre-treatment processes needed. Separation at source can increase the quality of the MSW reaching the dump, but changes in behavioural patterns of society are difficult to achieve [Milani et. al., 2008][34] because an ingrained process such as throwing household waste into one bin and leaving it outside the door for the waste collector has been in practice for a long time in Kolkata. The people first need to understand why they should change their routine and separate plastics and batteries and metals from other wastes and this will take time. The concept of a technology converting the MSW into electricity will diffuse slowly into the layers of society. Information must be shared and awareness campaigns should be initiated in the city so that people know they have an opportunity to contribute at a personal level to make Kolkata a more sustainable city. KMC and NGOs must take on this responsibility of information sharing in society. The population has to be involved with this project throughout its lifetime, and over time, change the way they deal with their waste streams. It may also happen that society refuses to change their patterns of dealing with waste and this will lead to complications whilst implementing new MSWM schemes.

Industries of Kolkata

There are factories, markets, hospitals, institutions and shopping malls and other public places in Kolkata which are responsible for generating waste. To be able to utilize these streams also in this MSW to power generation project, initiatives must be taken in order to organize the waste flow. Most company offices already have to follow standards with respect to waste handling and recycling. Different bins for plastic, paper and metals are currently the norm in most office buildings. So, the resistance to change is lesser in this case. The KMC can define some stringent procedures for office buildings, hospitals, institutions and factories and shopping mall authorities to collect their waste in a more sustainable manner. This helps the system as a whole because industrial waste is more difficult to handle owing to its toxicity. If paper, plastic, polymers and metals can be separated at the source itself, it becomes much easier to utilize the waste for power generation and also for the recycling system. KMC and the industries must collaborate together in order to utilize industrial waste as a supplemental source along with MSW to generate power. The industries need to be involved with this project throughout its operational lifetime.

Farmers of Dhapa

As mentioned before, the area around the Dhapa composting plant is currently used for farming by farmers to grow vegetables which are sold in the markets in Kolkata. If a waste to power generation plant is to be constructed in this site, the land needed to do so will have to be claimed by the municipality. This will potentially take away the livelihoods of some of the farmers. If this is the case, then there will be stiff resistance and in a society like Kolkata's, the power of the people cannot be undermined. Since this project wants to qualify as a CDM project, social sustainability is an aspect which needs to be fulfilled. KMC has to devise a strategy which allows the rehabilitation of the farmers and an alternate source of income for them. Instead of growing vegetables in large areas, a cash crop to make biofuels can be an alternative. Also, they can be employed in this project. However, the resistance to change is higher in sections of society that are not well educated. To make these sections understand the potential of a waste to power generation plant will take much more than information sharing. Before the land can be claimed, the farmers must be notified of the change, and their opinion needs to be heard. It has to be proved to them that the alternative source of income is as much as, if not greater than, what they used to earn before. Only if benefits like these are provided will the farmers yield to this project.

M/S Eastern Organic Fertilizers (India) Private Limited

Along with the KMC, M/S Eastern Organic Fertilizers (India) Private Limited set up a mechanized compost plant in April 2000 to treat a portion of the collected MSW and convert it into usable compost for agricultural purposes. The plant was designed with a capacity of around 700 tons/day. However, due to limited market demand for the compost and other financial disadvantages, the plant reduced its capacity to 300 tons/day. Since 2003, the plant has largely ceased operations, as the company was unable to sell the compost at a reasonable profit and failed to meet its commitments to KMC [Hazra and Goel, 2009][35]. If pyrolysis is adopted as a technology to process MSW and yield biogas and char, then this char can be utilized by mixing it in with the compost and thereby enhance the nutritional properties of the product. Hence, this private company can benefit from the proposed power plant at the Dhapa site. If the plant is not taken into consideration during the design of a new MSWM scheme, it will lead to losses due to sunk investments and deficits in revenue.

Waste collectors and scavengers

Waste collectors in Kolkata are responsible for door-to-door collection in residential areas. They transfer the collected MSW into municipality bins. These bins are then taken care of by the KMC waste collection system. The reason why waste collectors are important in this project is because they have the power to separate the waste streams at the source. This reduces complexity in the operation of the power plant as mentioned before. If people do not separate their waste streams, it is up to the collectors to sort it out when they collect the waste. KMC and NGOs can share the required knowledge amongst the collector unions and provide some financial benefits to the collectors so that they take on this responsibility.

Scavengers, beggars and ragpickers can also be involved in this project and increase their standard of living. The roads of Kolkata have considerable amounts of waste littered over them. The KMC cleaning program can only deal with a certain amount at a time. The scavengers and ragpickers can form a union and gather all the littered waste, separate the streams, and then sell it to KMC as fuel for their power generation plant and to recycling plants. NGOs need to get involved with this section of people to make them understand their role and also to encourage them to take this responsibility.

Scavengers and ragpickers in Dhapa

In the Dhapa dumping and landfill site, there are a number of scavengers and ragpickers who are dependent on the incoming waste stream for their livelihood. Human beings in the age group of 9-70 scourge the landfill site and separate plastics and metal objects from the waste stream. They collect these items and hand it over to the recycling companies for a small fee. This leads to useful combustible materials being removed from the waste stream thereby reducing the calorific value of the MSW even more.

This group of people can join the union as mentioned above or they can also be employed in the project itself as separators during the pre-treatment of the waste. However, this situation needs to be tackled carefully without antagonizing them and NGO's can get involved along with the KMC and the company that plans to invest in the power plant. This group of people need to be aware of their responsibility in the process and realise that they can be of immense help to the whole project.

NGOs in Kolkata

For this project to be implemented, every section of society needs to be involved at one stage or another. NGOs in Kolkata can aid the poorer sections of society and help them participate in this project and also make them understand that they can be a major force in making Kolkata more sustainable. Information and knowledge sharing, helping the farmers of Dhapa and initiating campaigns for sustainability in Kolkata are not easy tasks and people with a more social outlook are the ones who can perform them. KMC can support the NGOs who help the waste collectors and the scavengers. Also other NGOs can install more dustbins in the city of Kolkata so that waste is never wasted. The role of NGOs may be a small one in this project but it is extremely important and has to be present throughout the project's lifetime.

MNRE

The Ministry of New and Renewable Energy is the body responsible for overseeing the progress of renewable energy in the country of India. They formulate policies to promote the growth of renewables, establish guidelines for investors to set up projects and monitor the operations of renewable energy projects across the country. They are also responsible for allocating funds and subsidies to renewable energy projects and hence help developers financially as well by taking part ownership of the financial risks. They disperse their funds generally through IREDA which is a public limited government company and under the administrative control of the MNRE. The MNRE and KMC need to share information amongst each other so that MNRE deems this project to be a renewable energy project and assists its development by providing funds or subsidies or tax exemptions. Also based upon this feasibility report they can revise their schemes for waste to power generation in the country.

KMC and MNRE can be classified into a group of stakeholders who are going to be involved with the project since its inception. KMC has its stake in the project throughout the lifetime of the power plant. The MNRE assumes a supervisory role during project planning and financing stages.

UNFCCC

The United Nations Framework Convention on Climate Change is an international treaty of many countries with the basic objective of reducing GHG emissions and thereby abating global warming. The Kyoto Protocol is an addition to this treaty which has more powerful and legally binding measures requiring the participating countries to reduce their emission levels by an average of 5.2 % below 1990 levels during the first commitment period from 2008 to 2012 [UNFCCC, 2010][36]. India is a non Annex-I country which signed the UNFCCC in June, 1992 and ratified it on November 1993. India Subsequently signed and ratified the Kyoto Protocol on 26 August 2002 and ratified it on 26 August 2002, reinforcing its commitment to global climate action without compromising its economic development goals [37]. This means that under the UNFCCC, developing countries such as India do not have binding GHG mitigation commitments in recognition of their small contribution to the greenhouse problem as well as low financial and technical capacities. Annex-I and Annex-II countries are supposed to help India to reduce their targets by employing a mechanism known as the Clean Development Mechanism (CDM). It allows public or private sector entities in Annex I countries to invest in GHG mitigation projects in developing countries. In return the investing parties receive credits or certified emission reductions (CERs) which they can use to meet their targets under the Kyoto Protocol. While investors profit from CDM projects by obtaining reductions at costs lower than in their own countries, the gains to the developing country host parties are in the form of finance, technology, and sustainable development benefits. All CDM projects in India need to be validated for CDM certification before project implementation and the highest authority is the UNFCCC. For this waste to power generation project, the UNFCCC plays a very high-level but important role because it is the international authority that will decide whether a waste to power generation plant in urban India will lead to real, long-term and measurable GHG reductions as well as social development at every level.

Ministry of Environment and Forests

The Ministry of Environment and Forests is the nodal agency responsible for dealing with climate change issues in India. This ministry was made the National Designated Authority (NDA) for CDM projects in India and reports directly to the UNFCCC. All CDM projects that happen in India have to first prepare a Project Design Document (PDD) and apply for CDM approval to this ministry. The ministry then decides whether the goals of CDM are met and then forwards the PDD to the UNFCCC for the final validation. For this project to qualify as a CDM project the ministry has to be made aware of the entire project plan and then it has to assume the supervisory role of making sure that all the variables in the CDM framework are in place and all the constraints are met before sending in the PDD to the UNFCCC.

TU Delft& CSTEP

The Delft University of Technology is responsible along with KMC to provide the pre-feasibility report of a MSW to power generation plant in Kolkata. The faculty of Technology, Policy and Management at TU Delft is the incubator for the research of this feasibility study. The section of Energy and Industry in this faculty already has a concern called Next Generations Infrastructures (NGI) which works with CSTEP in India and does research on the implementation of smart grids and incorporation of renewables in the energy sector in cities. This feasibility report is an attempt to figure out whether Kolkata has the potential to convert its MSW to electricity. For implementation of new MSWM schemes in the future, TU Delft & CSTEP can play important roles as research institutions and CDM regulatory authorities.

3.2 Stakeholder map

Based upon the information gathered in the previous section where the roles and interactions of the various stakeholders were articulated, the stakeholder mapping process can now be done. To begin with, a model has been made which involves mapping the stakeholders on a three-dimensional matrix with the attributes being power, impact and attitude. This basically means that the stakeholders are grouped according to the power they have in this project, the impact that the project has upon them, and the attitude they have towards this project being implemented. This theoretical model has been derived from the power-impact grid designed by the Office of Government Commerce of the United Kingdom and the three-dimensional grouping of power, interest and attitude designed by Murray-Webster and Simon [Mosaic, 2009][38]. To guide strategic responses, the stakeholders in this project are categorized into groups with the following characteristics:

Influential Active Promoter

Stakeholders who attach a high priority to the development of this project and have enough power to push the reform in the MSWM infrastructure in a positive direction and are impacted in beneficial ways by this reform. At this stage of the project, *CESC* falls in this category along with the *KMC*, because they are the institutions which are responsible for the research required for an improvement to be made to the existing MSWM scheme. Here the positive side of CESC is reflected.

Influential Passive Promoter

Stakeholders who are powerful in their capacity to bring about reform and policy regulations using legislations but are not impacted too much by this project. They wait for the influential active promoters to share information and feasibility reports in order to make well informed decisions which will push the project in a positive direction. The *Ministry of Environment and Forests, MNRE* and *UNFCCC* fall in this category of stakeholders.

Insignificant Active Promoters

Stakeholders who want this project to be implemented so that they benefit in a positive way from it but have little power to actually participate in the implementation of this project. They depend upon the decisions made by the previous two stakeholder groups. Currently the *NGOs, M/S Eastern Organic Fertilizers (India) Private Limited*and*TU Delft* and *CSTEP* belong to this group of stakeholders.

Insignificant Passive Promoters

Stakeholders who want the development of this project so that they can benefit from the project but their business will go an as usual even if this project is not implemented. *Waste collectors* and *industries* of Kolkata are the only stakeholders in this category.

Influential Active Blockers

Stakeholders who attach a high priority to obstruct the development of this project and wield the power to do so because they believe that this project will bring about detrimental impacts to them. Currently, the *farmers of Dhapa* and the *ragpickers* and *scavengers* in the area believe that this project will take away their livelihoods and hence protest in numbers against this project. After sharing information with them and providing them with an alternate source of income, their attitude can be transformed into promoting this project. *CESC* also plays a role in this stakeholder group because they prevent IPPs from entering the market to preserve their monopoly in the electricity generation sector.

Influential Passive Blockers

Stakeholders who obstruct the development of this project because they feel threatened about the potential impacts of this project and can exercise their power to help the influential active blockers to stop this project from being implemented. The *opposition party* is the main stakeholder in this category because they feel that politically this project is detrimental. After discussions and knowledge sharing sessions, the opposition can be influenced to participate in the development of this project.

Insignificant Active Blockers

Stakeholders who do not have much power over the development of this project but believe that this project is harmful to their well being and attach a high priority to prevent this project from being implemented. The *resident people* of Kolkata belong to this category because they are unwilling to change their methods of waste disposal and on a social level refuse to accept changes in behavioural patterns such as separating waste streams at the source based on their characteristics. Once they are made to understand that they actually benefit by doing so with respect to energy demand, their attitude can be changed into that of a positive one for this project.

Insignificant Passive Blockers

Stakeholders who are not impacted by this project in any beneficial way and do not have enough power to obstruct the development of this project and hence do not attach any priority to this project. The *floating population* of Kolkata who use the city's resources only during their time of stay in the day, fall into this category. To be able to make them change their behavioural patterns with respect to waste disposal, only the organizations which these people work for, can intervene and make them change their stance with respect to this project and waste disposal.

This stakeholder analysis is bound to change over the course of time because knowledge sharing and progress reports will change the stance of the stakeholders and also the importance of each stakeholder will vary depending upon the timespan of this project. Hence it is necessary to have different stakeholder maps based upon the power, impact and attitude of the players later on this project. At the end of the feasibility study, another study of the actor network will be made with the changes incorporated in it. The map at this point of time in the feasibility study is depicted in Figure 9 below.

This chapter shows that grass-roots level stakeholders are important in the context of Kolkata's MSWM scheme. The garbage farmers and ragpickers of Dhapa need to be convinced that a change in the MSWM infrastructure of Kolkata by KMC will lead to growth in income and standards of living. Also, CESC has an important role to play if MSW is converted into electricity because they are the body responsible for buying the generated electricity. The population of Kolkata along with the industries need to adopt a more sustainable outlook in order to aid the KMC implement a new MSWM scheme. The next sections of the report build on this stakeholder anaylsis and present the development of the socio-technical system based upon the objectives of the stakeholders.

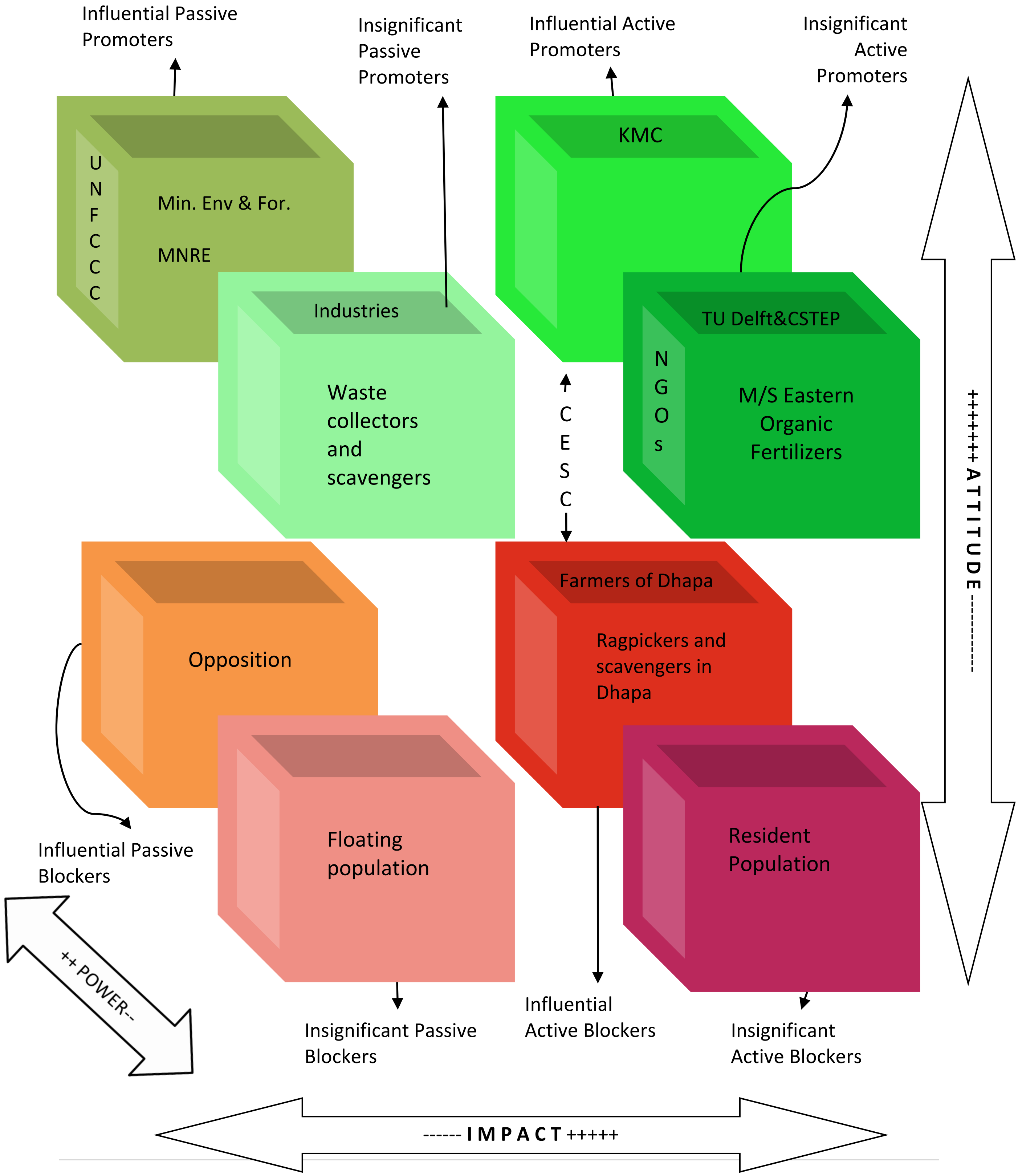

Figure 8 Power-Impact-Attitude Stakeholder map

4.MSWM overview of Kolkata

This chapter of the report deals with the analysis of the existent scheme of waste management in the city of Kolkata and the areas which need improvement and the barriers and constraints that need to be overcome in order to achieve these improvements. To begin with a brief analysis of the MSWM scheme employed by KMC today, is presented.

4.1 Existent MSWM scheme of KMC

KMC is responsible for managing the statutory function of municipal soild waste management in the city of Kolkata. Kolkata is divided into 16 boroughs and 144 electoral wards and SWM department of the KMC manages the waste in this area under four heads (Figure 10):

- Sweeping
- Collection
- Transportation
- Disposal

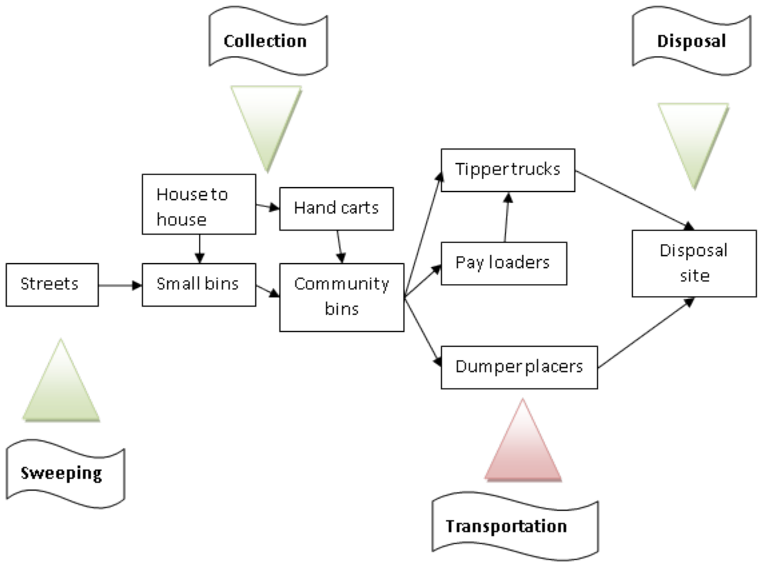

Figure 9 MSWM scheme of KMC

Primary collection of MSW

Sweeping of streets and house-to-house collection are together defined as primary collection of MSW. Each ward is divided into several blocks and each block has sweepers allocated for collection of MSW; each sweeper has a broom and a scraper to clean the streets, open drains, lanes and by-lanes in the block, and uses a containerized handcart or tricycle to place all collected waste (Figure 11).

Figure 11 Waste collector with tricycle cart

Sometimes mechanized sweepers and street-washing vehicles are deployed to clean major roads where the surface is even. After sweeping the streets, the sweepers go from house to house collecting domestic waste which is generally kept outside the doors of the houses or handed over at the doorstep.

Wastes from institutions such as office buildings and hotels and schools and hospitals are collected from a centralized point and it is the responsbility of the institutions to make sure that the waste is kept in one spot. Wastes from market places are collected by the shopkeepers and dumped in one open place. In the absence of more recent, officially published source-wise MSW generation statistics, early studies conducted under the Kolkata Environment Improvement Project (KEIP) remain the most comprehensive publicly available baseline. These figures are therefore treated as historical reference values rather than current estimates (Table 1).

Source of waste	Percentage
Household waste	34.2
Street sweeping	22.8
Institutional waste	6.32
Commercial and market waste	36.37

Table 1 Percent distribution of MSW from various sources in KMC[KEIP, 2003][39]

Sample-based surveys conducted in the early 2000s (notably Hazra and Goel 2009) documented significant inequities in MSW collection coverage across settlement types within the KMC area. These studies showed substantially higher door-to-door collection coverage in standard residential areas and registered slums, compared to unregistered slums, where waste was often deposited in roadside vats, vacant land, or canals, or left unattended.

Under the Solid Waste Management Rules, 2016, and the KMC Solid Waste Management Bye-Laws, 2020, door-to-door collection of segregated waste from all households—including slums—is now mandatory. KMC reports indicate that overall household coverage has increased over time, with approximately 60–65% of households currently reported as being served by door-to-door collection at the city level. However, no recent publicly available data disaggregate coverage by dwelling type, ward, or settlement status.

Accordingly, historical estimates (Table 2) are retained in this report as baseline indicators of structural service inequity, rather than as representations of current performance.

Collection method	Standard residential	Refugee colony	Registered slum	Unregistered slum	All categories
House to house	57.3	70.9	67.1	13.3	61.2
Disposal road side vat	3.9	1.8	12.6	6.1	6.8
Vacant land (no further pickup)	29.4	12.7	14.4	40.8	22.4
Canal (no further pickup)	8.6	12.7	3.6	39.8	8.2
Others	0.8	1.8	2.4	0	0.1
All	100	100	100	100	100

Table 2 Percent distribution of collection methods in different dwellings types in KMC[KMC, 2003][40]

Temporary storage of primary collected MSW

KMC operates a network of temporary MSW storage points in the form of masonry vats, containers, and dumper bins. Historical records indicate over 600 such storage locations, though their number, configuration, and condition continue to evolve. Waste collected during primary collection is deposited at these points for onward transport.

Despite policy intent to phase out open vats, overflowing bins and secondary littering remain persistent issues, particularly in narrow or congested roads where access by collection vehicles is constrained. Irregular vehicle arrival further exacerbates these problems (Figure 12).

Figure 12 Overflowing garbage bin

Secondary collection of MSW

Secondary collection involves transfer of mixed MSW (biodegradable and recyclable) is collected from various sources (domestic, commercial, institutional, municipal services) to the collection points as mentioned above for temporary storage. Waste is directly loaded from these storage points into trucks or trailers manually or by using pay loaders (Figure 13). Currently pay loaders collect waste from only 5% of the total collection points, while the rest is done manually or by private agencies. This is because the pay loaders cannot access the rest of the storage points owing to locations and narrow roads. KMC has a fleet of more than 245 conservancy vehicles (trucks, dumper placer vehicles, tractor trailers, refuse collectors, tipper trucks and pay loaders). Public–private arrangements are also used to supplement transport capacity. However, mismatches between vehicle design and waste characteristics frequently result in spillage during transport, contributing to environmental nuisance and inefficiencies (Figure 14).

Figure 13 Pay loader in action

Figure 14 Waste spilling out of truck

Final disposal of MSW

The KMC has three disposal sites at Dhapa, Garden Reach and Naopara. Dhapa, as mentioned earlier in the report, is the main point of disposal and landfill (Figure 15). Disposal at Dhapa has historically taken the form of open dumping, without engineered liners, leachate treatment systems, or systematic gas capture, and therefore does not conform to sanitary landfill standards.

Dhapa is part of the East Kolkata Wetlands (12,500 ha) which is the intricate man-made ecosystem that treats the sewage of the city naturally. The wetlands have water bodies covering around 46% of the area and 38.92 % is agricultural land. The remaining portion is occupied by urban and rural settlements and sites for garbage disposal. The man made wetlands of this region are also used for aquaculture and take in water from the sewage system of Kolkata. An ecological perspective has been adapted by the civilisation of Kolkata before, which has allowed the city to develop without having to operate or maintain a complicated waste water treatment plant. However, with the rising demand for land for landfill purposes and urban development, siltation is also playing a role in reducing the area occupied by the water bodies. Industries in the neighbouring region have made unauthorized connections to the sewers and contaminate the domestic sewage with their effluent waste water, thereby contaminating the ecology of the whole system of this distributed waste water treatment system in Kolkata. This has lead to the deposition of heavy metal residues in the canals and lower down in the supply chain – the fish and the vegetables produced in these wetlands [WWF, 2002][41]. Recently, industrial ecologists have begun to show concern about the quality of edibles coming into the market from these areas [Dutta et al., 2005][42]. Studies have shown that there can be adverse genotoxic effects caused due to the heavy metal residues if some vegetables are consumed beyond a limit [Patra et al., 2001][43]. In order to reach a sustainable solution to the problems of Kolkata's MSWM, an ecological approach which considers the relationships between the solid waste management system and the waste water treatment ecosystem, needs to be adapted again to preserve the balance.

The landfill area of Dhapa consists of four sectors where garbage is dumped for composting purposes and landfill gas extraction. The 24.71 hectares (ha) that have been used for dumping purposes (since the past 80 years) are also used by farmers to do garbage farming (Figure 16) [KEIP, 2003][44].

Figure 15 Landfill site at Dhapa

Figure 16 Garbage farming at Dhapa

Layers of silt from street sweepings and drainage cleanings are laid over the garbage on a daily basis but these layers do not provide enough compressive strength for movement of heavy vehicles over the Dhapa site. Two bulldozers are employed at the disposal ground for spreading and compacting the garbage (Figure 17).

Figure 17 Bulldozer at Dhapa site

Today there is no treatment provided for the solid waste. Ragpickers and scavengers separate recyclable items from the waste manually after each truck dumps its contents into the landfill site (Figure 18). The ragpickers separate out recyclable streams and collect them. They sell their stock to recycling companies on a per kg basis.

Figure 18 Ragpicker at work

As described earlier in the report, KMC faces a tough task to manage the solid waste generated in the city of Kolkata keeping in mind the projected population rise and the shoratge of landfill area in the Dhapa region. Interviews with the chief municipal engineer and other engineers at KMC reveal that they are aware of this problem and are looking for innovative solutions. Waste to energy conversion is an option that has been looked into previously by them as well as CESC and Astonfield (IPP). This option will lead to alleviation of the problem to a great extent but there are constraints and barriers that need to be overcome in order for such a project to be implemented in a city like Kolkata. The next section analyzes and describes these obstacles faced by KMC and CESC and other IPPs. Since Astonfield's information is deemed to be confidential, this report looks into the efforts of CESC and KMC in terms of MSW to electrical power conversion.

4.2KMC's barriers and constraints

Despite regulatory strengthening and incremental operational improvements, Kolkata Municipal Corporation faces several structural, institutional, and political barriers in transitioning towards a more sustainable and effective MSWM system.

Shortage of land

The Dhapa disposal site, under KMC's control, has functioned as an open dump for several decades and is approaching saturation. Large portions of the site are environmentally degraded, marshy, or structurally unstable, rendering them unsuitable for conversion into a sanitary landfill or for heavy industrial construction without extensive reclamation. Legacy waste deposits also generate leachate that is difficult to intercept or treat retroactively. These conditions significantly constrain the feasibility of expanding disposal capacity or hosting large-scale waste processing infrastructure at Dhapa.

Bounded rationality and Data limitations

Selection of appropriate MSW treatment technologies depends critically on the quantity and composition of waste streams, particularly the relative shares of biodegradable material versus paper and plastics. While Kolkata's waste composition is known to be evolving with economic growth and changing consumption patterns, KMC lacks reliable, regularly updated datasets on waste characteristics and long-term generation trends. This information gap limits the Corporation's ability to make confident, long-term technology commitments. Overcoming this barrier requires systematic waste characterisation studies and the development of forecasting tools capable of accounting for demographic and behavioural change.

Political Opposition and Institutional Continuity
Municipal decision-making in Kolkata is shaped by a politically competitive environment, where long-term infrastructure commitments are often perceived as risky. Proposals involving allocation of land at Dhapa or engagement with private investors have historically faced resistance from opposition parties, resulting in delays or stalemates. Such political uncertainty reduces investor confidence and weakens institutional continuity for large MSWM projects..

Rehabilitation of scavengers and farmers

Dhapa supports a substantial informal economy, including ragpickers, scavengers, and farmers engaged in "garbage farming." Proposed changes to disposal or processing practices are frequently perceived as threats to livelihoods, leading to social resistance. Addressing this barrier requires proactive rehabilitation strategies, livelihood integration, and engagement with civil society organisations. Without explicit social safeguards, MSWM reform efforts risk conflict and implementation failure.

Financial constraints

The KMC already incurs substantial recurring expenditure on the operation and maintenance of its existing MSWM system. Budget documents and project reports indicate that annual MSWM-related expenditure has historically been of the order of ₹1,800–2,000 million per year, covering sweeping, collection, transportation, and disposal activities. These costs constitute a significant share of KMC's discretionary municipal spending.

Proposals for MSW-to-energy or large-scale waste processing facilities typically require tipping fees in the range of ₹350–400 per tonne of MSW to achieve financial viability under prevailing electricity tariffs. Given Kolkata's daily waste generation of approximately 3,500–4,000 tonnes per day, this would imply an additional annual fiscal burden of roughly ₹450–550 million, over and above existing MSWM expenditures.

Passing this additional cost on to residents through higher municipal taxes or user charges is politically and socially challenging, particularly given the city's large low-income population and the already uneven quality of service provision. As a result, KMC's ability to internalise tipping fees within its current fiscal framework remains limited, making long-term contractual commitments to MSW processing or energy recovery projects financially risky without external subsidies or higher tariffs.

Environmental control standards

As the local authority responsible for permitting industrial facilities, KMC must ensure compliance with air emission and noise standards stipulated by the Central Pollution Control Board (CPCB). Given the limited domestic track record of advanced MSW conversion technologies (e.g., gasification, pyrolysis) under Indian waste conditions, KMC has been cautious in granting approvals without credible, site-specific evidence of environmental performance.

4.3 CESC's plans and potential barriers and constraints

CESC is the supplier of electricity to the city of Kolkata. CESC now draws on an integrated portfolio of thermal stations in West Bengal, primarily Budge Budge (750 MW), Haldia (600 MW), Southern (135 MW) and the smaller Crescent plant (40 MW), with these four together supplying power to the Kolkata licence area

Recently, under the Electricity Act of 2003, the West Bengal Electricity Regulatory Commission (WBERC) has implemented the Cogeneration and Generation of Electricity from Renewable Sources of Energy Regulation in 2010. According to this regulation, CESC has to have a mix of renewables in its electricity portfolio of 2% in the year 2010-11, 3% in the year 2011-12 and 4% in 2012-13 [WBERC, 2010][45]. To meet this obligation, CESC have been putting efforts into generation of electricity from solar and wind power. They have also carried out research in the field of MSW to electricity conversion.

CESC submitted a proposal for a 2 MW pilot plant (MSW to syngas to electricity) to the KMC in October 2010. However, it did not proceed beyond the proposal stage and can be considered unsuccessful, primarily due to the following factors.:

Low calorific value of MSW

The calorific value of the waste collected at the landfill site was found to be in the range of **1000 – 1100 kcal/kg**. This is a constraint because with such low values the energy content of the waste cannot be utilized. The reason behind this is the high moisture content in the waste. This acts as a barrier for direct combustion of the waste because the steam produced is not of the required quality to drive a steam turbine and hence generate electricity. To overcome this barrier, CESC realises the need for a pre-treatment plant which produces Refuse Derived Fuel (RDF) from the MSW at Dhapa. It was found that upon drying up the MSW and rejecting the inerts, the calorific value could be increased to the range of 2500 – 3000 kcal/kg. However, 4 tons of MSW will generate only 1 ton of RDF. This RDF could either be processed in an aerobic gasification chamber to generate syngas which would drive a gas engine and hence generate electricity, or it could aslo be treated in the conventional boiler-turbine-generator process where steam would be generated to drive a steam turbine and generate electricity. In both cases the maximum installed capacity that can be achieved with the MSW stream of Kolkata is around 40 MW.

Financial viability

Even though CESC is willing to provide the initial capital expenditure for the power plant, it still fails to make a business case with a suitable IRR because the WBERC has restricted the unit price of electricity from MSW to **R. 4.50/kWh**. Even after including CDM involvement in the business plan, there is still a shortage in the revenue from the sales of the power plant. To make a worthy business case, CESC wants a **tipping fee** of **Rs. 350-400/ton** of MSW from the KMC. The tipping fee is a concept which shows that the KMC should pay CESC a certain amount of money for taking responsibility of processing the waste and solving the problem of KMC even though the problem owner is not CESC but KMC itself. KMC on the other hand refuses to pay this tipping fee because it argues that the land and the water that is to be given to CESC for the power plant will be given to them free of cost and this should compensate for the tipping fee. **Astonfield** had demanded a tipping fee of **Rs 750-800/ton**. In order to overcome this financial barrier, CESC wants to implement a 2 MW pilot plant in order to prove that the technology is valid and that the tipping fee is essential for such a plant to be constructed on an industrial scale. This is why CESC is looking for foreign aid to bridge the gap that is being caused by the absence of the tipping fee.

Unproven technology

Owing to the high moisture content and low calorific value of Kolkata's MSW, the only proven technology to convert MSW to electricity (direct combustion) requires a substantial investment amount in a pre-treatment facility. The existent MSWM regime allows the recycling industry to interact with the Dhapa dumping ground. Ragpickers painstakingly separate recyclables from the daily MSW and rely on the recycling industy for their livelihoods. The non-recyclable part of the daily MSW is the waste flow that is available to the electricity generation system as fuel. If direct combustion of MSW is carried out then the recyclables need to be included in the feedstock. This would render the ragpickers and scavengers jobless and make the recycling industry link to MSWM redundant.

The technologies that exist today to convert RDF to energy are relatively new and have not been proven over a substantial period of time. Another reason for the KMC to not provide a tipping fee or give away the land is because they are skeptical about the technology that is to be implemented. This barrier can be overcome if small scale pilot plants can be set up to verify the simulation results of the innovative technology. Since the MSW collected amounts to nearly 4000 tpd, the scope to actually implement more than one technology with multiple pilot plants is observed. However, even a pyrolysis/gasification pilot plant requires initial investments and technical expertise and skilled labour. Knowledge transfer and technology transfer can assist the setting up of pilot plants in the context of Kolkata. The pilot plants can serve as R & D centres for the industry and research institutions to facilitate innovation in the technologies used to utilize MSW streams. Any other company instead of CESC will face the same problems when it comes to electricity generation from Kolkata's MSW.

4.4 Barriers and constraints exclusive to IPP's

Astonfield is the only IPP that submitted a formal proposal to the KMC to set up a direct combustion power plant using Kolkata's MSW as fuel. However, they faced the same barriers faced by CESC. It will be the same case for any other IPP. The other barrier in the path of any IPP is the existence of complete monopoly of CESC over the electricity generation and distribution market in Kolkata. WBERC Regulations 2010 state that it is the financial responsibility of the IPP to establish an electrical connection between the grid sub-station and the generating station. The regulations also state that the scheme applicable to MSW plants is of the Availability Based Tariff (ABT) mode and a 24 hours day ahead schedule needs to be submitted by the IPP to the Nodal Agency. The IPP is liable to pay unscheduled/mismatch charges on a weekly basis. To be able to break into the locked-in regime, political and financial backing is essential for an IPP because the path dependency is to reach an agreement with CESC to buy the electricity.

This chapter shows that the existent MSWM scheme employed by KMC in Kolkata needs improvement in terms of *collection* (more vehicles and efficient logistics) and *final disposal*. The Dhapa site is getting saturated at a rapid rate and a more innovative technique of dealing with the MSW stream needs to be implemented. The primary barriers and constraints faced by the KMC are *lack of finances, resistance from the opposition party, bounded rationality regarding characteristics of MSW* and *rehabilitation of ragpickers, scavengers and farmers of*

Dhapa. CESC, Astonfield and other IPPs face the problems of *unproven technology, lack of financial viability* and *low calorific value of Kolkata's MSW.* CESC's monopoly also prevents the entry of IPPs into the electricity sector of Kolkata.

Now that the objectives of the stakeholders have been identified along with the barriers and constraints that are associated with implementing a MSW to power plant in the city of Kolkata, the feasibility study can progress to the next stage i.e. the technical and economic aspects of a MSW to power plant. This is dealt with in the next three chapters.

5.CHARACTERISTICS OF KOLKATA'S MSW

One of the principal challenges in designing effective municipal solid waste management (MSWM) systems in Kolkata is the quality and heterogeneity of the feedstock, namely municipal solid waste (MSW) itself. The Kolkata Municipal Corporation has collaborated with research institutions such as National Environmental Engineering Research Institute (NEERI) and utilities including CESC Limited to characterise the composition of MSW generated in the city. MSW characteristics in Kolkata evolve over time in response to changing socio-economic conditions, influencing both the quantity generated and the physical and chemical composition of the waste stream. Additional factors such as seasonal variation, dietary practices, local climatic conditions, and behavioural patterns further contribute to spatial and temporal variability in MSW composition across the city. The broad sources and typical waste types observed in urban systems across Asian cities are summarised in Table 3 providing a conceptual framework for understanding source-wise variation in MSW.

Sources	Typical Waste Generators	Types of MSW
Residential	Single and multifamily dwellings	Food wastes, paper, cardboard, plastics, textiles, glass, metals, ashes, special wastes (bulky items, consumer electronics, batteries, oil and tires) & household hazardous wastes
Commercial	Stores, hotels, restaurants, markets, officebuildings	Paper, cardboard, plastics, wood, food wastes, glass, metals, special wastes, hazardous wastes
Institutional	Schools, government center, hospitals,prisons	Paper, cardboard, plastics, wood, food wastes, glass, metals, special wastes, hazardous wastes
Municipal services	Street cleaning, landscaping, parks, recreational areas	Street sweepings, landscape and tree trimmings, general wastes from parks, and other recreational areas

Table 3 Sources and types of MSW, adapted from [UNEP, 2009][46]

This variation in the MSW characteristics from different sources makes it difficult to obtain a consistent data set regarding the composition of MSW in Kolkata. In spite of this, researchers have published data sets for 1970, 1993 and 2005. Additional source-specific characterisation exercises were undertaken in collaboration with CESC to examine MSW characteristics under different collection conditions; these datasets are used in this report to establish indicative operating ranges rather than point estimates.
Comparison across these datasets provides insight into how Kolkata's waste stream reflects broader transitions in socio-economic conditions, consumption patterns, and behavioural

practices. These trends also offer useful indications of how MSW characteristics may continue to evolve as the city develops further.

5.1 MSW in the 70's and 90's in Kolkata

First a comparison between the MSW in 1970 and 1993 is made [West Bengal govt., 1996][47]. Figure 19 shows the physical characteristics of the MSW in 1970. At this point of time, the city of Kolkata had just begun to witness economic growth and the population was on the rise. The physical composition of the waste from 1970 shows that consumeristic habits were not prevalent in society yet.

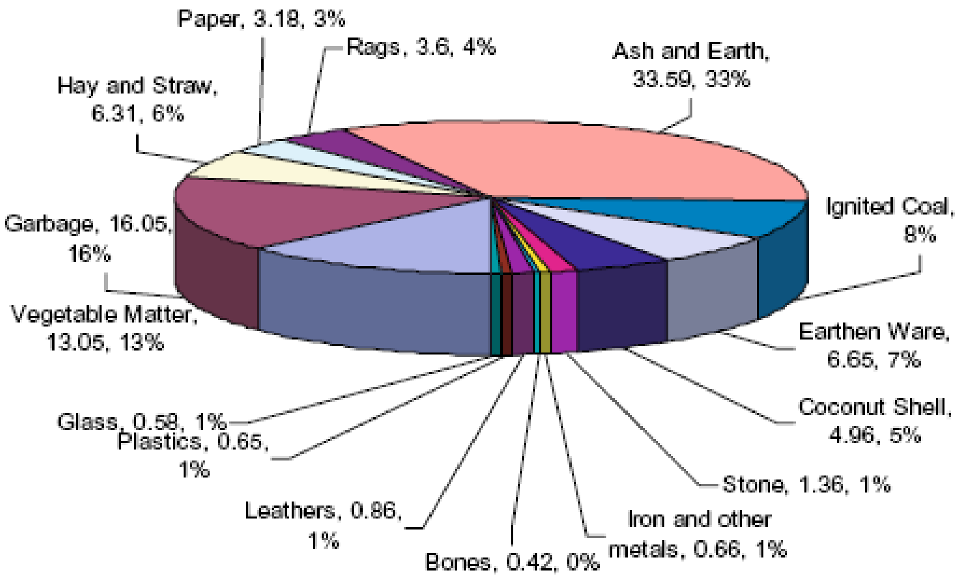

Figure 19 Composition of the MSW of Kolkata in 1970 (All values are in percent by wet weight.)

In 1993, there were some significant changes in the composition of the MSW as shown in Figure 20. Green coconut shells amounted to 9% of the city's MSW. The ash and earth percentage went down to 17% from 33%. Bones formed 4% of the composition which implies that the city consumed more meat than before: an indicator of the economic development. The garbage percentage increased from 16% to around 30%. Also ignited coal dropped from 8% to 2.5%. This shows the increase in the use of domestic LPG for cooking displacing coal as the primary fuel.

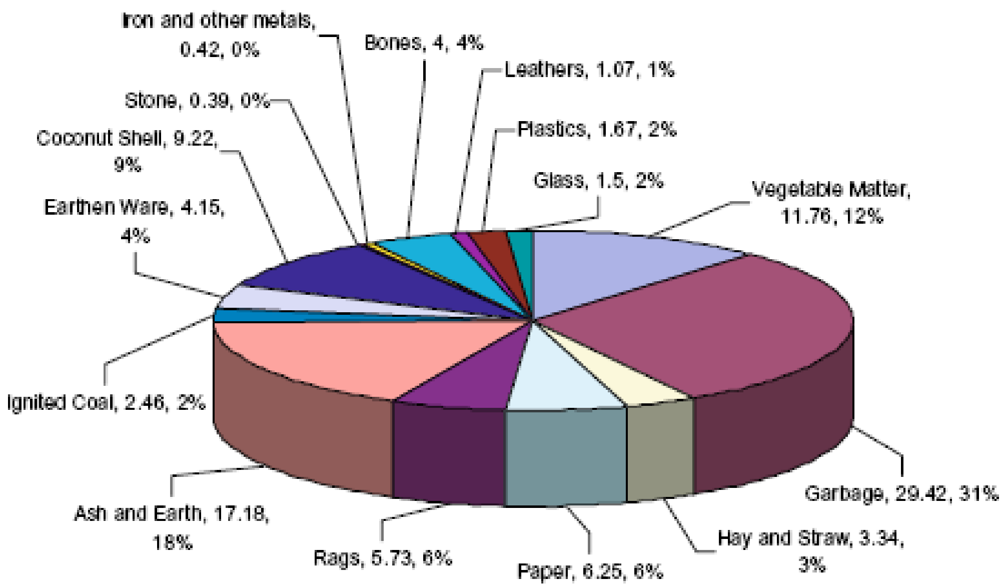

Figure 20 Composition of the MSW of Kolkata in 1993 (All values are in percent by wet weight.)

The chemical characteristics of the MSW is available for the years 1970 and 1995. The characteristics of the MSW in 1993 and 1995 do not vary too much and since the 1995 values are more reliable according to the KMC, the reference has been made to this year. Table 4 lists the chemical characteristics of MSW in 1970 and 1995 [Chattopadhyay et. al., 2009][48].

Parameters	1970	1995
Moisture	42.84	61.57
pH	7.31	6.33
Loss on ignition	35.24	46.78
Carbon	19.58	25.98
Nitrogen as N	0.55	0.88
Phosphorous as P_2O_5	0.57	0.58
Potassium as K_2O	0.4	0.93
C/N ratio	35.6	29.53
Calorific value kJ kg^{-1}	2300	2717

Table 4 Chemical characteristics of MSW in Kolkata in 1970 and 1995 (All values are in percent by dry weight basis except pH, C/N ratio and calorific value)

A sharp increase in the moisture content is observed here. This is because of the increase in quantity of fresh and unprocessed vegetable waste in the MSW stream. This trend shows that the population increased in these years in Kolkata. As the existent population improved their financial conditions and refined their food habits, the poorer sections of society had people coming in from different parts of the state of West Bengal and other regions in the vicinity. This led to more food consumption and hence the increase in vegetable waste. Another interesting trend is the increase in the carbon content of the MSW. This is an encouraging indicator for technological progress as a higher carbon content in the MSW shows that the energy yield of the MSW can be utilized in more efficient ways such as electricity or bio gas production. However, the calorific value did not increase much in 25 years which meant that it was still too early to think about energy conversion from MSW. The C/N ratio is a measure of how much carbon exists in the MSW with reference to the amount of nitrogen in it. Carbon is important because it is an energy producing factor whereas nitrogen is important because it builds tissue for growth of organisms. The C/N ratio is an indicator of the quality of the compost that can be achieved. Compost is used along with soil for agriculture because it enhances plant growth by adding or fixing nitrogen to the soil. During the composting process, the carbon is dissipated more rapidly than nitrogen, thereby bringing down the C/N ratio. Since the ratio went down from 35.6 in 1970 to 29.53 in 1995 making the MSW suitable for composting [CPHEEO, 2000][49], composting was thought to be a feasible treatment process to aid the landfilling at the Dhapa site by the KMC.

5.2 MSW post 2000 in Kolkata

As methodologies and scientific instruments became more sophisticated with the advent of technology, NEERI continued its research in characterizing the MSW generated in Kolkata. In 2005, they published their data along with KMC [NEERI, 2005][50] to characterize the MSW of 2005. The physical characteristics are shown in Figure 21. Compared to the previous data sets, significant changes in consumption patterns can be observed.

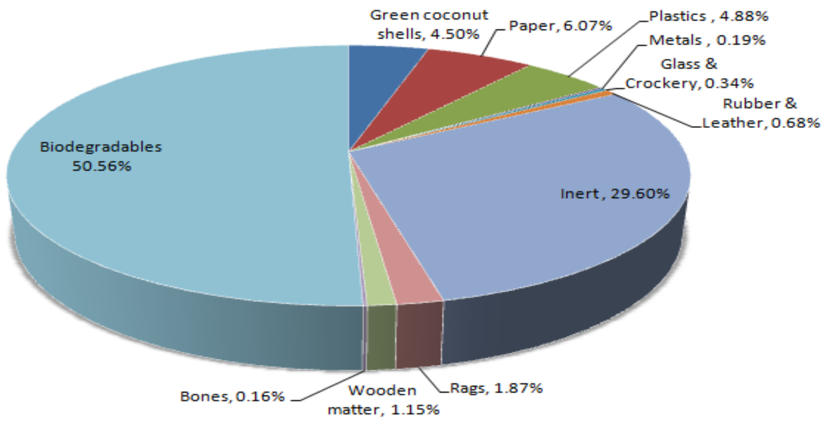

Figure 21 Composition of the MSW of Kolkata in 2005 (All values are in percent by wet weight.)

The biodegradable part of the MSW forms a significant portion and is ideal for composting. The compost plant run by M/S Eastern Organic Fertilizers which had by then started operation used this part of the MSW as feedstock for its finished compost product. Green coconut shells continued to be a high percentage in the MSW content whereas ignited coal had disappeared. This meant that in the hot and humid conditions of Kolkata, the population had made green coconut water consumption an irreplacable pattern. Also domestic LPG had taken over as fuel and coal was no longer used. The amount of paper (6%) and plastics (4.88%), including materials such as food containers and wrapping materials, was noted to be much lower than in developed countries such as the USA (65%) and Western Europe (48%) [IGES, 2001][51]. This meant that unlike these countries, direct combustion would not be a viable option for MSWM in Kolkata. However, compared to the data from 1970 where paper was 3.8% and plastic was 0.6-1%, there is a significant increase. This shows that with economic growth, the consumeristic attitude of the people begins to influence the characteristics of MSW.

The chemical characteristics (Table 5) show some interesting changes from the 1995 data set. The moisture content had gone down to 46% whereas the calorific value had risen significantly to 5028 kJ kg^{-1}. The C/N ratio had come down to 31.81 making the MSW ideal for composting purposes as had already been proved by the operation of the composting plant.

Interesting options that came into being were the innovative processes of biogasification and pyrolsysis.

Parameters	2005
Moisture	46
pH	0.3-8.07
Loss on ignition	38.53
Carbon	22.35
Nitrogen as N	0.76
Phosphorous as P_2O_5	0.77
Potassium as K_2O	0.52
C/N ratio	31.81
Calorific value kJ kg^{-1}	5028

Table 5 Chemical characteristics of MSW in Kolkata in 2005 (All values are in percent by dry weight basis except pH, C/N ratio and calorific value)

5.3 MSW characteristics of Kolkata in 2009

When CESC started investigating the possibilities of generating electricity using the MSW of Kolkata as feedstock for the process, they collaborated with NEERI in 2009 to obtain comprehensive sets of data regarding the composition of the MSW. This time separate analysis was done for MSW collected from the Dhapa dumping ground, markets and hotels in the city. Table 6, Table 7 and Table 8 show the characteristics of the MSW from the respective places as obtained by NEERI.

ANALYSIS OF KOLKATA MUNICIPAL SOLID WASTES (DHAPA DISPOSAL SITES), AS RECEIVED BASIS																	
SI No.	Source Point	Gross Weight (kg)	Moisture %	Organic waste (kg)	Non Organic Waste (kg)									Calorific Value (kcal/kg) wet weight	tential Yield per MT of Wa		Calorific Value (kcal/kg) dry weight
					Recyclables(%)				Others(%)								
					Plastic	Paper	Metal	Glass	Inert	Rubber & Leather	Rags	Wooden Matters	Others		CH_4 (Nm^3)	Compostible (Kg)	
1	D-1	12.2	49.4	6.25	8.19	6.56			18.04		12.29		3.68	1,216	124.92	729.6	2,986
2	D-2	10.35	49	5.30	9.66	3.86		0.97	19.8		5.8		8.69	1,064	106.32	628.2	2,660
3	D-3	11.13	50.5	3.55	8.98	4.94		1.35	40.87		8.98		2.97	917	95.02	539.1	2,462
4	D-4	11.1	50.5	4.20	4.5	4.5			37.38		8.11		7.65	862	88.69	523.7	2,351
5	D-5	12.3	49.5	6.20	21.94	2.03		0.81	15.05		3.66		6.1	854	84.48	560.8	2,277
6	D-6	13.5	50	4.90	6.67	4.81		1.48	20.74	16.67	4.81	1.85	6.66	899	91.18	522.2	2,395
7	D-7	9.45	54	8.50	7.94	5.82			16.93		2.12	3.17	2.64	929	109.77	724.9	2,721
8	D-8	11.1	51.5	6.80	7.66	9			19.83		2.25		1.8	1,002	108.61	707.1	2,700
9	D-9	13.05	52	4.90	8.43	4.65		0.38	37.56		3.83	1.91	5.7	753	80.93	487	2,215
10	D-10	11.42	49	7.95	7.44	5.25			16.4			1.31		988	97.84	761.9	2,511
11	D-11	10	54	5.60	10	3			30		1			680	78.86	600	2,179
12	D-12	9.7	51	6.45	8.76	6.18		0.51	17.01	1.03				993	105.61	726.9	2,648
13	D-13	12	51	7.20	10	5.83			17.91		2.08		4.17	879	92.34	595.8	2,415
14	D-14	9.45	51	6.3	8.99	2.12			21.16		1.06			857	89.86	698.5	2,372
15	D-15	10.2	50.5	5.05	20.59	10.78			12.26	0.98	0.98		4.9	993	103.82	622.5	2,616
16	D-16	13	49.5	7.15	11.54	5.36		0.78	14.23	3.08	6.54		3.47	1,037	105.17	676.8	2,640
17	D-17	15.88	52	8.38	6.93	5.67		0.31	23.3	0.94	3.78		6.31	936	102.72	655.1	2,597
18	D-18	11.8	50	6.50	6.78	10.59	0.42		16.52	0.85	4.66	2.97	2.11	1,146	119.44	733.1	2,890
19	D-19	13.6	51	7.30	9.56	5.51		0.36	28.67				2.2	811	84.49	606.8	2,278
20	D-20	10.3	49.5	6.04	13.11	11.65	0.49	0.49	12.62		2.91		0.97	1,097	111.92	723.2	2,758
21	D-21	12.3	50.5	7.28	8.54	7.93			21.94				2.44	954	99.24	695.2	2,536
22	D-22	9.36	52	5.91	5.88	1.07			16.02		1.61	3.2	9.08	958	105.37	759.6	2,643
23	D-23	11.7	50.5	5.20	5.98	4.71			17.43		1.71	0.85	24.78	1,214	129.24	756.5	3,062
24	D-24	10.75	50	5.35	7.44	2.79	1.39	0.46	19.52		2.79		17.67	1,059	109.46	711.8	2,715
25	D-25	10.9	51.5	5.40	6.44	4.59			15.59	2.75	1.37		19.73	1,081	117.91	747.8	2,863
26	D-26	9.575	49.5	4.88	5.22	3.65			32.37		6.27		1.56	950	95.31	618.9	2,467
27	D-27	10.58	51.5	4.95	11.35	7.09			20.56		0.71		13.48	944	101.81	659.6	2,581
28	D-28	12.2	50.5	6.85	5.74	3.69			32.79		0.82		0.82	787	80.01	606.5	2,199
29	D-29	12.65	47.5	6.30	5.14	10.28			31.62	1.58			1.58	1,008	94.96	600.8	2,461
30	D-30	10.25	53	5.75	12.68	5.86			17.55		7.8			995	113.83	697.7	2,792

Table 6 Physical characteristics of Kolkata's MSW in 2009 in Dhapa dumping ground [Unpublished NEERI data, 2010]

ANALYSIS OF KOLKATA MUNICIPAL SOLID WASTES (SELECTED MARKETS),																	
SI No.	Source Point	Gross Weight (kg)	Moisture %	Organic waste (kg)	Non Organic Waste (kg)									Calorific Value (kcal/kg) wet weight basis	otential Yield per MT of Was		Calorific Value (kcal/kg) dry weight basis
					Recyclables(%)				Others(%)								
					Plastic	Paper	Metal	Glass	Inert	Rubber & Leather	Rags	Wooden Matters	Others		CH_4 (Nm^3)	Compostible (Kg)	
1	M-1	21.95	45	14.30	5.09	2.96			20.96		1.82	0.22	3.86	1,132	99.90	737.9	2,548
2	M-2	13.5	50	10.65	0.55	1.11	1.11		17.77		0.55			962	98.46	805.5	2,522
3	M-3	14.4	50	7.10	6.94	8.33			26.39		4.86	1.39	2.78	1,007	103.50	656.2	2,611
4	M-4	9.8	52	6.30	8.16	4.59	0.511		19.39		3.06			885	96.62	719.2	2,490
5	M-5	12.75	58	8.90	5.1	7.84		1.18	8.67		1.96		5.49	900	123.96	850.9	2,969
6	M-6	9.45	54	7.85	2.65	2.65			10.54		0.53	0.53		922	108.98	867.7	2,707
7	M-7	11.85	56	9.08	2.53	0.63			18.95				1.26	797	101.31	778.5	2,572
8	M-9 **	12.8	57	8.85	8.19	6.43	0.58		12.12	1.42	2.12			802	106.11	775.5	2,657
9	M-10	10.57	60	5.77	10.64	9.22			22.7		1.42		1.42	650	98.34	666.6	2,520
10	M-11	11.17	54	8.07	1.34	4.70			7.62				14.09	1,085	129.14	903.3	3,060
11	M-12	10.3	62	7.40	1.45	3.40			18.93		0.49		3.88	686	113.24	757.4	2,781
12	M-13	13.45	54	9.15	3	6.69			21.18		1.1			872	102.69	757.9	2,596
13	M-14	12.3	50	7.80	1.63	13.01			9.76			8.13	4.05	1,329	140.28	845.6	3,255
14	M-15	13.35	60	9.00	0.56	1.12	0.56	1.12	24.73			0.56	3.93	632	95.86	713.5	2,477
15	M-16	12	56	6.90	8.75	3.13			27.51	1.87	0.62		0.62	621	78.51	737.5	2,173
16	M-17	12.67	55	8.32	3.55	8.28			8.28				14.21	1,072	132.13	881.7	3,112
17	M-18	13.1	58	10.25	4.96	7.63			7.25		1.92			882	121.48	893.2	2,926
18	M-19	11.6	53	9.80	0.86	6.46	0.43		5.6				2.16	1,070	122.87	909.6	2,950
19	M-20	9.65	52	7.85	1.55	1.04			14.51			1.55		949	104.30	839.7	2,625
20	M-21	13.35	50	10.12	0.6	3.37			19.66			0.56		999	102.63	797.7	2,595
21	M-22	12.6	54	9.45	2.38	7.74			11.31				3.57	996	118.14	857.2	2,867
22	M-23	10.8	52	7.95	2.08	0.69			23.61					836	90.89	743.2	2,390
23	M-24	11.55	58	7.25	3.46	10.39		1.73	14.72				6.92	800	110.32	749.1	2,730
24	M-25	12.25	55	8.75	4.49	6.12			15.91				2.04	848	103.69	775.4	2,614
25	M-26	11.6	52	7.90	4.31	4.31			8.19		1.72		13.36	1,064	117.92	836.1	2,863
26	M-27	15.6	56	10.15	1.92	10.9		0.64	7.36		6.41		7.69	1,028	131.23	823.8	3,097
27	M-28	13.8	56	9.90	3.98	3.62			15.21		0.36		5.07	852	108.48	757.4	2,698
28	M-29	14.7	54	10.75	5.44	5.44		2.38	10.2				3.4	882	103.99	716.2	2,619
29	M-30	11.95	56	6.65	10.04	11.71			11.72	2.09	0.84		7.95	921	117.39	736.4	2,854

Table 7 Physical characteristics of MSW of Kolkata in 2009 in markets [Unpublished NEERI data, 2010]

ANALYSIS OF KOLKATA (SELECTED) HOTEL WASTES, AS RECEIVED BASIS																	
SI No.	Source Point	Gross Weight (kg)	Moisture %	Organic waste (kg)	Non Organic Waste (kg)									Calorific Value (kcal/kg) wet	otential Yield per MT of Was		Calorific Value (kcal/kg) dry
					Recyclables(%)				Others(%)								
					Plastic	Paper	Metal	Glass	Inert	Rubber& Leather	Rags	Wooden Matters	Others		CH_4 (Nm^3)	Compostible (Kg)	
1	H-1	12.5	70	9.08	3.61	10.84							12.64	825	117.44	843.5	4,143
2	H-2	11	68	7.50	7.76	7.31			1.83				14.61	872	101.54	758	3,996
3	H-3	14.1	63	9.95	5.69	9.96	2.85	5.69					5	1,141	113.00	807.7	4,102

Table 8 Physical characteristics of MSW of Kolkata in 2009 in hotels [Unpublished NEERI data, 2010]

These data sets reflect the diversity in the composition of the MSW in Kolkata in different parts of the city. However, there are some positive signs for CESC, KMC or any other IPP when they study the characteristics of the MSW of 2009 in Kolkata. The calorific value of the MSW after treatment wherein which the moisture content is reduced to an appreciable extent, is found to be in the range of 10-14 MJ kg^{-1}. Also the chemical characteristics are found to be more or less the same as that of 2005 which means that now there are options to generate electricity from the RDF as well as make compost from the MSW. CESC has been taking positive steps in the direction of generation of electricity from the RDF whereas the composting plant is now operating at around 300 tpd capacity.

The next section of this chapter compares the MSW characteristics of Kolkata to that of developed and developing countries. This is done in order to understand that technologies applied in other countries might not suit the MSW of Kolkata because of the differences in characteristics and how they change over time.

5.4 Comparison with developed countries

While analysing the barrier of bounded rationality in the previous sections, it was deduced that the changing characteristics of Kolkata's MSW led to the KMC being unable to reach a definitive course of action regarding MSWM. Although the climatic conditions of Kolkata are not going to change, the economic growth and consumption patterns of society are bound to influence the MSW characteristics of the city [Nath, 1993][52].

To be able to have an idea of how the MSW composition will change in the future, it is worthwhile to compare the present day MSW characteristics and quantity of Kolkata to those of developed countries. Figure 22 shows the physical composition comparison [Troschinetz et. al., 2009][53]. These figures show that the consumeristic attitude of society in Kolkata is still low as compared to developed countries and this is likely to rise if the current rates of industrialization and economic growth set a trend for the future. The quantity of plastics and paper in the waste stream are bound to rise and hence the KMC and other companies should keep this aspect in mind before designing a long term solution for Kolkata's MSWM. Since the prediction of future MSW characterics cannot be made accurately at present, viable options for the KMC and other companies are to design small scale pilot plants to test the feasible technologies and provide feedback to the long term solution design space. This learning by doing paradigm can help in the implementation of a more sustainable MSWM scheme by taking information from experience into account.

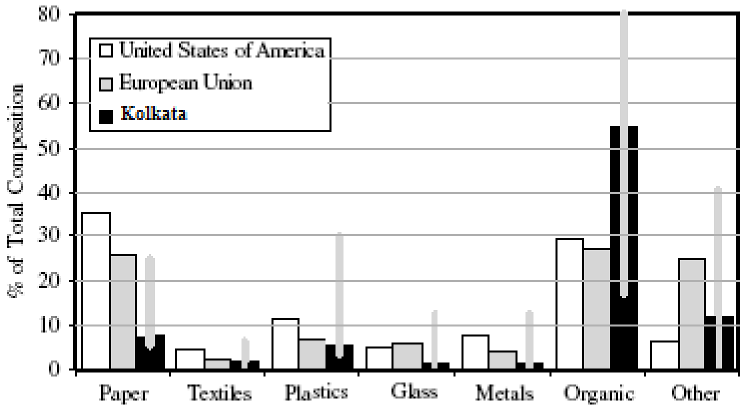

Figure 22 Comparison of municipal solid waste composition of developed countries with Kolkata

This chapter shows that the MSW characteristics of Kolkata evolve over time and are catching up with those of developed countries in terms of papers and plastics in the waste stream. This reflects the growth in economy which is accompanied by a more consumeristic attitude in society. However, due to local climatic conditions, the moisture content in the MSW will always be on the higer side thereby making pre-treatment a necessity for further MSW processing.

Now that the characteristics of Kolkata's MSW have been analysed, the study shifts its focus to how these characteristics affect the choices of technology that can be implemented to convert the collected MSW into electricity. The next chapter of this report deals with the technologies that are being considered by CESC and other IPP's to generate electricity as well as other innovative technologies that have been invented to obtain better energy conversion systems when it comes to MSW.

6.TECHNOLOGIES UNDER CONSIDERATION

As explained in the methodology chapter of this report, the design space consists of a set of technologies that are applicable to MSW conversion and this research chooses the ones that are applicable in Kolkata's context and compares their performances in order to make the right choices of technology. The technology superstructure is formulated in the next section and then the appropriate choices of technology are selected for comparison.

6.1 Technology Superstructure

The scope of this study is restricted to analyzing technologies relevant only to MSW conversion to energy. Based on this and the demands of the system of MSWM in Kolkata, a superstructure can be generated listing the options available for each stage in the conversion process involved (Figure 24).

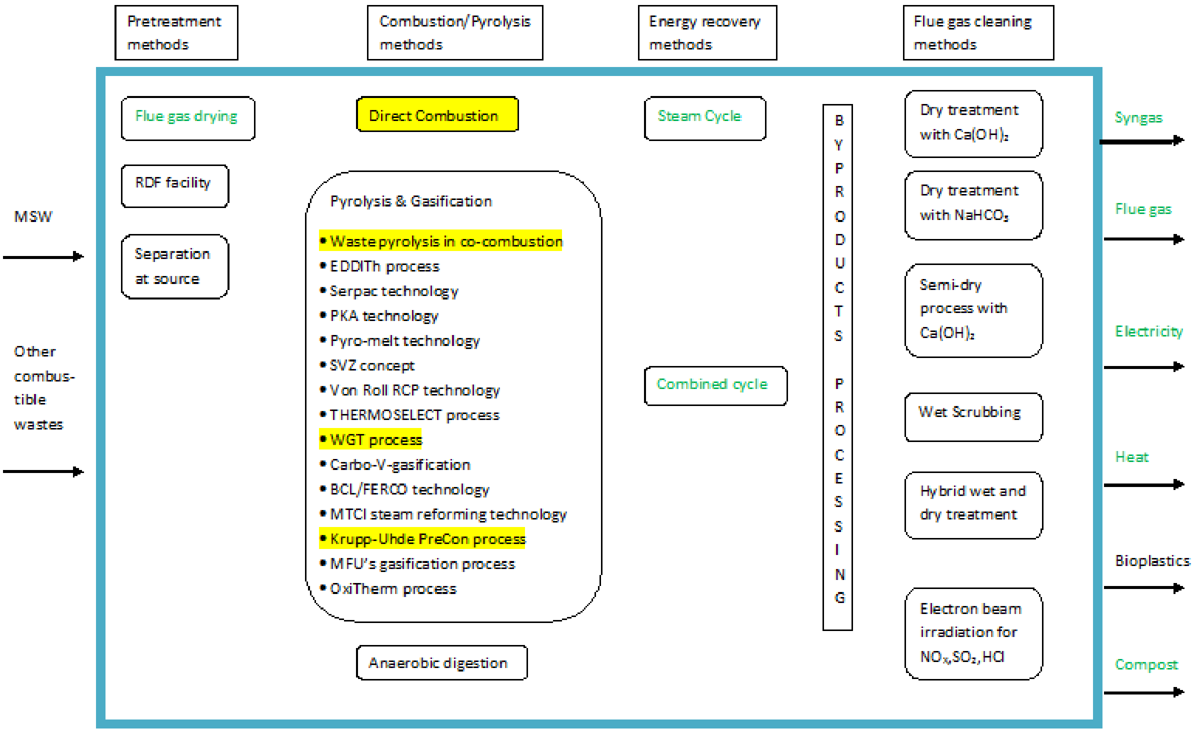

Figure 23 Technical superstructure for research

From the results of the previous section, it can be derived that the biggest obstacle that lies in the path of waste to electrical power generation in Kolkata in terms of technology implementation, is the high moisture content in the MSW of the city. The moisture content lowers the calorific value of the MSW, hence making it unsuitable for direct combustion or pyrolysis or gasification. However, research has shown that if the moisture content is brought down to the range of 20-25%, the calorific value of the MSW goes upto 10-14 MJ kg^{-1}. This range of calorific value makes the MSW suitable for power generation using any of the methods mentioned above. It is imperative however, to have a fuel pre-treatment system which involves sorting of the MSW and a drying process to remove some moisture content. The energy recovery phase usually consists of a steam cycle or an integrated gasification combined cycle (IGCC). The by-products processing stage is not within the scope of this research. Flue gas treatment is an important phase of any energy conversion process when it comes to MSW because of the environmental impacts of the flue gases. All the technologies proposed by CESC, Astonfield and other IPP's to implement MSW to electricity generation, include these design element in their plans.

This research will include a brief study of how a RDF facility can be set up, and how heat recovery from flue gases can be achieved in the pre-treatment phase. In the energy conversion mechanisms, direct combustion has been analyzed from the perspective of an IPP (Astonfield). Amongst the innovative techniques of pyrolysis and gasification the following have been analyzed for energy performance:

- Waste pyrolysis in co-combustion
- WGT process
- Krupp – Uhde PreCon process

The characteristics and reaction conditions of the other options were studied [Malkow, 2004][54] and these three were chosen because of the following reasons:

- Applicable to the context of Kolkata (climatic, suitable MSW characteristics)
- Knowledge by doing in pilot plants in similar locations allow for information and industry data to be made available for research
- Concentrates on electricity generation as Kolkata's heat demand is negligible

In the energy recovery phase, both steam cycles for direct combustion and IGCC for pyrolysis/gasification are analyzed. An overview of the flue gas treatment methods in each technology is presented in this report. The research also quantifies the electricity, heat and flue gas compositions which are the final products of the conversion processes.

The following section looks at the direct combustion technology as proposed by Astonfield and pyrloysis and gasification and compares the performances in order to prove the technical feasibility of a MSW to electrical power generation plant in the city of Kolkata.

6.2 Astonfield's WTE solution for Kolkata – Direct combustion

Astonfield proposed to set up a power plant in Kolkata with Veolia as their technical partner which would use the entire MSW stream of Kolkata as feedstock for combustion in a furnace and then use the heat of the reaction to generate steam which drives a turbine coupled to an electricity generator. The power plant design was based on the following technical features:

- Capacity of the power plant – 57 MW installation

- Land and water to be supplied by KMC for free

- Daily feedstock – 3200 tons of MSW and no separation of paper/plastics at site by ragpickers and scavengers for recycling purposes

- Pre-Processing of MSW to reduce moisture content and increase calorific value with output as pre-processed waste (PW) with calorific value of 10.9 MJ kg^{-1}

- Net power output after boiler – turbine –generator (direct combustion of PW) process – 37 MW to be evacuated to the grid of Kolkata

- Flue gas cleaning to be done adhering to environmental standards and plant ash to be recycled used to create 30 acres of green park land

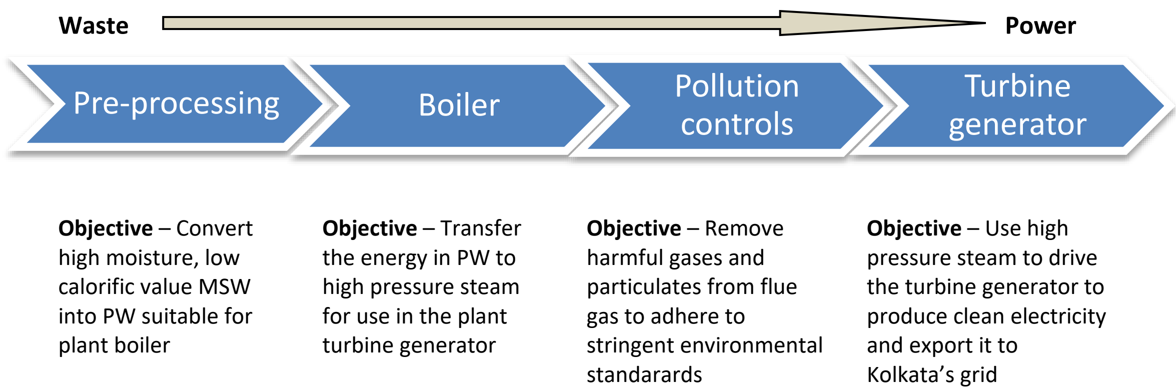

Figure 24 Astonfield's four stage process flow for WTE plant in Kolkata

The process flow of this proposed waste to energy plant is depicted in Figure 25. Each stage is now analyzed in detail in the following sections.

Pre-processing

- Unprocessed, raw waste from the Dhapa dumping ground will be collected and unloaded into a storage bunker. This storage bunker will be separated into two compartments. The first compartment will receive the raw MSW to be treated whereas the second compartment will be used to store PW and give a combustible buffer volume to operate the incinerators for 2 days with the assupmtion that there will be no waste delivery.

- Three refuse cranes will be installed above the bunker and hoppers of the pre-treatment plant. These cranes will be used to feed the raw MSW to the pre-treatment plant as well as to feed the PW to the incinerator hoppers.

MSW as received	**3200 tpd**	**Moisture = 45%**
Sand/Grit/Earth	496 tpd	Moisture = 30%
Stone/ceramics/bricks/other	47 tpd	Moisture = 30%
Unusable biomass/paper/textile	326 tpd	Moisture = 35%
Evaporation	480 tpd	Moisture = 100%
Free leachate (max 5%)	96 tpd	Moisture = 98%
Organic waste after initial processing	**1413 tpd**	**Moisture = 45%**
Plastic/rubber/leather/biomass/paper (combustible)	**342 tpd**	**Moisture = 20%**
PW for boiler	**1755 tpd**	**Moisture = 30%**

Table 9 Sorting of PW from MSW based on material flow and mass balance

- The segregation process of the MSW along with drying of moisture content is done in six stages. Table 9 gives an overview of the end product after segregation and drying of the MSW.

Stage – I (feeders)

The hoppers are linked to "Vibratory cum Gross Screening Feeders". While more than 90% of the MSW (size < 300mm) passes on the main conveyor belt, oversized material is both mechanically and manually removed. The remaining oversized items are fed into a parallel conveyor, feeding these into a shredder which gives a product suitable to be stored in the PW storage bunker.

Stage – II (manual and mechanical segregation)

Now the MSW goes into an elevated inspection belt which is manned by 6 to 9 personnel. The items removed at this stage are:

- Big stones/bricks etc.
- Broken sanitary wares
- Left over textiles, jute bags etc.
- Green coconut shells, wooden pieces etc.

The first two fractions are taken out of the processing limits whereas the other two fractions are fed into the shredder to augment the PW. The stream is now passed below a magentic separator to remove the ferrous objects in the MSW.

Stage – III (Trommel 1)

The remaining textile free material is subjected to de-dusting in a trommel to remove surface adhering soil, sand and grit. A slight vacuum in a fully enclosed system is used for this purpose along with an injection of hot air to facilitate surface drying thereby loosening the soil.

Stage – IV (Hot air drying of PW)

A horizontal slow speed rotary dryer is used to dry the MSW stream using hot air. The fine and lighter particles produced during primary shredding gets entrained into the hot air stream, which are then removed from the exit gases by cyclones, settling chamber and bag filters. The hot air which is used is produced with the help of air/steam exchangers with the steam being supplied from the bleed flows of the steam turbines used in the power plant. This increases the energy efficiency of the whole system and reduces water consumption also. This innovative technique has been proven in the industry.

Stage – V (Trommel 2)

After drying, the material is finally screened through a screening trommel (size 6-8mm). This screening is essential to improve the quality of PW. Owing to its organic content, the undersized fraction could be an excellent soil conditioner.

Stage – VI (Ballistic separator)

This final and critical stage separates the waste stream into two major fractions by vibratory operation in a specialized unit known as the Ballistic Separator. The lighter fraction obtained is mostly organic in nature and taken as final product (PW fluff). The heavier fraction contains inorganic materials along with a good percentage of heavier organic material. To increase the quantity of the PW, the heavier fraction is further treated to recover the organic part and then added to the PW stream. The ballistic rejects are sent to a Reject Processing Area (RPA) for disposal purposes so that they do not compromise the quality of the PW.

Combustion of PW

The PW is now sent to a furnace for combustion through a chute. Since the combustion of the PW is an exothermic process, no auxiliary fuel is required to sustain it. The grate surface of the furnace comprises of fixed and moving step grates arranged alternatively in an inclined gradient and air will be allowed to pass through the gaps. The air of combustion will be drawn from the refuse bunker and will be introduced into the furnace through the underside of the incinerator grates. Automatic control of this combustion process will be made possible using a digital control system which will regulate air distribution in the furnace and the rate at which PW enters the furnace depending upon its calorific value.

The PW is further dried up before combustion in the slow moving reverse acting grate which allows increased agitation of the refuse to achieve efficient combustion. The drying and combustion processes proceed almost simultaneously and the residual combustibles are burnt in the glowing area and the after-combustion area. Drying, combustion and post combustion processes will occur in succession in the path of refuse flow. A clinker roller system will control the discharge of ash. This process is depicted in Figure 26.

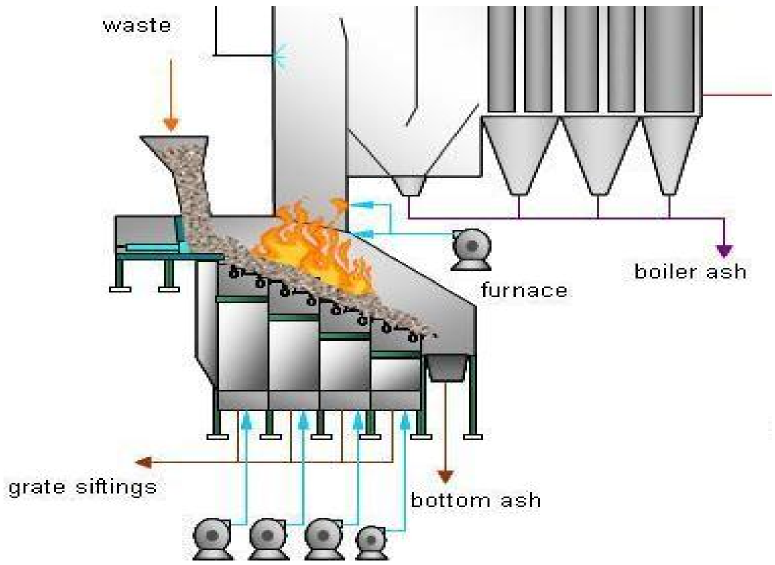

Figure 25 Waste combustion in grate furnace

Boiler

The plant will have three water tube boilers of natural circulation, fed by a top-suspended single drum. 1500 m^3 of water is expected to be used per day and this water will be drawn from the underground water table using bore wells and pumps. Each of the three boilers will be designed to generate steam from the heat released in the combustion unit at maximum continuous rating (MCR). The design data is expected to be as follows:

- Live steam pressure and temperature — 65 bar and 430°C
- Feedwater temperature — 130°C
- Live steam throughput — 3 × 80 tonnes hr^{-1}
- Reference temperature for ambient air — 35°C
- Flue gas temp. at economizer outlet — < 200°C

Flue Gas Treatment System (FGTS)

The FGTS will treat the flue gas produced from the refuse combustion before it is discharged to the atmosphere. The flue gas treatment system installed after each boiler unit will be composed of a Spray Drying Absorption (SDA) system using lime slurry prepared with Hydrated lime powder (Calcium Hydroxide, $Ca(OH)_2$) sprayed in a reactor to remove the acidic contents of the flue gas leaving the boiler. An activated carbon injection system will remove dioxins and heavy metals from the flue gas stream. From the reactor, the flue gas will pass through a bag house filter, which will be capable of removing more than 99.99% of the dust content in the flue gas. The clean flue gas will be dispersed through chimneys of 60m in height. This FGTS system is represented in Figure 27.

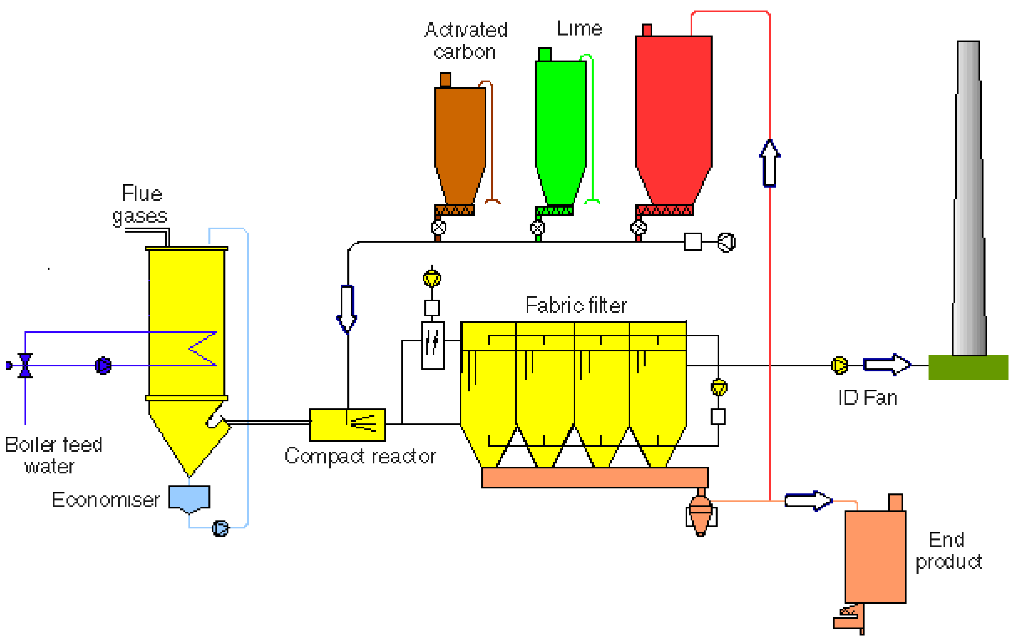

Figure 26 FGTS after combustion

Ash and Scrap Handling System

The burnt residue which will mainly consist of ash and scrap metal, will fall from the stoker clinker roller into the ash extractors. The ash extractors will always be filled with water to cool the hot ash as well as to seal the sub-atmospherically maintained furnace from the outside air. The cooled ash will then be discharged from the hydraulically operated swing type ash extractors to the scraper ash conveyors, which in turn will transfer the ash onto the vibrating screen station.

Ash and slag thrown unto the screen station will be separated into coarse and fine materials by a meshed screen. Scrap metal in the fine ash will be recovered by magnetic separators installed above the fine ash conveyor.

Steam Turbine and Bypass Station

Superheated steam at 65 bar and 430°C will be expanded through two condensing turbines. The turbines will be of the reaction type using fixed and moving blades. Each turbine will drive a generator using a shaft to produce electricity. Each turbo-generator set will be rated at 27 MW, 37 MVA at 10.5 kV and power factor of about 0.9. They will have cylindrical rotors and synchronous 2 pole design. The two turbo-generators will run in parallel. In case of one turbo-generator outage, the steam can be quickly channeled to the other set to maximize power generation. Any excess steam will then be diverted through a pressure reducing bypass station. To keep the whole cycle of the thermal power plant closed, the steam will be condensed and recycled back from the condensate tanks into the boiler.

Superheated steam or saturated steam will be extracted from the three turbine bleeds for heating purposes. Feed water and condensate will be heated by Low Pressure (LP) heaters to enable savings in heat consumption of the plant. A limited quantity of stream extracted from the High Pressure (HP) bleed of the steam turbine will be used to produce the heated air needed to dry the MSW in the rotary dryers in the pre-processing stage.

Electrical Network

The plant's generators will be synchronized with the electricity grid in the region. A portion of the electricity generated (47.7 MW) will be consumed by the plant equipment (21% - 5.25 MW for power plant internal consumption and 4.5 MW for pre-processing facility) during the operation, while the surplus (37 MW) will be sold to the grid through HV step up transformers. The HV feeders connected the grid may serve as incoming or outgoing feeder. Power generated by the plant will be exported to the grid using these feeders. When the generators are not satisfying the demand of the internal consumption of the plant, power can be imported through these feeders as well. The power consumed in the plant will be exported using 10.5/6.6 kV transformers whereas the power exported to the grid will be via 10.5 kV/ HV grid level set-up transformers.

A standby diesel generator will ensure that the plant will have an emergency source of power in case of blackout or grid power supply interruption. A 220Vac safe system (UPS) will be used to power critical electrical equipment during a total plant power failure.

Summary of Astonfield's WTE power plant

Astonfield's power plant plans require 40 acres of land from the KMC and 1500 m^3 of water on a daily basis. The project is designed to receive more than 3200 tpd of MSW and convert it into electricity by using the process of direct combustion. With Veolia Environmental Services as their technical partner, Astonfield have made a sound technical proposal to the KMC to build-own-operate such a power plant. The power plant is supposed to generate 47.7 MW on a continuous basis. After utilizing about 21% of generated power for auxiliary plants and drives, on the basis of 24 hours and 8000 hours at PLF of 90%, the new power generation for the purpose of export to the grid is estimated to be around 255,762 MWh per year. The implementation period has been taken as three years from the issuance of all permits and grants and the date of placement of order for the main plant and equipment. The plant will have a positive impact on GHG emission levels, as the proposed technology will save more than 150,000 tons of carbon dioxide equivalent per year thereby generating well over 150,000 CERs per year. For operation and maintenance of the plant a total of 219 personnel will be required and the lifetime of the plant has been estimated to be 25 years minimum. The process flow diagram of the integrated power plant is depicted in Figure 28 with data given at nominal case. Of all the technologies analyzed in this research, this technology of direct combustion of MSW is the only one that is a proven technology when it comes to implementing large scale power plants to handle a bulk of MSW in a populated city.

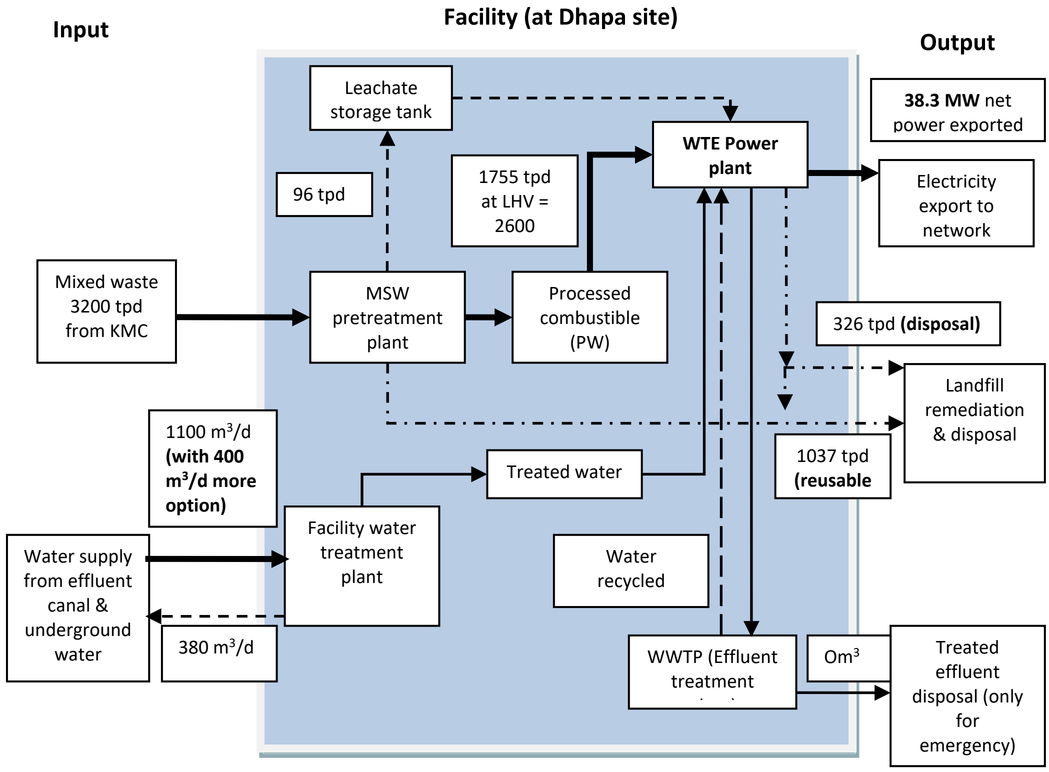

Figure 27 Process flow diagram of integrated power plant proposed by Astonfield at Dhapa

The next section of this technical research focusses on the innovative techniques of pyrolysis and gasification to convert MSW to energy. Before the specific processes are analyzed, this report presents an overview of how the technologies of pyrolysis and gasification work taking in MSW as input.

6.3 Pyrolysis and gasification of MSW

Pyrolysis is a thermochemical decomposition of organic matter at elevated temperatures in the absence of air/oxygen. It occurs under pressure and operating temperatures of above 430°C. The absence of air makes this process different from other high temperature processes and although it is impossible to achieve a completely oxygen depleted atmosphere to prevent oxidation, pyrolysis is a promising technology when it comes to MSW conversion to energy. The products yielded from MSW pyrolysis are biogas (mixture of CO, CH_4, H_2, CO_2& H_2O vapours), bio-oil and char (carbonisation) [Xiao et. al., 2007][55].

Gasification is a specific kind of pyrolysis which involves the conversion of carbonaceous materials such as coal, biomass (MSW) into carbon monoxide and hydrogen by reacting the feedstock with a controlled quantity of air/oxygen and/or steam at elevated temperatures of above 700°C under pressure. The resulting gas mixture is called syngas and is a second generation fuel.

The following research map (Figure 29) shows the aspects to be considered while analyzing the processes of pyrolysis or gasification. This study focusses on electricity generation and hence the analysis concentrates on how to increase the gas yield from the processes. Bio-oil and char are ignored in the pyrolysis process.

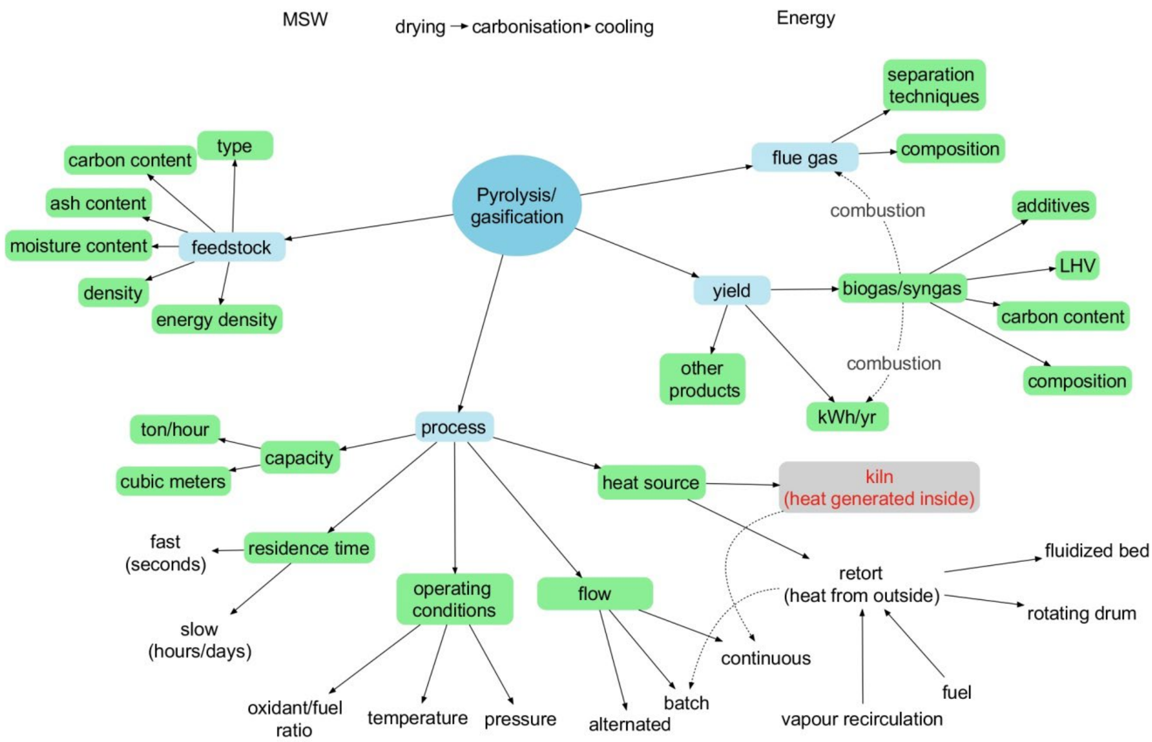

Figure 28 Pyrolysis/Gasification of MSW map (in collaboration with Pietro Galgani, Industrial Ecology, TU Delft)

While analysing a system which incorporates pyrolysis or gasification technologies or both to convert MSW to energy or biogas, the following technical aspects need to be studied in order to understand the process:

- Feedstock
- Process conditions

- Yield
- Flue gas

Feedstock

When MSW is used as a feedstock for a pyrolysis or gasification process the main characteristics that define the process conditions are:

- ***Type of feedstock*** – For analysis purposes, it is important to classify different kinds of waste present in the foodstock i.e. organic matter, industrial wastes, agricultural wastes, paper and plastics, glass, textiles, etc. Based upon these, screening can be done to obtain a feedstock which is suitable for pyrolysis or gasification.

- ***Carbon content*** – This factor shows how much carbon is present in the MSW feedstock relative to other elements. Higher carbon contents allow for higher energy recovery after pyrolysis or gasification.

- ***Ash content*** – Grit/ash act as deterrents to the process and need to be separated out before the chemical reaction takes place.

- ***Moisture content*** – The amount of moisture in the feedstock affects the rate of the equation and also consumes more energy during the chemical process thereby reducing efficiency. If the moisture content is too high, then the need of a pre-treatment drying system arises to increase the yield of combustible fuels and the calorific value of the generated gas mixture.

- ***Density*** – The bulk density of the MSW affects the formation of RDF. If the MSW is compact, then there is not much need for pre-treatment but if the MSW density is low, then a compaction process has to be included in the pre-treatment system.

- ***Energy density*** – The energy density of MSW defines the calorific value of the yielded gas mixture as well as the energy released during the chemical reaction. It also shows what the residence time needs to be in order to maximize energy efficiency in the energy conversion process.

While designing the chemical process itself, these factors relevant to the feedstock properties need to be taken into account.

Process conditions

While designing the chemical processes that occur inside the pyrolysis chamber or gasifier, the main design variables need to be identified in order to model the reaction. The heat source for the reaction, the type of process, the reaction parameters and the capacity are the most important design variables.

Heat source

Pyrolysis or gasification of biomass is an endothermic process and requires heat for the reaction to sustain itself. This heat can be supplied internally or externally. If a kiln is used then the heat can be generated inside the kiln by using heat exchanging equipment and a batch process in order for sufficient heat transfer between the heating elements of the kiln and the MSW to be pyrolysed. If heat is supplied externally, then either a feedback of the combusted flue gases are used or additional fuel is used in a furnace to supply the heat. For external heat source processes, either a circulating fluidized bed reactor or a rotating cone/drum is used for effective heat transfer between MSW particles and heating medium which is usually sand.

Flow

The chemical reaction can either be a batch process or a continuous process or alternate flows wherein which the first stage and second stage are continuous processes by themselves but form a batch process when integrated. Also the flow is determined by the separation techniques used to separate the pyrolysis or gasification reaction from the actual combustion of the yielded gas mixture. External separation using pyrolysis chambers or gasifiers leads to a discontinuous batch process allowing for materials recovery and co-processing of the char to suit the needs of the plant. Internal separation using a furnace or boiler or kiln with different chambers is a continuous process which requires sound balancing of the waste feed, pyrolysis or gasification conditons and actual combustion in order to maximize energy recovery from both the latent and sensible heats of the fuel.

Capacity

The amount of feedstock entering the reaction is measured in kg/sec or tons/hr. This measurement gives an idea of what the volume of the reactor should be in order for the reaction to sustain itself. The volume of the reactor is measured in cubic meters.

Residence time

The time it takes for the reaction to complete itself in order to yield the desired products is the residence time of the fuel in the reactor. It defines the reaction rate as well as the equilibrium constants in the reaction.

If the residence time is small (seconds) then it is called flash pyrolysis which involves high heating rates and yields more bio-oil as compared to char and biogas [FAO, 1994][56]. This research does not focus on this kind of pyrolysis.

Slow pyrolysis is carried out in pyrolysis chambers or circulating fluidised bed reactors where the residence time is in hours or days. The final products are rich in biogas and char content. MSW can be modelled as having residence times of an hour in the pyrolysis or gasification chambers in order to identify the yielded products accurately.

Reaction conditions

The main reaction conditions that need to be analyzed for pyrolysis or gasification systems are operating temperature and pressure, and the oxidant to fuel ratio in case of gasification. The characteristics and composition of the yielded products depend on the specified operating temperature and pressure conditions which also define the reaction rate. In case of gasification the oxidant to fuel ratio quantifies the amount of oxidant being used to convert the MSW into syngas and influences the reaction rate.

Yield

Once the process of pyrolysis or gasification is complete, the products that are yielded are analyzed. Since this research focusses only on technologies to convert MSW to electricity, the main product of concern is the gas mixture. The composition of the gas mixture along with the carbon content and lower heating value (LHV) are measured and the need for additives is deduced from these measurements. The LHV determines the useful energy that can be extracted from the gas mixture after combustion in order to generate electricity (kWh/yr). The other products obtained are identified and separated.

Combustion of product gas

The gas mixture obtained from the pyrolysis or gasification process needs to be combusted in order to generate electricity. Although pyrolysis and gasification technologies have been used in the industry for a long time now, specific applications in the field of MSWM are scarce. Since the application is relatively new, researchers try to integrate them with other new technologies such as fuel cells in order to achieve higher energy efficiency [Kivisaari et. al., 2002][57]. However, MSWM is an infrastructure of its own and problem owners are hesitant to apply unproven technologies because the risk is high. Studies have also shown that it is possible to integrate MSW pyrolysis and gasification systems with conventional technologies such as combustion in an internal combustion gas engine [Stassen et. al., 1997][58] and combined cycle gas turbine plants [Ståhl et. al., 1998][59]. The coupling of MSW conversion with conventional power generators can aid in the diffusion of these technologies in the industry. This section analyzes the two methods, describes the process flow in both cases and compares the performances in terms of energy efficiency and environmental impacts.

Internal combustion gas engine

This technology is the most simple and oldest way of generating electricity from a fuel by using an internal combustion engine. The schematic of such a system is show in Figure 30.

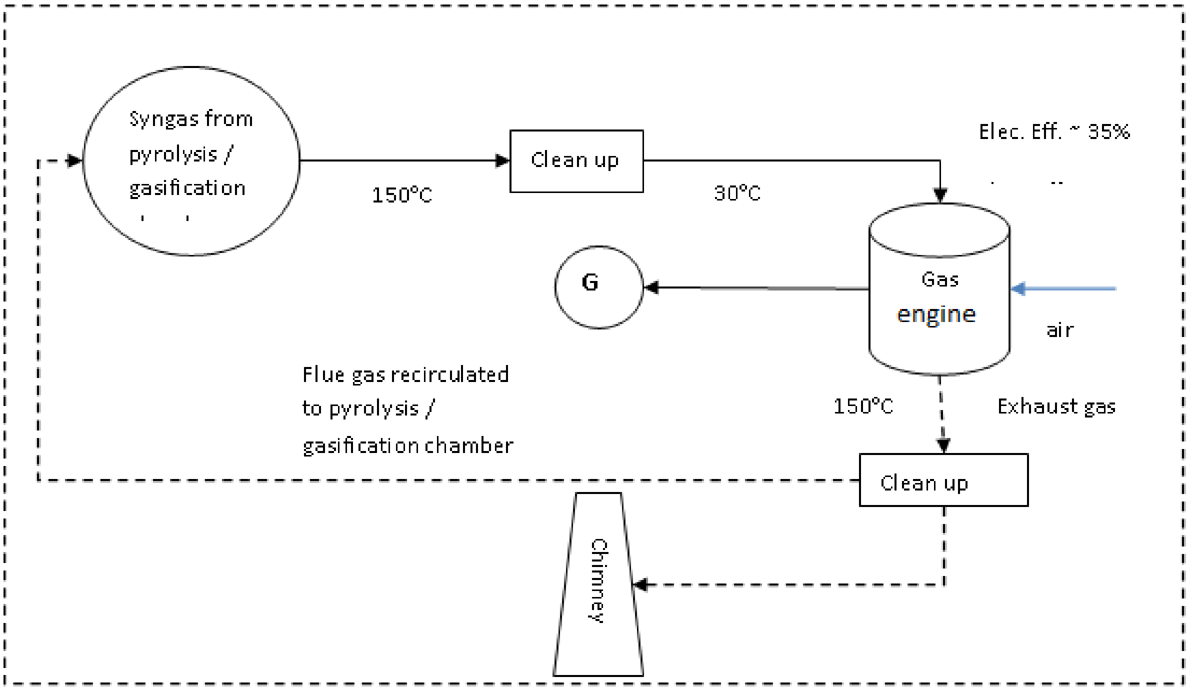

Figure 29 MSW gasification/pyrolysis coupled with IC gas engine

The syngas produced in the pyrolysis or gasification chamber is piped through a clean up section to the IC gas engine to generate electricty. The flue gas from the outlet of the engine is passed through another clean up section before a part of it is recirculated to the pyrolysis or gasification chamber to provide heat energy required for the reaction to sustain itself and the rest is piped to the chimney.

All plant stages operate at normal atmospheric pressure. The global energy efficiency of this plant can be increased by recovering heat before the first clean up section and by increasing the quantity of flue gas being recirculated.

IGCC

For processes which demand higher electricity output than heat, the integrated gasification combined cycle approach can be taken. Figure 31 shows the schematic of such a system. There are two stages of electricity generation in this method of combustion of syngas. The syngas is first piped through a clean up section to a row of compressors which increase the pressure and temperature of the syngas. The compressed gas is then combusted in a burner and the flue gases are used to drive a gas turbine in order to generate electricity. A part of the bleed gas from this turbine is then piped into a heat recovery steam generator section where a flow of water extracts heat from the flue gas and forms steam at high pressures. This steam is used to drive a steam turbine. The other part of the exting flue gas from the turbine is recirculated into the pyrolysis or gasification chamber in order to provide heat for the reaction. The exhausted flue gas is then passed over another clean up section and into the chimney.

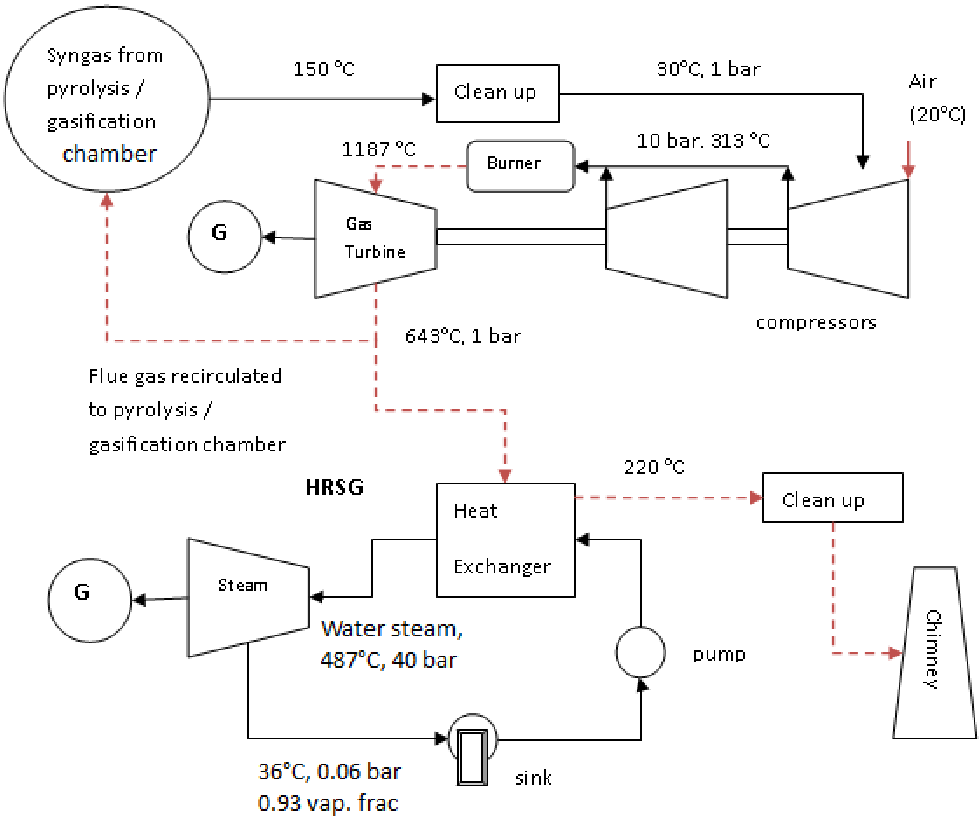

Figure 30 IGCC scheme for MSW

Comparison of performace of IC and IGCC schemes

Table 10 summarises the performances and characteristics of both the schemes [Baratieri et. al., 2009][60]. The performance analysis is based on experiments done with biomass collected from different samples. Since CESC is carrying out research in the field of IC engines and the electrical efficiency of IGCC is higher and the environmental impact is lower and because of Kolkata's low heat demand, this study focusses on IGCC schemes for pyrolysis and gasification of Kolkata's MSW.

	IC Engine	IGCC scheme
Susceptibility to impurities	More tolerant towards contaminants Tar contamination is tolerated	Alkali (Na & K), sulphur and chlorine compounds have detrimental effects Tar contamination below 800°C is detrimental
Energy efficiency	Global efficiency:72.4-73.5 % Electrical efficiency:30.7-31.6 %	Global efficiency:47.1-47.8% Electrical efficiency:40.3-40.9%
Environmental impact	Flue gas composition O_2-5%, N_2-77%, CO_2-18% CO_2 emission coefficient 1.25 kg/kWh_{el}	Flue gas composition O_2-12%, N_2-80%, CO_2-8% CO_2 emission coefficient 0.85 kg/kWh_{el}

Table 10 Comparison of syngas combustion in IC engines and IGCC schemes

Flue gas

The combustion of the gas mixture leads to the production of flue gases which can be used for heat recovery steam generation cycles in order to increase the energy efficiency of the system. The composition of the flue gases needs to be analyzed so that the proper separation techniques can be applied. Also the flue gas composition gives information about the emission coefficient of the process and hence is an indicator for the environmental impact of the technology.

Advantages of pyrolysis/gasification over direct combustion

Although direct combustion is the dominant technology when it comes to thermal treatment of MSW, there are drawbacks when it comes to energy efficiencies and environmental impacts. Compared to fossil fuel fired power plants, MSW incineration plants have energy efficiencies in the range of 13-24 % because the steam used for generation of electricity is at a lower temperature in order to prevent severe boiler corrosion, fouling and slagging in the boiler. The emissions of GHGs per kWh produced in the process is also larger as compared to fossil fuel plants but direct combustion does reduce the uncontrolled GHG emissions into the atmosphere from landfills [Smith et. al., 2001][61]. However, harmful emissions [Porteous, 2001][62] of acidic gases (SO_x, HCl, HF, NO_x etc.) and volatile organic compounds (VOCs) – especially polyaromatic hydrocarbons (PAH), polychlorinated biphenyls (PCBs) and polychlorinated dibenzo-p-dioxine/-furans (PCDD/Fs) [Bruce et. al., 2001][63] – are produced along with heavy metals in the flue gas. Final process residues also create problems for power plant owners. To take care of these issues, heavy investments are needed in order to comply with regulation standards.

Pyrolysis and gasification of MSW is an attractive alternative to direct combustion because these processes have the following advantages:

- Corrosions and emissions are reduced to a great extent because the alkali and heavy metals (except mercury and cadmium), sulphur and chlorine, are contained within the process residues. This prevents PCDD/F formation and NO_x formation is reduced due to lower operating temperatures and reducing conditions. Slagging gasification may also lead to destruction of hazardous compounds and vitrification of various residues, thereby reducing environmental impacts

- Although chlorine and sulphur still exist in the form of HCl and H_2S in the fuel gas, smaller fuel gas volumes demand lower investment costs when it comes to gas clean up. Using oxygen as an oxidant in gasification processes increases these costs, but raises the calorific value of the fuel gas yielded thereby leading to higher energy recovery in these processes.

- The yielded fuel gas can have many applications other than just generating electricity as compared to direct combustion. It can be used as an energy source or raw material. This study concentrates on converting the fuel gas into electricity using IGCC schemes in order to raise the energy efficiency of the MSW conversion process.

Now that the concepts of pyrolysis and gasification have been analyzed, the study focusses on the specific technologies prevalent in industry to convert MSW to electricity using innovative pyrolysis or gasification techniques. The RDF plant as proposed by Astonfield is assumed to be present for all cases.

6.4 Waste Pyrolysis in co-combustion

The PYROPLEQ process [Bracker et. al., 1998][64] by Mannesmann Demag Energie- und umwelttechnik GmbH (MDEU) now part of the French engineering company TECHNIP is based on MSW pyrolysis at 450–500(842–1022°F) in an externally heated rotary drum and combustion of the gas at 1200°C (2192°F) after HGC while integrated in existing or newly constructed power plants. Several plants have been built and operated in Austria, Germany, Italy, Korea and Switzerland during 1987–1996 to treat wastes such as contaminated soil, plastics, refinery and coke residues as well as oil and sewage sludge.

Cycle Tempo model

This research models the involved technology in the Cycle-Tempo software developed at the Process and Energy section at TU Delft. Figure 32 represents the schematic of the model that has been constructed in cycle tempo. The main components of the model are:

- ***Fuel dryer*** – RDF from Kolkata's MSW is fed to the fuel drying section which reduces the moisture content from 50% to 15% thereby increasing the calorific value of the fuel stream. Heat recovery is made from the flue gases exiting the process.

- ***Pyrolysis drum***– This is modelled using a gasifier with an oxidant-fuel ratio of 0.1% ensuring an almost ideal environment for pyrolysis.

- ***Gas clean up/evaporation***– The fuel gas yielded in the pyrolysis chamber is cleaned up in this section in order to reduce corrosion in the following sections. The temperature of the yielded fuel gas is also brought down in this section.

- ***Gas turbine***– The clean fuel gas is fed into a combustion chamber which is connected to a gas turbine coupled to a generator. A part of the power generated is used for the air compressor which feeds air into the combustion unit and into the pyrolysis chamber with the help of another compressor.

- ***HRSG*** – This section consists of a waste heat boiler which stores the water involved in the whole process, and a steam turbine coupled to a generator and a condensor pressure decrease unit. The heat of the flue gases from the gas turbine section is recovered to raise steam in the waste heat boiler. This steam drives the turbine generating electricity. The bleed from this turbine is fed into the condensor pressure decrease unit to bring down the temperature and pressure of the condensed water.

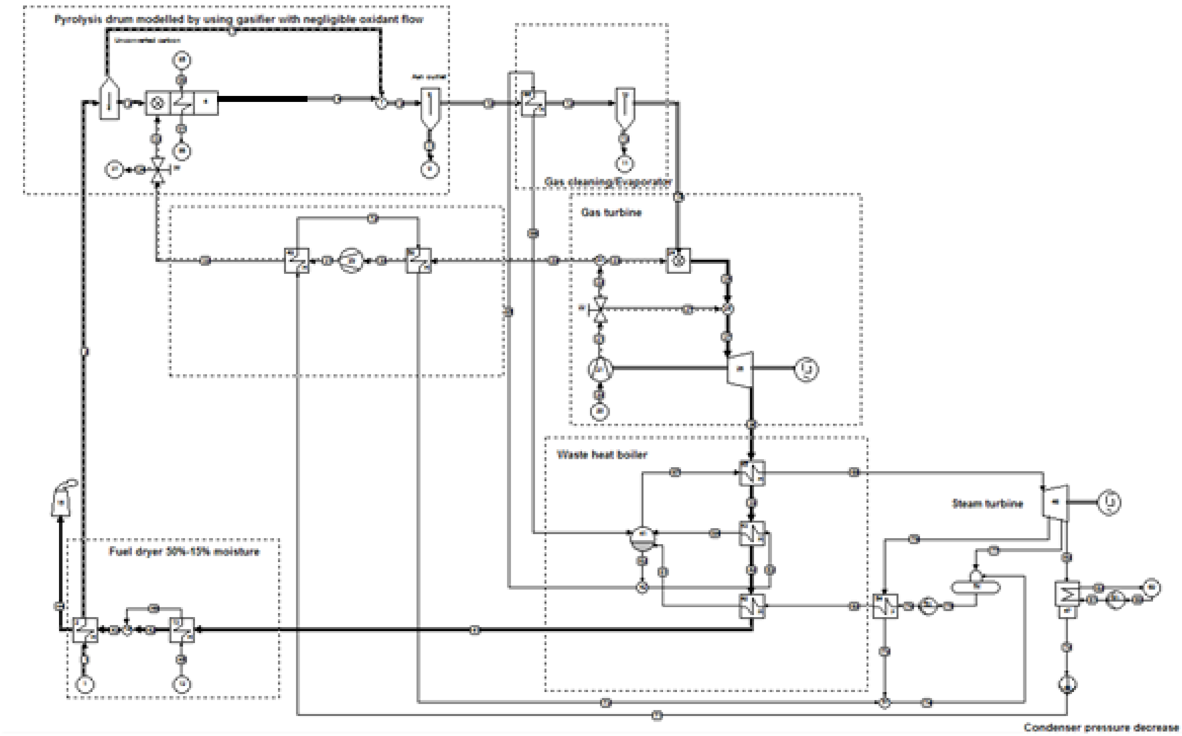

Figure 31 Waste pyrolysis in co-combustion model

Input characteristics and operating conditions

The feedstock for this process is taken to be the MSW generated in Kolkata. The characteristics of the fuel entering the fuel dryer section is tabulated (Table 11) below:

Kolkata's MSW	C	H	H_2O	N	O	SiO_2
Mass fraction	0.2235	0.0509	0.49	0.0076	0.2212	0.0068
LHV of fuel = 7000-8600 kJ/kg						
Max. Mass flow rate = 13.4 kg/s **Min. Mass flow rate = 3.2 – 8kg/s**						

Table 11 Characteristics for fuel input to model

Taking into account that only 1000 tpd of RDF can be produced from the daily collection of MSW in Kolkata and the plant needs to operate on a continuous basis, the maximum mass flow rate of RDF into the process is 13.4 kg/s. However, since there are no large scale pyrolysis plants installed in the industry yet, the minimum mass flow rate is taken to be 3.2 kg/s for modelling a small scale pilot plant.

The operating conditions for modelling the PYROPLEQ process in Cycle Tempo are tabulated below (Table 12).

Temperature of pyrolysis process in drum	Pressure	Oxidant/fuel ratio	Combustion temperature in gas turbine section
450-500°C	5 bar	0.1%	1200°C

Table 12 Operating conditions of PYROPLEQ process

Results of simulation

For the mass flow rate of 13.4 kg/s, the following results (Table 13) were obtained after running the Cycle Tempo model.

Total electrical power to grid	**58.8 MW**
Electrical energy efficiency	73 %
CO_2 emission coefficient	0.4 kg/kWh_{el}
Amount of water required by plant	1148 m^3/day

Table 13 Results of full utilization of Kolkata's MSW in PYROPLEQ process

For the pilot plant, the mass flow has been assumed to be 3.2 kg/s and the simulation yielded the following results (Table 14).

Total electrical power to grid	**8 MW**
Electrical energy efficiency	43 %
CO_2 emission coefficient	0.73 kg/kWh_{el}
Amount of water required by plant	284 m^3/day

Table 14 Results of pilot plant model

The technical details of this PYROPLEQ process modelled in Cycle Tempo are available in Appendix II – Cycle Tempo simulations.

6.5 WGT process

Waste Gas Technology UK Limited (WGT) practises a process which converts different kind of wastes (MSW, sludges, rubbers and plastics, wood and straw) into fuel gas using the technique of gasification of pre-treated dry RDF. The RDF is fed into a cylindrical gasification section operating at temperatures of 700-900°C under pressure to yield a high calorific value gas [Lawson, 2000][65]. The gas is quenched and cleaned of contaminants prior to use in a gas engine or turbine and possible IGCC plants. The scheme of the process is depicted in Figure 33. Small scale plants are in operation in New South Wales, Australia and France.

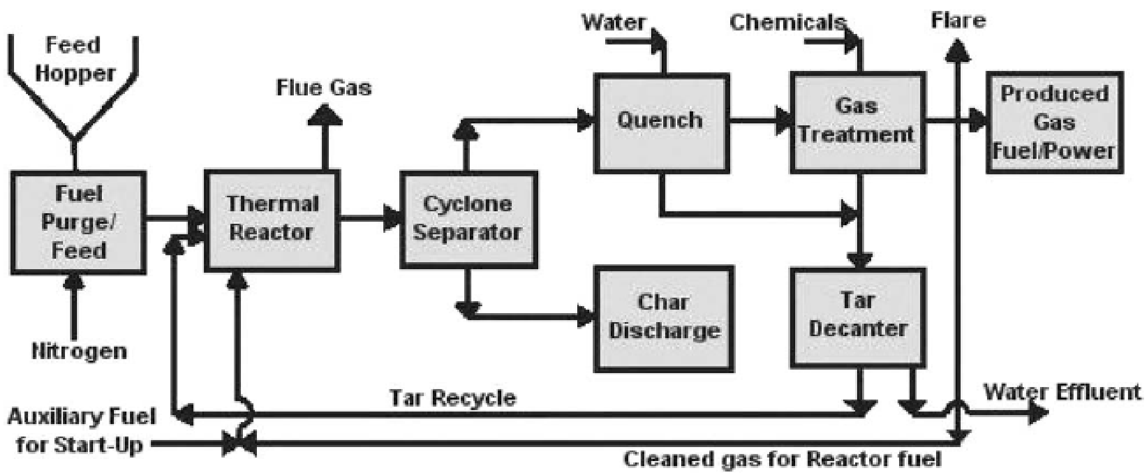

Figure 32 WGT process overview

Cycle Tempo model

The model used in Cycle Tempo to simulate the WGT process with respect to the MSW generated in Kolkata is shown in Figure 34.

The model is similar to the PYROPLEQ process in every way other than the thermal treatment system. Instead of using a pyrolysis drum, a gasification chamber is used with an oxidant-fuel ratio of 1.67 %.

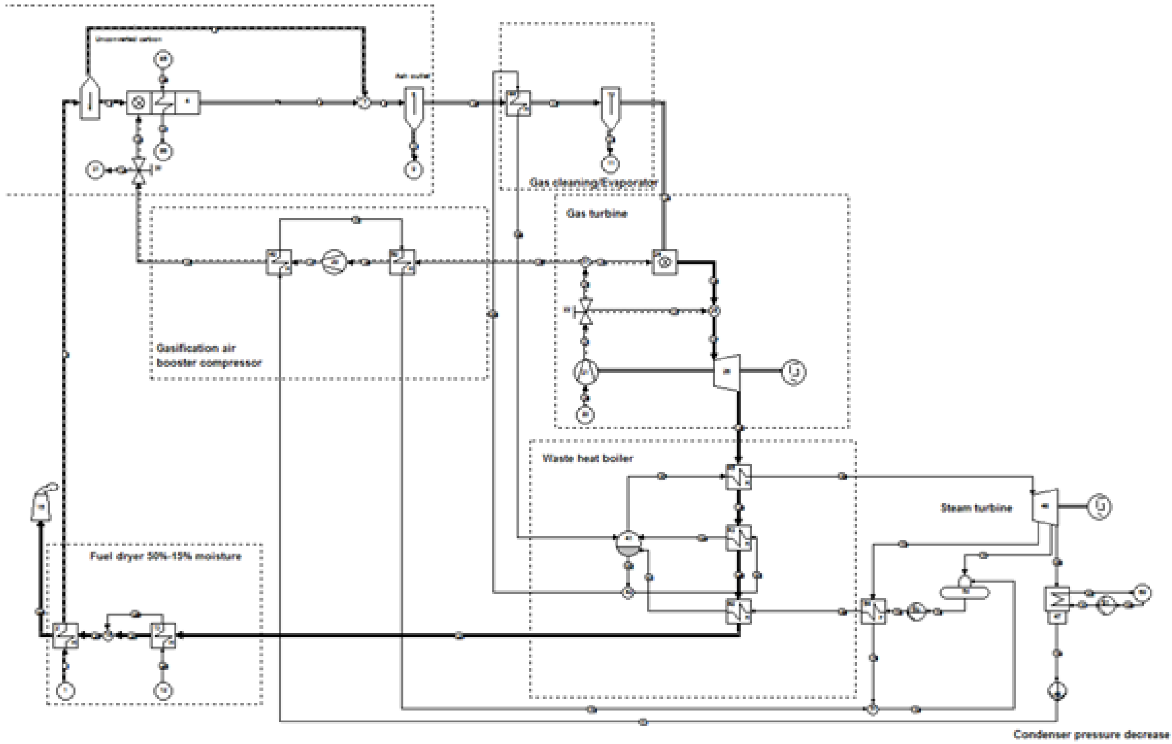

Figure 33 WGT model in Cycle Tempo

Input characteristics and operating conditions

The feedstock for this process is taken to be the MSW generated in Kolkata. The characteristics of the fuel entering the fuel dryer section is tabulated (Table 11) in the previous section which dealt with the PYROPLEQ process.

The operating conditions for modelling the WGT process in Cycle Tempo are tabulated below (Table 15).

Temperature of pyrolysis process in drum	Pressure	Oxidant/fuel ratio	Combustion temperature in gas turbine section
700-900°C	28.6 bar	1.67%	1200°C

Table 15 Operating conditions for WGT process

Results of simulation

For the mass flow rate of 13.4 kg/s, the following results (Table 16) were obtained after running the Cycle Tempo model.

Total electrical power to grid	**42.8 MW**
Electrical energy efficiency	45.6 %
CO_2 emission coefficient	0.52 kg/kWh$_{el}$
Amount of water required by plant	1123 m^3/day

Table 16 Results of full utilization of Kolkata's MSW in WGT process

For the pilot plant, the minimum mass flow has been calculated to be 5 kg/s and the simulation yielded the following results (Table 17).

Total electrical power to grid	**9.6 MW**
Electrical energy efficiency	40.4 %
CO_2 emission coefficient	0.88 kg/kWh$_{el}$
Amount of water required by plant	315 m^3/day

Table 17 Results of pilot plant using WGT process

The technical details of this WGT process modelled in Cycle Tempo are available in Appendix II – Cycle Tempo simulations. The results presented in this section are derived from the simulation.

6.6 Krupp – Uhde PreCon process

The PreCon process is a collaborative effort by Krupp Uhde GmbH and Rheinbraun AG of Germany [Adlhoch et. al., 2000][66]. This process consists of a modular fluidised bed gasification technology to treat waste, biomass, rejected coal in the form of RDF, thermally to produce a fuel gas which is utilized in an IC gas engine or a gas turbine followed by a HRSG scheme. At first, the fuel (ASR, contaminated coke, lignite, MSW, post-consumer plasticsand sewage sludge) is screened for scrap metal removal and dried to <15 wt.% moisture followed by air or oxygen blown High-temperature Winkler (HTW) gasification at ambient or upto 30 bar pressures and steam raising while a melting module for ash and filter dust vitrification is optional.Figure 35 below depicts the schematic for the PreCon process. Although most of the installations which use this technology use the resulting syngas as a raw material for other chemical processes, it has a potential of generating electricity in the context of Kolkata’s MSW.

Currently, a 20 tpd MSW-fuelled steam raising plant at Sumitomo Heavy Industries Ltd (SHI)’s Niihama facility in Sikuku, Japan utilises the concept using a gasifier at 1.5 bar pressure and the ash vitrification module.

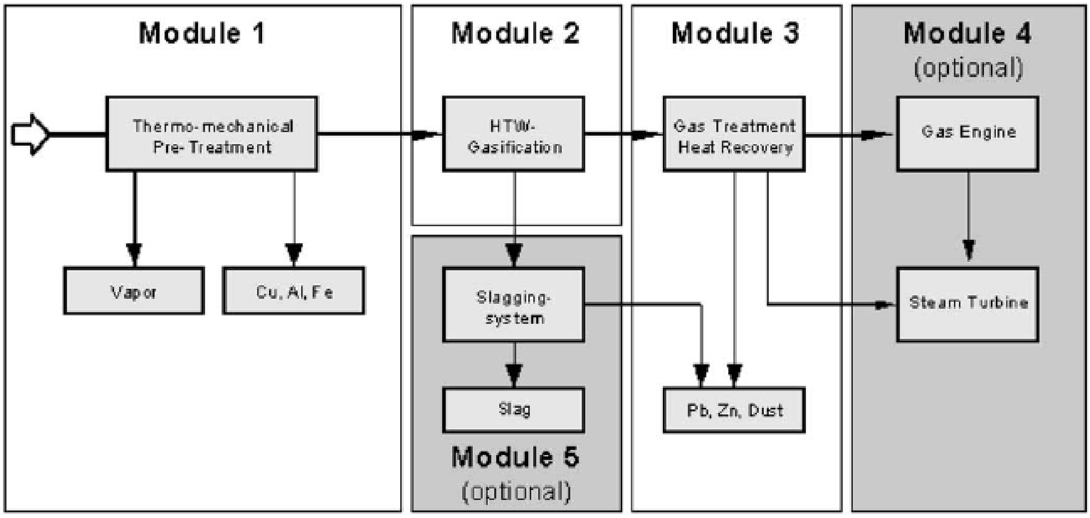

Figure 34 Schematic for PreCon process

Cycle Tempo model

The model used in Cycle Tempo to simulate the PreCon process with respect to the MSW generated in Kolkata is shown in Figure 36.

The model is similar to the WGT process in every way other than the thermal treatment system. Instead of using a gasifier operating at 800°C, it used a gasifier operating at 1000°C and has an oxidant-fuel ratio of 1.8%. The operating pressure is kept at 15 bar. The gasifier unit is modelled using two equilibrium stages. The first stage has an oxidant-fuel ratio of 1.8% at 800°C whereas the second stage has an oxidant-fuel ratio of 0% at 1000°C.

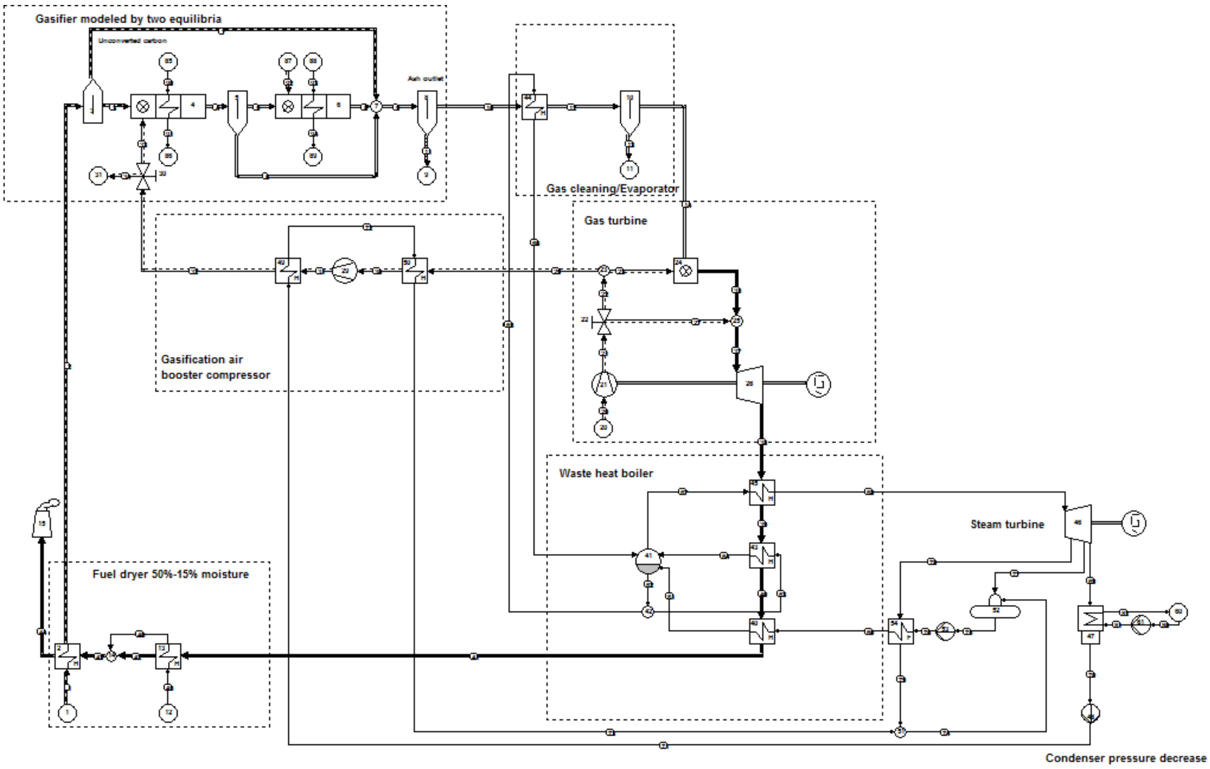

Figure 35 Cycle Tempo model to simulate PreCon process

Input characteristics and operating conditions

The feedstock for this process is taken to be the MSW generated in Kolkata. The characteristics of the fuel entering the fuel dryer section is tabulated (Table 11) in the previous section which dealt with the WGT process.

The operating conditions for modelling the PreCon process in Cycle Tempo are tabulated below (Table 18).

Temperature of pyrolysis process in drum	Pressure	Oxidant/fuel ratio	Combustion temperature in gas turbine section
800-1000°C	15 bar	1.8%	1200°C

Table 18 Operating conditions for PreCon process

Results of simulation

For the mass flow rate of 13.4 kg/s, the following results (Table 19) were obtained after running the Cycle Tempo model.

Total electrical power to grid	**49.6 MW**
Electrical energy efficiency	46.3 %
CO_2 emission coefficient	0.56 kg/kWh_{el}
Amount of water required by plant	1193 m^3/day

Table 19 Results of full utilization of Kolkata's MSW in PreCon process

For the pilot plant, the minimum mass flow has been calculated to be 8 kg/s and the simulation yielded the following results (Table 20). Unlike the PYROPLEQ and WGT process, the characteristics of Kolkata's MSW do not allow this process to be technically feasible at capacities less than 29 MW.

Total electrical power to grid	**28 MW**
Electrical energy efficiency	40.8 %
CO_2 emission coefficient	0.62 kg/kWh_{el}
Amount of water required by plant	553 m^3/day

Table 20 Results of pilot plant using PreCon process

The technical details of this PreCon process modelled in Cycle Tempo are available inAppendix II – Cycle Tempo simulations.

The results of these simulations in Cycle Tempo show that with Kolkata's MSW, it is indeed possible to generate electricity at competitive energy efficiency and environmental impact levels using pyrolysis and gasification techniques besides direct combustion. The WGT & PreCon processes show potential in terms of electricity generation. The next chapter deals with the economics associated with the technologies analyzed in this chapter.

7. ECONOMICS OF WTE POWER PLANTS IN KOLKATA

The previous chapter showed that while a large scale direct combustion plant for the conversion of MSW to electricity is technically feasible in Kolkata, the pyrolysis and gasification plants can only be technically implemented in pilot project scale levels because the technologies if applied to MSW are still at a nascent stage. The next element in this feasibility study setup is the economics of these plants. As discussed in the previous sections, there has been more than one proposal regarding the implementation of a MSW to power plant in Kolkata. Each proposal that has reached the KMC has asked for a tipping fee and these figures have not been consistent with each other. This chapter of the report analyzes the economics of each kind of power plant discussed in the previous chapter and shows the need for support mechanisms such as tipping fees in order to make each technology commercially viable for implementation in Kolkata.

Each technology is analyzed in terms of economics in the following stages:

- Initial Investment for construction of the power plant
- Operational and maintenance costs of the power plant
- Revenue model of the power plant
- CDM involvement

As mentioned in the methodology chapter, the economic performance of the plants are measured in terms of Internal Rate of Return (IRR) and the payback period. The payback period is calculated by using the Net Present Value (NPV) method. The calculations take into account the depreciation rate which is applicable to MSWM schemes (100% in first year) for tax savings purposes. The discount rate is taken to be 5%. The tax rate is 33.9% [Income Tax Department, India 2010][67].

The electricity that is produced by each each technology is sold to the market at a fixed price of Rs. 4.5/kWh. The land and water required for the plants are supplied by the KMC free of cost and can be ignored in the calculations. In case of CDM involvement, only the emission coefficient of the power plants are taken into account and the baseline is defined to be the emission coefficient of coal based grid electricity (0.96 $kgCO_2/kWh$) [UNFCCC, 2007][68]. However, this is not an accurate measurement of GHG mitigation, as there is no specific methodology to account for the emissions into the atmosphere from the open dump site. More research is necessary to obtain ultimate anaylsis of the emissions from the landfill site, in order to get a more accurate estimate of the GHG mitigation. The data for these calculations have been derived from the data set supplied to this research by CESC.

7.1 Economics of 54 MW direct combustion plant

To be able to determine the initial investment cost of a direct combustion plant as proposed by Astonfield, the cost for each section of the plant is looked at separately. The data used for calculation purposes in this research is extrapolated from the informal report handed in by Astonfield to KMC and is presented in Table 21.

Cost of Pre-Treatment and RDF facility	Rs. 190 cr
Cost of Boiler & Generator	Rs. 156 cr
Cost of Balance of Plant (BOP) and Flue gas treatment facility	Rs. 270 cr
Cost of electrical connection to the grid	Rs. 6 cr
Total investment cost for plant	**Rs 622 cr**

Table 21 Investment costs for 54 MW direct combustion plant

Now that the initial investment cost has been estimated, the focus shifts to the operational and maintenance cost for the plant. The lifetime of the plant is taken to be 25 years. The operational costs per year include:

- Maintenance of plant (every 5 years machinery replacement costs amount to 10% of initial investment costs)
- Labour costs
- Overhead
- Charges, tax, insurance
- Raw materials
- Utilities
- Operating materials

Since the raw material is supplied to the plant free of cost, the labour costs, charges, utilities and operating materials amount to only 10% of the initial investment costs. During the whole lifetime of the power plant, this amounts to Rs. 833 cr taking depreciation and discount rate into account.

After calculating the O & M costs, the revenue model is formulated. Taking into account depreciation and tax payments and not including CDM aspects, the figures obtained in the research are tabulated in Table 22.

Capacity of the plant	54 MW
Capacity for export to the grid	37 MW
Capacity factor	80%
No of operation hrs per day	24
No of operational days per year	340
Total electricity generation exported to grid per year	251,600 MWh
Total electricity generation exported to grid over lifetime	6,290,000 MWh
Effective price of power	Rs 1.98/kWh
Selling price of electricity to the grid	Rs 4.5/kWh
Revenue from electricity sales per year	Rs. 1,248,250,500
IRR (without CDM) **Payback Period (without CDM)**	**8 %** **13 yrs**

Table 22 Revenue model of 54 MW plant

The NPV of the power plant over its lifetime is depicted in Figure 37 and shows that the payback period of the power plant is 13 years. These figures are unacceptable to any company in the electricity industry in terms of profit because the expected IRR is a minimum of 12% and the payback period shoud be less than 10 years. It is clear that additional financial instruments are needed in order to improve the economic performance of the plant. CDM activity can be used to generate CERs which add to the revenue of the plant.

The CO_2 emission coefficient for a direct combustion power plant based on Kolkata's MSW is obtained from the data supplied by Astonfield for their proposed pilot plant. The results obtained from the financial calculations are tabulated in Table 23.

CO_2 emission coefficient	0.4 kg/kWh
CO_2 savings from MSW per year (tons/yr)	140,896
Current price of a CER	$20
Revenue generated from CERs	Rs. 126,231,966.31
IRR (with CDM) **Payback Period (with CDM)**	**12 %** **10 yrs**

Table 23 CDM economics of direct combustion plant

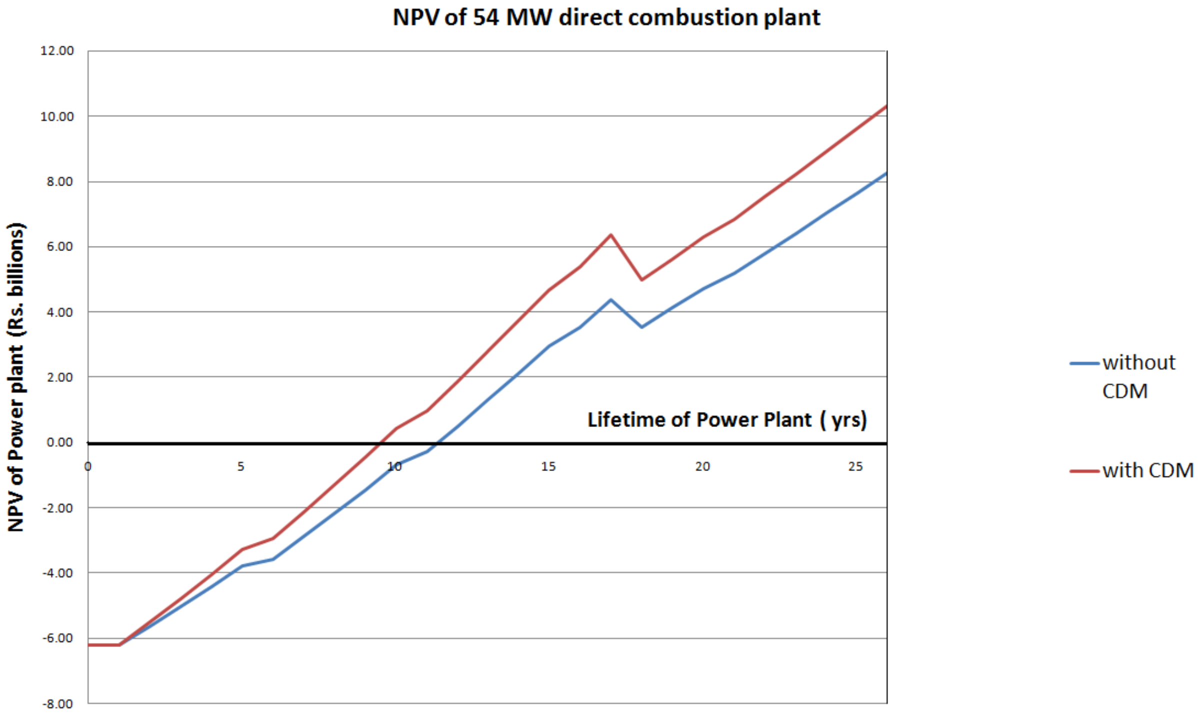

Figure 36 NPV of direct combustion plant

Figure 37 shows the NPV of the direct combustion plant with and without CDM activity. CDM increases the IRR to 12% and reduces the payback period to 10 years, thereby making the plant financially viable for any private investors. However, there are questions regarding the reliability of the data supplied by Astonfield to KMC with respect to the CDM activity, because the information obtained by simulating models of pyrolysis and gasification in this research shows that the emission coefficient of direct combustion is much lesser than the ones of the pyrolysis and gasification techniques. In spite of this anomaly, it can be seen that a tipping fee is actually not needed for making the direct combustion plant financially feasible and even if it is needed, it is lesser than Astonfield's demands of Rs 750-800 per ton of MSW received from KMC. More details about the business plan for this direct combustion plant is presented in Appendix III – Economics of power plants.

7.2 Economics of 9 MW Waste Pyrolysis in co-combustion plant

For the PYROPLEQ process, the data available regarding the cost structure of the components of the plant has been made available by the research that CESC has been carrying out with respect to MSW conversion to electricity in Kolkata.

Cost of Pre-Treatment and RDF facility	Rs. 49 cr.
Cost of Pyrolysis drum unit along with the energy recovery unit (Since the drum is made in China, there is an import duty of 25 % on its cost which leads to higher initial investment costs)	Rs. 64 cr
Cost of Balance of Plant (BOP) and Flue gas treatment facility	Rs. 37 cr
Cost of electrical connection to the grid	Rs. 3 cr
Total investment cost for plant	**Rs 153 cr**

Table 24 Investment costs for PYROPLEQ plant

The investment costs for the 9 MW PYROPLEQ plant are tabulated in Table 24.

Now that the initial investment cost has been estimated, the focus shifts to the operational and maintenance cost for the plant. The lifetime of the plant is taken to be 25 years. The operational costs per year are because of the same expenses as for a direct combustion plant as mentioned in the previous section.

Since the raw material is supplied to the plant free of cost, the labour costs, charges, utilities and operating materials amount to 8% of the initial investment costs. During the whole lifetime of the power plant, this amounts to Rs. 164.3 cr. taking depreciation and discount rate into account.

After calculating the O & M costs, the revenue model for the plant is formulated. Taking into account depreciation and tax payments and not including CDM aspects, the figures obtained in the research are tabulated in Table 25.

Capacity of the plant	9 MW
Capacity for export to the grid	8 MW
Capacity factor	80%
No of operation hrs per day	24
No of operational days per year	340
Total electricity generation exported to grid per year	54,400 MWh
Total electricity generation exported to grid over lifetime	1,360,000 MWh
Effective price of power	Rs 1.95/kWh
Selling price of electricity to the grid	Rs 4.5/kWh
Revenue from electricity sales per year	Rs. 269,892,000
IRR (without CDM) **Payback Period (without CDM)**	**8 %** **13 yrs**

Table 25 Revenue model of 9 MW pilot plan

These figures (Figure 38) show the need for additional financial instruments in order to make the plant financially viable. Since the IRR is less than 12 % and the payback period is 13 years, the need for CDM activity to aid financial profitabality for the investor is apparent.

The CO_2 emission coefficient for a pyrolysis plant based on Kolkata's MSW is obtained from the data obtained from the Cycle Tempo model for the proposed PYROPLEQ pilot plant. The calculations are tabulated in Table 26.

CO_2 emission coefficient	0.73 kg/kWh
CO_2 savings from MSW per year (tons/yr)	12,512
Current price of a CER	$20
Revenue generated from CERs	Rs. 13,625,568
IRR (with CDM) **Payback Period (with CDM)**	**9 %** **12 yrs**

Table 26 CDM economics for 9 MW PYROPLEQ pilot plant

The payback period is reduced to 12 years as shown in Figure 38. Even after including CDM activity, it is seen that the economics of the pilot plant are not attractive to investors. Hence, if KMC wants a private investor to enter the MSWM scheme with a pilot plant for pyrolysis, the need for a tipping fee is clear. Calculations show that if 1000 tpd of MSW is processes into feedstock for the plant by the RDF facility, the **tipping fee** required to bring the **IRR up to 13%** is **Rs. 200/ton of MSW**. This tipping fee brings the **payback period down to 9 years** (Figure 38) thereby making the business plan feasible for investors. More details are available in Appendix III – Economics of power plants.

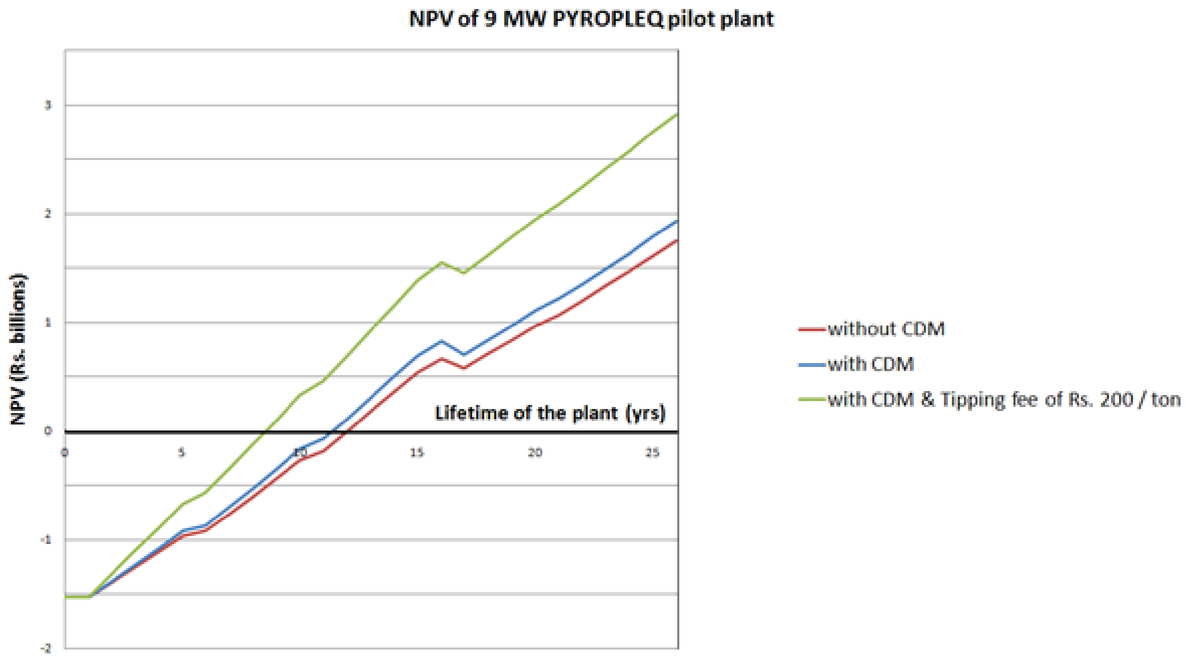

Figure 37 NPV of 9 MW PYROPLEQ pilot plant

7.3 Economics of 10 MW WGT plant

For the WGT process, the data available regarding the cost structure of the components of the plant has been made available by the research that CESC has been carrying out with respect to MSW conversion to electricity in Kolkata. The investment costs for the 10 MW WGT pilot plant are tabulated in Table 27.

Cost of Pre-Treatment and RDF facility	Rs. 49 cr.
Cost of gasification unit along with the energy recovery unit (Since the gasifier is made in China, there is an import duty of 25 % on its cost which leads to higher initial investment costs)	Rs. 62 cr
Cost of Balance of Plant (BOP) and Flue gas treatment facility	Rs. 36 cr
Cost of electrical connection to the grid	Rs. 3 cr
Total investment cost for plant	**Rs 150 cr**

Table 27 Investment costs for 10 MW WGT pilot plant

Now that the initial investment cost has been estimated, the focus shifts to the operational and maintenance cost for the plant. The lifetime of the plant is taken to be 25 years. The operational costs per year are because of the same expenses as for a direct combustion plant as mentioned in the previous section.

Since the raw material is supplied to the plant free of cost, the labour costs, charges, utilities and operating materials amount to 8% of the initial investment costs. During the whole lifetime of the power plant, this amounts to Rs. 161.1 cr.

After calculating the O & M costs, the revenue model for the plant is formulated. Taking into account depreciation and tax payments and not including CDM aspects, the figures obtained in the research are tabulated in Table 28.

Capacity of the plant	10 MW
Capacity for export to the grid	9.6 MW
Capacity factor	80%
No of operation hrs per day	24
No of operational days per year	340
Total electricity generation exported to grid per year	65,280 MWh
Total electricity generation exported to grid over lifetime	1,632,000 MWh
Effective price of power	Rs 1.59/kWh
Selling price of electricity to the grid	Rs 4.5/kWh
Revenue from electricity sales per year	Rs. 323,870,400
IRR (without CDM) **Payback Period (without CDM)**	**12 %** **9 yrs**

Table 28 Revenue model of 10 MW WGT pilot plant

The economics without CDM activity are encouraging for the WGT technology. The payback period is less than 10 years as can be seen in Figure 39. If CDM were to be involved, the business plan would become more attractive.

The CO_2 emission coefficient for the WGT plant based on Kolkata's MSW is obtained from the data obtained from the Cycle Tempo model for the proposed WGT pilot plant. The calculations are tabulated in Table 29.

CO_2 emission coefficient	0.88 kg/kWh
CO_2 savings from MSW per year (tons/yr)	5,222.4
Current price of a CER	$20
Revenue generated from CERs	Rs. 4,678,868.25
IRR (with CDM) **Payback Period (with CDM)**	**12 %** **9 yrs**

Table 29 CDM economics of 10 MW WGT pilot plant

Although the IRR and payback period do not vary because of CER generation, the revenue obtained because of CDM activity can be used for the upliftment of the poorer sections of society involved in the MSWM scheme of Kolkata. These calculations also show that there is no requirement for a tipping fee for this technology. More details about the business plan for the WGT process is presented in Appendix III – Economics of power plants.

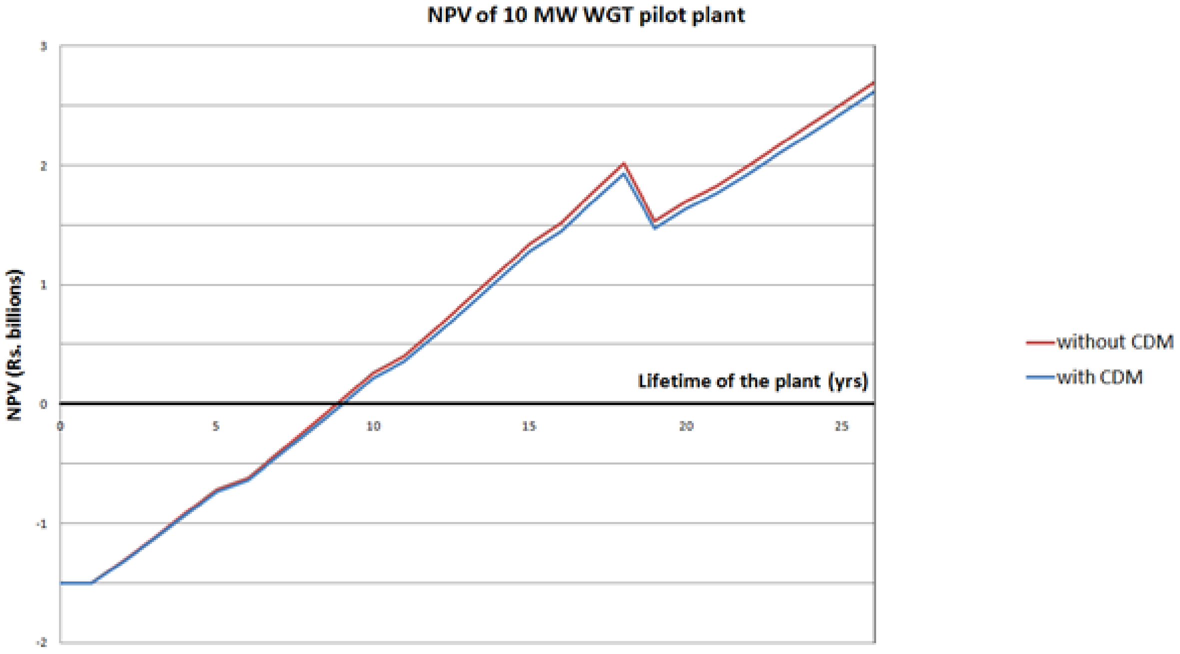

Figure 38NPV of 10 MW WGT pilot plant

7.4 Economics of 29 MW PreCon plant

The PreCon technology has shown that it is not possible to operate a small scale pilot plant unlike the PYROPLEQ and WGT processes. The lowest capacity plant that can be set up using this technology is a 29 MW plant with an input flow rate of 8 kg/s of MSW. Since there was no data available for the estimation of the cost structure of a 29 MW plant, this research uses the Guthrie factor for calculating the investment costs taking economies of scale into account and extrapolating the cost structure of the 10 MW WGT plant because the scheme has the same components as the PreCon process.

The total investment cost for a 29 MW PreCon plant can be calculated using the following equation with the base reference being taken as the 10 MW WGT plant.

$$I = I_0 \times (C/C_0)^n$$

where I = initial investment for 29 MW plant

I_0 = initial investment for 10 MW WGT plant = Rs. 150 cr.

C = Capacity of PreCon plant = 29 MW

C_0 = Capacity of WGT plant = 10 MW

n = Guthrie's factor = 0.8 for biomass energy systems [Dornburg et. al., 2001][69]

The total investment for the 29 MW PreCon plant is estimated to be Rs. 351.6 cr.

Now that the initial investment cost has been calculated, the focus shifts to the operational and maintenance cost for the plant. The lifetime of the plant is taken to be 25 years. The operational costs per year are because of the same expenses as for a direct combustion plant as mentioned in the previous section.

Since the raw material is supplied to the plant free of cost, the labour costs, charges, utilities and operating materials amount to 10% of the initial investment costs. During the whole lifetime of the power plant, this amounts to Rs. 471.9 cr. taking depreciation and discount rate into account.

After calculating the O & M costs, the revenue model for the plant is formulated. Taking into account depreciation and tax payments and not including CDM aspects, the figures obtained in the research are tabulated in Table 30.

Capacity of the plant	29 MW
Capacity for export to the grid	28 MW
Capacity factor	80%
No of operation hrs per day	24
No of operational days per year	340
Total electricity generation exported to grid per year	190,400 MWh
Total electricity generation exported to grid over lifetime	4,760,000 MWh
Effective price of power	Rs 1.48/kWh
Selling price of electricity to the grid	Rs 4.5/kWh
Revenue from electricity sales per year	Rs. 944,622,000
IRR (without CDM)	**16 %**
Payback Period (without CDM)	**8 yrs**

Table 30 Revenue model for 29 MW PreCon plant

The economics without CDM activity are extremely encouraging for the PreCon technology at the conceptual design phase. The payback period is 8 years as can be seen in Figure 40. If CDM were to be involved, the business plan would become more attractive.

The CO_2 emission coefficient for the Pre-Con plant based on Kolkata's MSW is obtained from the data obtained from the Cycle Tempo model for the proposed PreCon pilot plant. The calculations are tabulated in Table 31.

CO_2 emission coefficient	0.62 kg/kWh
CO_2 savings from MSW per year (tons/yr)	64,736
Current price of a CER	$20
Revenue generated from CERs	Rs. 70,497,504
IRR (with CDM) **Payback Period (with CDM)**	**19 %** **7 yrs**

Table 31 CDM economics of 29 MW PreCon plant

This increases the IRR to 19% and the payback period reduces to 7 years (Figure 40). However, the accuracy of these estimations is dependent on the Guthrie factor that has been assumed for the PreCon process. For KMC or any other investor to make an informed decision, more research is required to gather industry data to be able to determine the economics of a PreCon plant more accurately. These calculations also show that there is no requirement for a tipping fee for this technology. More details are presented in Appendix III – Economics of power plants.

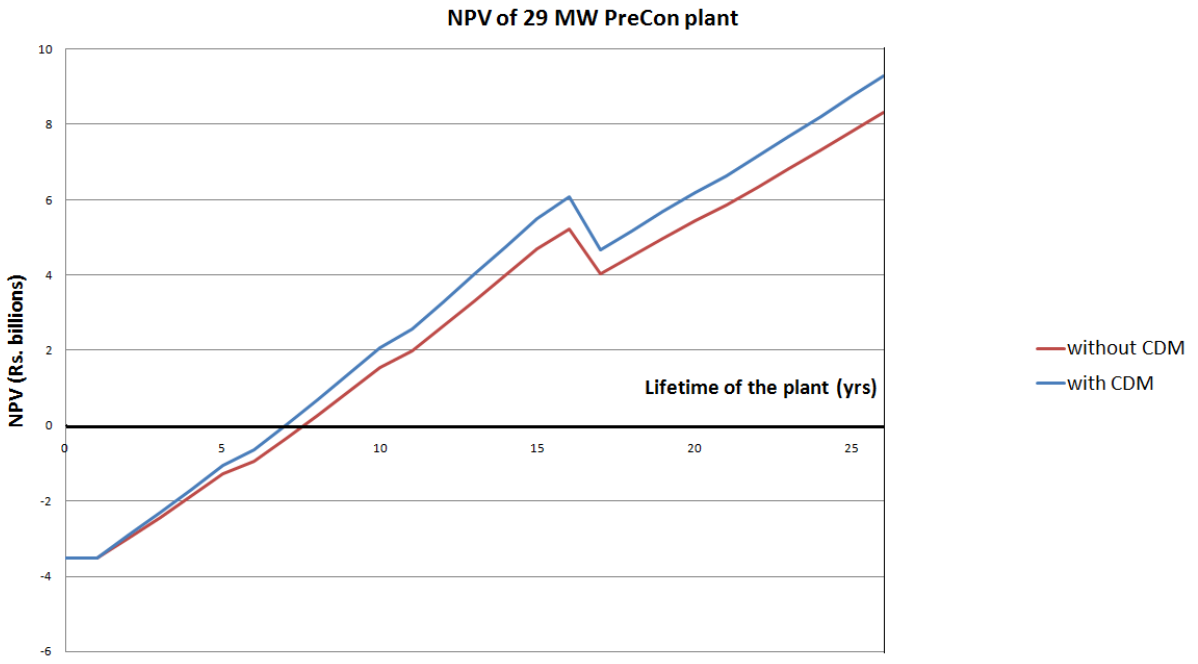

Figure 39 NPV of 29 MW PreCon plant

This chapter proves that it is financially feasible to implement MSW to electricity power plants in Kolkata at a pilot level. Only the PYROPLEQ process scheme needs a tipping fee of Rs. 200/ ton of MSW received by the power plant from the KMC. The economics of the WGT pilot plant in particular look attractive for investors. Now that the technical and economic aspects have been deemed to be feasible, the study moves on to a total system design phase incorporating the results of the previous chapters to bring the system into being.

8. TOTAL SYSTEM DESIGN

The previous chapters have analyzed the problem of MSWM in Kolkata, India and defined the objectives and roles of the stakeholders. The barriers and constraints that hinder progress in the field of MSW to energy conversion have been identified. The research has tried to overcome these obstacles by exploring innovative technologies such as pyrolysis and gasification and has proven that they can be financially and technically feasible to implement in the context of Kolkata's MSWM. Now the study focusses on the integration of these technologies into the existent MSWM scheme and how the scheme can be redesigned into a more sustainable one. This chapter of the report analyzes how the other feasibility criteria affect the choices of technology to be implemented after further comparisons are made to verify the total feasibility of the system. The actor networks which need to be in place in order to bring the system into being are analyzed. Also the financing mechanisms which can be used to arrange for initial investments of the plants are presented.

To be able to determine which technologies can fit into the scheme of MSWM in Kolkata, a comparison is made based on the feasibility indicators and a SWOT (strengths – weaknesses – opportunities – threats) analysis is performed on the four technologies that have been analyzed in this research.

8.1 Comparison of technologies based on feasibility indicators

The feasibility indicators were identified in chapter 2 of this report, and in this section the technologies are analyzed for feasibility by checking if the criteria defined by each of the indicators are satisfied by each technology. Table 32 shows the comparison of the four technologies based upon the research done in this study so far.

	Technical	Environmental	Social	Institutional	Economic
Direct combustion	Acceptable electricity generation & energy efficiency Large scale implementation possible	No recycling of paper and plastics Emission co-efficient surprisingly low (more research)	Creation of jobs Upliftment of standards of living for poor sections	Does not allow Institutional Capacity Building if done by IPP Adheres to regulations and policies	IRR and payback period is acceptable if CDM is involved
PYROPLEQ process	Pilot scale installation with acceptable power output and energy efficiency	Recycling of paper and plastics allowed Emission co-efficient allows for displacement of coal based electricity	"	Allows Institutional Capacity Building of KMC irrespective of IPP Adheres to regulations and policies	IRR and payback period is acceptable only when CDM and Tipping fee is involved
WGT technology	"	"	"	"	IRR and payback period is acceptable without CDM
PreCon process	Pilot scale project is not possible	"	"	"	" CDM increases IRR and reduces

	payback period

Table 32 Comparison of technologies with feasibility indicators

8.2 Comparison of technologies – SWOT analysis

The methodology of SWOT analysis is derived from the business management literature and was adopted in the 1980s by public administration across such areas as regional development and municipal planning [Karppi et. al., 2001][70]. SWOT analysis has been used to evaluate options in the fields of regional energy planning [Terrados et. al., 2007][71] and MSWM schemes [Srivastava et. al., 2005][72]. This research uses SWOT analysis as a tool to compare the technology options in order to see which ones can be implemented in the context of Kolkata. The two main components of SWOT are the indicators of the internal situation described by the strengths and weaknesses of the technologies, and the indicators of the external environment described by existing opportunities and threats [Markovska et. al., 2009][73]. The performances of the technologies are analyzed from a technical, financial, social and environmental perspective in Table 33.

	Strengths	Weaknesses	Opportunities	Threats
Direct combustion	Proven technology Large scale plant Feasible business case without tipping fee	No scope for recycling of paper and plastics Unreliable industry data supplied to KMC Difficult to get CDM registration High initial investment	Immediate solution to Kolkata's MSW problems Improvement of standards of living of poorer section because of job creation	Bounded rationality about MSW characteristics Evolution of technology might make this obsolete Opposition by farmers and ragpickers
PYROPLEQ process	Innovative technology Integrates well with ecology and environment Pilot scale project allows for modular expansion if positive results are obtained after operation	Unproven technology Needs financial support - CDM and tipping fee High initial investment	For research, a pilot plant can yield valuable data for future planning Institutional Capacity Building by KMC Job creation	Evolution of technology Resistance from CESC to allow IPP to enter the market Opposition by farmers and ragpickers
WGT technology	Innovative technology Integrates well with ecology and environment Pilot scale project allows for modular expansion if positive results are obtained after operation Feasible business case with/without CDM	Unproven technology High initial investment	For research, a pilot plant can yield valuable data for future planning Institutional Capacity Building by KMC Job creation	Evolution of technology Resistance from CESC to allow IPP to enter the market Opposition by farmers and ragpickers
PreCon process	Innovative technology Integrates well with ecology and environment	Unproven technology Risks of installing a high capacity (29 MW) plant exist	For research, a pilot plant can yield valuable data for future planning	Evolution of technology Resistance from CESC to allow IPP to enter the market

	Feasible business case with/without CDM	High initial investment	Institutional Capacity Building by KMC Job creation	Opposition by farmers and ragpickers

Table 33 SWOT analysis of technology options

The SWOT anaylsis allows this research to design a scheme which incorporates the appropriate technologies by:

- Building on the strengths
- Eliminating weaknesses
- Exploiting opportunities
- Mitigating threats

After comparing the four technologies, it can be deduced that the WGT technology is a suitable choice for implementation at a pilot level scale for Kolkata's MSWM scheme. The reasons behind this choice are:

- No risks present in the installation and operation of a pilot scale plant (10 MW)
- Energy efficiency and environmental impacts are acceptable
- Business case is sound without additional financial instruments
- Institutional Capacity Building of KMC possible by owning and operating the plant leading to sustainable social development, CDM involvement and valuable research data collection

8.3 Conceptual design of Kolkata's MSWM scheme

As described earlier in the methodology section of this report, the research intends to present a conceptual system design based upon the information and knowledge gained over the course of this study. The system that has to be designed is taken to be a complex socio-technical system with environmental, institutional and economic impacts. The following design takes each step of the MSWM process of Kolkata and identifies the different design elements that need to be incorporated in order to bring about reform to the MSWM infrastructure in Kolkata.

The existing system is analyzed in each chapter of the report so far. The stakeholders and actors involved in the MSWM scheme have been identified and their objectives have been defined. KMC being the problem owner, have the responsibility of changing the MSWM scheme in order to relieve the pressure on the Dhapa site. CESC and other IPPs have an opportunity to enter the sector and collaborate with KMC to achieve a more sustainable system. An important factor that has been considered while designing the system is the role of the grass-root level stakeholders i.e. the garbage farmers of Dhapa and the ragpickers and scavengers who depend on the Dhapa site for their livelihood. This social aspect when incorporated in the system design ensures the sustained economic growth of this section of society which stands to benefit from a new MSWM scheme.

The technical aspects of the system have been developed by incorporating the technical research that has evolved in this study. The research has not looked at by-product processing and dioxin effects on the soil and leachate quality. Hence the design does not include these technical elements. It only incorporates the viable technology in terms of energy efficiency and environmental impacts in terms of emissions directly associated with the proposed technology. The emissions that are related to the open dumping of the MSW at Dhapa have not been taken into account because the methodology to calculate these emissions is not perfect as of today in terms of accuracy.

The socio-technical system involves complex interactions between the actors present. All the financial flows, knowledge and information flows and product flows are translated into who needs to do what in the system in order to bring it into being. Also, the institutional aspects such as CDM involvement, Institutional Capacity Building and policies and regulations have been incorporated into the system design.

This level of detail ensures that the system is bound together by all the factors that enable it to function over time. The complexity of the system is better understood when all these factors are analyzed in terms of how each one influences the other. The total conceptual design of the design now follows from the research performed in this study. The scheme that has evolved out of this research is depicted in Figure 41.

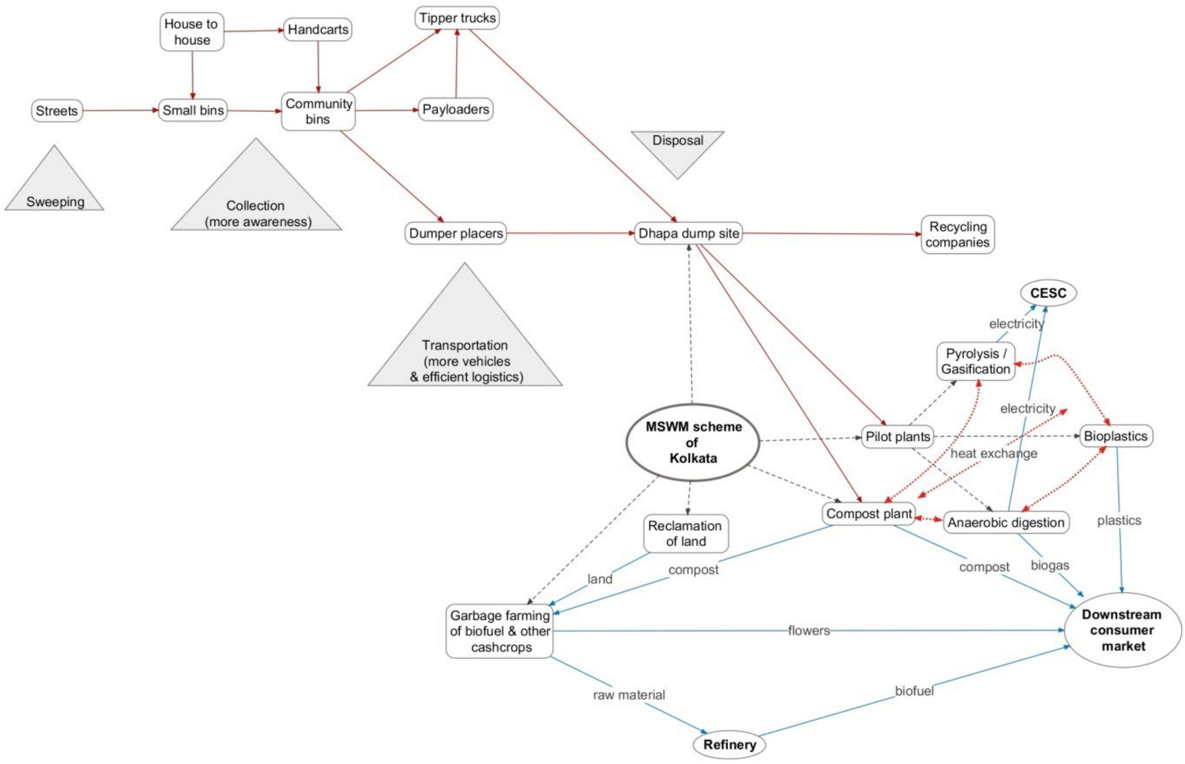

Figure 40 Conceptual design of Kolkata's MSWM scheme

The salient features of the new MSWM scheme are:

- Improvement in disposal, collection and storage of MSW
- Reclamation of saturated land

- Increasing the capacity of the compost plant
- Installing pilot plants to convert MSW to other products such as electricity, biogas and bioplastics

Improvement in disposal, collection and storage of MSW

As discussed in the previous chapters, the waste disposal, collection and storage schemes of KMC are not adequate to cater to the increasing rates of MSW generation in Kolkata. By creating more awareness at the grass roots level, the population and industries of Kolkata can dispose of their MSW in a more structured way which will enable KMC to collect the MSW in a more effective way. Using better logistics and more vehicles, the collection and transportation of the MSW to Dhapa can be made more efficient and this will lead to less buildup of MSW in the streets of Kolkata. Other than these changes, the existing MSWM scheme does not need to be altered because a central collection point like Dhapa makes it easier to distribute MSW to the pilot plants in the vicinity.

Reclamation of land

As discussed before, a large portion of the land allocating for dumping purposes in Dhapa has become saturated over the years. Also the land used for garbage farming near the dump site is contaminated with toxins and heavy metals making the vegetables unsuitable for consumption. These land spaces need to be reclaimed by the KMC and the patterns of farming need to be altered. Bio-fuel crops such as Jatropha or sugarcane can be an alternative to vegetables. The possibility of growing flowers should also be explored because of the high demand in downstream markets for flowers. The fertility of these lands can be improved by using compost produced in the compost plant in Dhapa. If bio-fuel crops are cultivated, then a refinery needs to be installed in order to process the raw materials coming in from the fields and make bio-fuel which can be sold in the downstream consumer market thereby ensuring that the farmers have a sustainable source of income.

Increasing the capacity of the Compost plant

Since the C/N ratio of Kolkata's MSW shows that biological processes are more suitable than direct combustion of the MSW, the Compost plant should play a more prominent role in the MSWM scheme of Kolkata. Increasing the capacity and production of the plant will lead to more MSW being treated in a sustainable manner. The compost can be sold in the downstream consumer market and directly to the farmers in the Dhapa region.

Installation of pilot plants

The research in this study shows that besides composting, other biological processes can be feasibily implemented in order to convert Kolkata's MSW into electricity. This design incorporates the installation of multiple pilot plants:

- ***WGT gasification plant***– The technical research shows that a 10 MW pilot plant can be operated using the WGT technology using Kolkata's MSW.

- ***Anaerobic Digestion plant***– A major barrier in the scheme of Kolkata's MSWM is the existence of complete monopoly of CESC. It is possible to overcome this obstacle by involving them in the scheme as well so that they have a positive stake in the project. They are carrying out research in the field of anaerobic digestion and they should set up a pilot plant to contribute to the R & D efforts being made by KMC and gather more information using the paradigm of "learning by doing".

- ***Bioplastics plant***– Although this study has not looked into this possibility, yet the potential of this emerging technology cannot be ignored [Linton et. al., 2009][74]. A small scale pilot plant can be set up to receive the waste streams of the anaerobic digestion plant and a portion of the segregated organic waste fraction of Kolkata's MSW and can be converted to bioplastics. This R & D effort will lead to valuable information and experience in the field of bioplastics from MSW.

These three pilot plants will receive RDF from one central facility. The clustering of these plants will allow waste heat utilization among the three plants for their respective processes, thereby improving the global energy efficiency of the whole system of MSWM.

8.4 Bringing the new MSWM scheme of Kolkata into being

One of the most important aspects of system design is to implement the system and bring it into being in reality. This section of the report looks into the actor networks, the financing mechanisms and the policies and regulations that need to be implemented in order to bring this system into existence.

Actor networks

To be able to bring a system into being, it is essential to know which stakeholder/actor plays what role and what are the interactions between them. The designed MSWM scheme of Kolkata depends heavily on these flows to fall into place for it to be implemented in reality. The flows have been classified as:

- Information and knowledge flows
- Financial flows
- Product flows

Information and knowledge flows

Since the designed MSWM scheme of Kolkata involves innovative technologies and is looked at from a systems perspective, it is important to have a knowledge sharing network which will enable the different actors to understand the proposed scheme and how to strategize their positions in the new scheme and what changes they need to make in order to integrate themselves into the scheme.

Since the scheme is dependent on CDM activity, two separate knowledge networks need to be defined. The CDM network involves UNFCCC, MNRE, TU Delft, Pilot Plant Owners, industries, KMC and the opposition. TU Delft and KMC are responsible for carrying out the research for the MSWM scheme and this research knowledge will lead to the formulation of a Project Design Document (PDD) for the scheme involving the co-operation of the proposed pilot plant owners. This PDD will contain information about the technicalities of the system, the sustainability aspects of the system and proof of additionality required for CDM registration [Ghosh, 2010][75]. This PDD is to be sent to the MNRE and Ministry of Environment and Forests for approval before being sent to the UNFCCC for final certification. A monitoring body with a reliable reputation such as CSTEP needs to be involved in the project to ensure that the CDM requirements are met over the lifetime of the project. This CDM knowledge and information network is depicted in Figure 42.

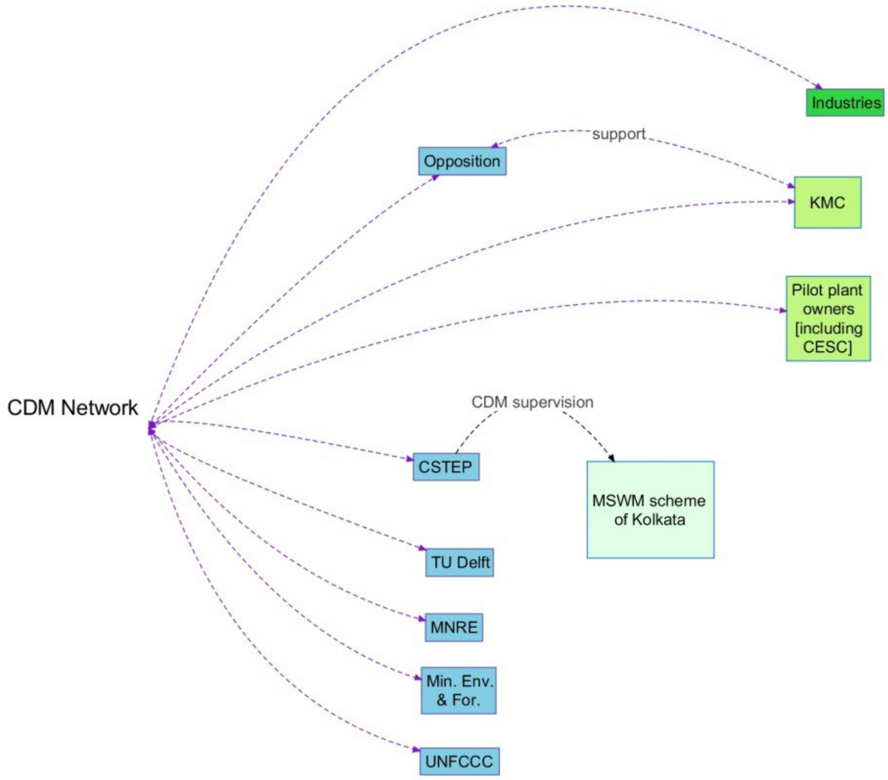

Figure 41 CDM information and knowledge network for Kolkata's MSWM scheme

Since the MSWM scheme also involves role changes for the society, farmers and ragpickers and scavengers in Dhapa, the need for grass roots level knowledge and information is necessary for the diffusion of scheme into the different layers of society. The secondary knowledge and information network comprises of the KMC, NGOs, industries, Pilot plant owners, the population of Kolkata, the ragpickers and scavengers whose roles change into those of farmers, site operators and pilot plant employees, and the recycling companies. The NGOs and KMC are responsible for disseminating knowledge and information about the new scheme to the other actors. The farmers of the region will share their knowledge with the ragpickers who change their roles to those of farmers. Information about how to improve the standards of living for the poorer sections will be shared by the NGOs. This network is depicted in Figure 43.

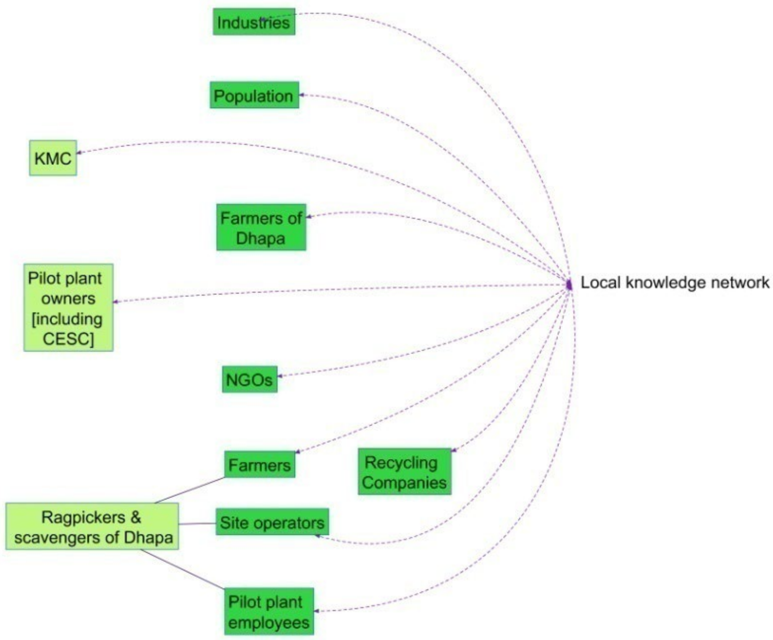

Figure 42 Secondary local knowledge network for Kolkata's MSWM scheme

Financial flows

Financial aspects of a system need to be understood in order to make sure that the system does not fail financially and that every stakeholder/actor benefits in an economic sense. This section of the report deals with the investments to be made in Kolkata's MSWM scheme, how revenue is earned and presents an overview of the other financial flows in the system.

First, the focus is on the investments that need to be made. KMC and the pilot plant owners including CESC need to make investments into the MSWM scheme of Kolkata. M/S Eastern Organic Fertilizer Ltd. needs to invest in order to increase the capacity of the compost plant. Municipal solid waste to energy plant development projects require financing and funding obviously to get off the ground. In order to understand how to arrange the initial investments for the power plant that converts MSW to electricity in Kolkata, this section presents an overview of the possible financing mechanisms.

A2Z (a waste to energy company) raises finances by issuing shares to the public and their stakeholders. The rest of the investment is obtained in the form of a loan from L&T Infrastructure Finance [A2Z, 2011][76].

Energy Funding 123, LLC is another company that deals with MSW to energy plants financing. At EF123, options for financing projects for municipal solid waste to energy plants developments include funding techniques that can include debt and/or equity infusion. They can provide up to 100% debt capitalization which is available for qualified business models. Other options can include up to 100% loan to cost/value by using debt in combination with equity injection. A typical ratio could be 75%/25% debt to equity but can vary depending the business model. Developing MSW can be done with 100% debt and or equity as mentioned above with a strong business plan. This means minimal capital requirements from the sponsors and developers. On the 100% debt only programs, payment moratoriums for up to nearly 4 years allow for cash flow stabilization before servicing the debt is required. Some lender/investors donot require that the physical assets be securitized or liened for loan purposes. 100% debt programs allow the sponsors to keep all of the equity among themselves. The tax credits are even retained by the sponsors on these programs. Payment amortization schedules as high as 20 years provide for optimized cash flow [EF123, 2010][77].

Research [Woodward, 1992][78] has shown that approaching financial institutions such as banks and international organisations such as IMF or the World Bank leads to a more secure source of investments. If foreign investments are made into Kolkata's MSWM scheme, because of political implications and international relations, the scheme will be more transparent and close monitoring will ensure the success of the plant in terms of finance over time.

Now that the investments have been analysed, the research moves on to the operational and maintenance costs involved in the scheme. The pilot plant owners and M/S Eastern Organic Fertilizer Ltd. need to inject these costs every year into the scheme to pay for the wages of the labor, for raw materials, for machinery costs and utilities.

Now income patterns are analyzed. KMC receives income in the form of taxes from the population of Kolkata and the industries. TU Delft and CSTEP (CDM regulatory authority) receive research grants from the investments made into the MSWM scheme of Kolkata. The NGOs also receive grants from this source. The pilot plant owners receive income from UNFCCC (CER trading) and from the downstream market which consumes their products. They also receive income from CESC by selling the electricity to them. CESC receives its revenue from the consumers who utilize the electricity supplied by CESC. The recycling companies pay wages to the site operatives along with KMC. The recycling companies generate revenue from the downstream market. Farmers receive their livelihood by selling their products in the downstream market too. The pilot plant employees receive their wages from the pilot plant owners. This financial flow pattern is depicted in Figure 44.

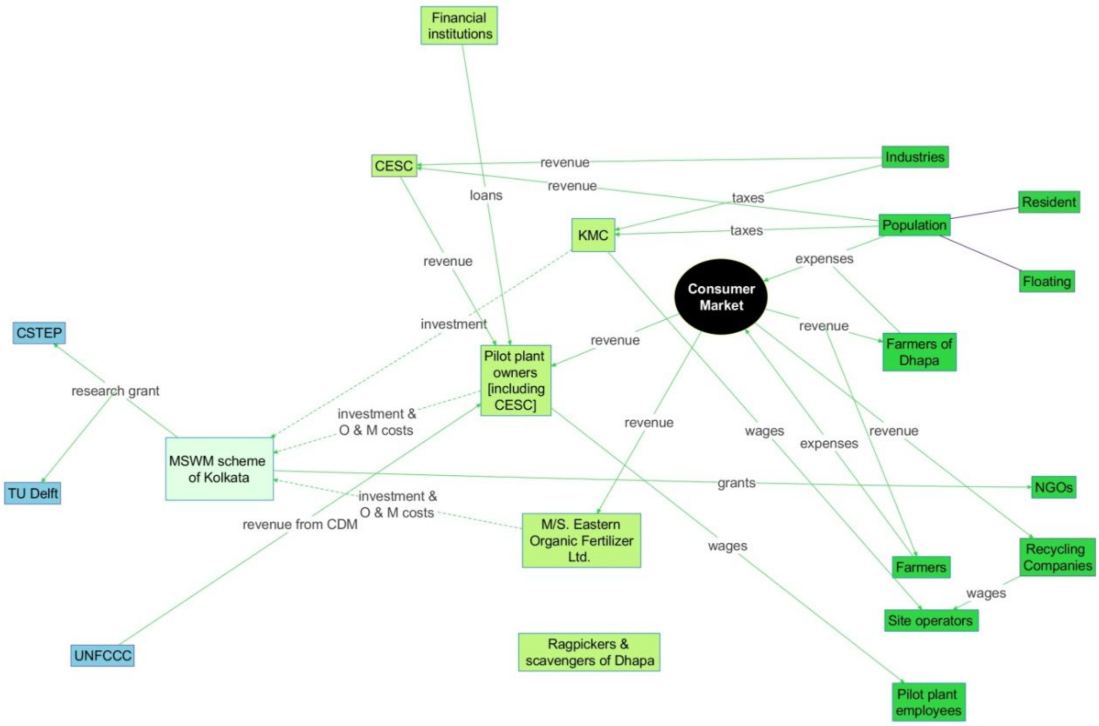

Figure 43 Financial flows in Kolkata's MSWM scheme

Product flows

The final aspect of the actor networks is the analysis of the product flows that exist between the different actors. The products generated in Kolkata's MSWM scheme are:

- Electricity
- Compost
- Vegetables, cash crops, flowers
- Recyclable materials and recycled products
- Bioplastics

The products that are consumed in the MSWM scheme are:

- MSW and industrial waste
- Wastewater converted to clean water for the pilot plants

The population and industries and other sources generate MSW and industrial waste which is collected by the MSW. Suitable waste after processing is sent to the pilot plants and the compost plant. Electricity generated by the pilot plants are sold to CESC. Compost is sold in the downstream market and to the farmers in Dhapa. The vegetables, cash crops and flowers grown by these farmers are sold in the consumer market. The recycling companies take in suitable recyclable waste and convert them into recycled products which are sold in the downstream consumer market. The bioplastics made by the bioplastics plant are also sold in this market. The water required for the operation of the pilot plants is received from the sewage water treatment plant operated by KMC. This product flow is depicted in Figure 45.

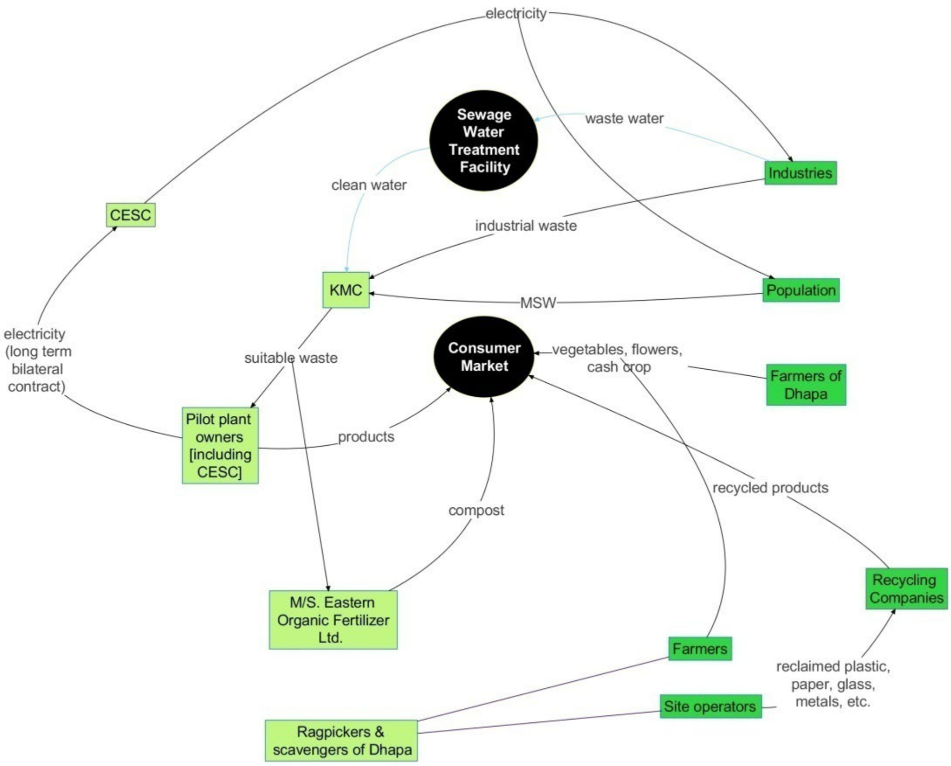

Figure 44 Products flow in Kolkata's MSWM scheme

Policies and regulations

In order for the MSWM scheme designed in this study to come into being, certain policies and regulations need to be implemented by authorities. KMC has to realise the need for Institutional Capacity Building if it wants to involve itself in the CDM aspect of the scheme. It needs to form collaborations with the pilot plants and the CDM regulatory bodies in order to manage Kolkata's MSW in more effective and efficient ways. It should also implement policies regarding separation at source of MSW by grass roots level stakeholders such as the population, markets, industries and other institutions. This should be a gradual process so that the knowledge is diffused amongst all the stakeholders in the scheme. Policies to improve the standards of living of the ragpickers of Dhapa and the farmers should be taken as an initiative by the KMC in order to aid sustainable social development. The opposition party needs to lend its support to KMC in order to successfully implement these policies.

In order to break the monopoly of CESC and overcome the obstacle posed by it, WBERC should pass regulations compelling CESC to sign long term bilateral contracts with the pilot plant owners to buy the electricity from these pilot plants throughout the lifetimes at a competitive rate. Also regulations regarding the choice of crops grown in the Dhapa region should be modified in order to prevent toxic edibles from entering the downstream consumer market.

This section summarizes what needs to be done, who needs to do what and what sort of policies and regulations need to be implemented in order to bring Kolkata's proposed MSWM scheme into being. It shows the need for KMC to participate in Institutional Capacity Building. It also shows that the blockers mentioned in the stakeholder analysis in chapter 3 of this report, need to transform their outlook and become promoters for the MSWM scheme after realizing that the scheme benefits every layer of society and the city of Kolkata itself. It also shows the need to monitor the development of the proposed scheme throughout its lifetime in order to achieve sustainable socio-economic development.

After the conceptual design of Kolkata's new MSWM scheme has been visualized, the study focusses on the generation of a framework that researchers can apply while conducting feasibility studies for conversion of MSW to energy in other cities.

8.5 Evolutionary framework

The study aimed to generate an evolutionary framework to set up feasibility studies for MSW conversion to energy in densely populated cities. Taking the case study of Kolkata as an example, this research has led to the development of a generic framework which can be applied by researchers when they embark on performing feasibility studies for MSW to power conversion. The framework is derived from the frameworks developed by Dijkema and Herder at the faculty of TPM (Section: Energy and Industry), TU Delft regarding conceptual design of systems. The framework is divided into two parts:

- Problem definition and description
- System design

Problem definition and description

To begin with, a researcher has to first identify the need or opportunity to change the existing MSWM scheme of a city. Since MSWM is an infrastructure which involves every level of society and industry in it unless the present MSWM scheme is failing or there is a scope for significant improvement in the infrastructure, the reason to carry out research in this field does not exist. MSWM is not a profitable industry and private companies do not risk entering the sector unless the need is dire.

If there is truly a need or an opportunity to transform the existing MSWM regime of a city into a more sustainable one, then the research can be carried out. The first step is to define the problem. The definition of the problem includes

- identification of the problem owner (in most cases the municipality)
- analysis of the shortcomings of the existing MSWM scheme
- description of the background of the city and the relevance for the research

After defining the problem, the researcher will need to gather cognate facts about the system. These facts and information cover a wide range of aspects:

- ***Linkages/relationships to other infrastructures and industries***– MSWM is often related to other infrastructures and industries. It is essential for the researcher to identify these linkages. MSWM invariably has an integration with the local ecological system of the city. The environmental impacts of the present MSWM scheme and how it interacts with the ecological system need to be analysed.

  The relationships that exist between the recycling industry, the chemicals and fertilizer industry and the utility companies need to be identified to understand how the new MSWM scheme can be designed keeping in mind that these relationships need to be kept intact or made more sustainable.

- ***Stakeholder analysis***– A stakeholder analysis needs to be made to identify the roles, interactions and objectives of all the participants within the MSWM scheme. The stakeholder analysis should be derived from:

  - power to influence the regime transformation
  - the impact that the change will have on the stakeholder
  - attitude of the stakeholder to either promote or block change

- ***Demand for energy*** – It has to be seen whether the city has a demand for energy in terms of electricity or heat which is not fulfilled by the utilities supply companies. If the demand is low, then there is no point in investing heavily in MSW to energy conversion systems.

- ***Scope for improvement*** – The researcher needs to analyse the sectors which need to be improved in order to bring about a more sustainable MSWM scheme in the city. The scope for improvement may be with respect to:

    - Sustainable social development
    - Technological advent
    - Financial benefits
    - Environmental impacts
    - Institutional Capacity Building

- ***Boundary and exogenous conditions*** – The researcher has to base his feasibility study on the conditions that he cannot change. The local climatic conditions and the policies existing in the field of MSWM in terms of land usage and finances are taken to be constants for the research. Other boundary conditions such as availability of land or water should also be taken into account.

- ***Barriers and constraints*** – The obstacles that lie in the path of improvement of MSWM schemes in the city need to be analysed. These barriers and constraints arise from the following aspects:

    - Institutional
    - Technical
    - Financial
    - Environmental
    - Social

    These factors need to be analysed by the researcher to identify the potential barriers and constraints. Also information gathered from previous attempts made by industries and researchers to enter the MSWM scheme of the city can help the researcher to identify the barriers and constraints. These form a design variable in the later stage of system design.

- ***Characteristics of MSW in the city*** – The characteristics of the MSW in a city have a major impact on the kind of technologies that are applicable for conversion processes. The researcher needs to analyze the following aspects of the MSW:

    - Physical composition
    - C/N ratio
    - Moisture content
    - Calorific value
    - Chemical composition
    - Rate of generation of waste (tpd)

    Data for this can be obtained from databases maintained by research organisations associated with MSWM in the city or by performing experiments collecting samples of MSW from different sources. These characteristics form another design variable.

- ***Desired feasibility aspects*** – The researcher needs to identify the aspects that define the feasibility of the system. These feasibility aspects form another design variable. The factors which contribute to the feasibility of a MSWM scheme are:

    - Institutional
    - Technical
    - Financial
    - Environmental
    - Social

The system is now defined with its boundaries and the researcher can create and screen the specific problems that he wants to analyze in his feasibility study. These steps lead to the statement of the problem and the output from this stage of the framework are the design variables, the stakeholder objectives and the boundary and exogenous conditions.

System design

In the conceptual design phase of the feasibility study framework, the inputs are the design variables, the stakeholder objectives and the boundary and exogenous conditions which are yielded by the problem definition phase. Based upon these, the choices of technology are to be explored by the researcher. The available options can be listed in a superstructure based upon literature studies about existent technologies for MSW conversion and knowledge from industry experience. The systemic generation of the superstructure will result in the choices of technology that are applicable to the context of the MSW generated in the city where the researcher is conducting his feasibility study:

- Pyrolysis/gasification of MSW
- Composting
- Anaerobic Digestion followed by Bioplastics from waste stream
- Direct Combustion

Based upon the knowledge of local experts and knowledge transfer from industries, the specific technologies that can be applied to the MSW of the city are to be screened. This evolutionary modification of the superstructure will result in a few choices of technology which can be applied to the city's MSW. These technologies can be modelled by using simulations in softwares such as MATLAB or Cycle Tempo or others. The models and the feasibility criteria obtained from the previous stage can be used to develop a test. The feasibility criteria that are applicable to most feasibility studies of MSW conversion to electricity are depicted in Figure 6 of this report. The test involves running the simulations or models and then checking if the results conform to the feasibility criteria. Also the results need to be assessed and compared using either a SWOT analysis or other methods of comparison. Then the favourable choices are to be optimised for the specific MSW of the city using algorithms and heuristics. The feasible schemes are to be selected and then a total system design can evolve from the feasibility study. To bring this system into being, the researcher will need to define the actor networks and the policy and regulation changes that need to be implemented. This is the last step of the framework. The framework is depicted in Figure 46.

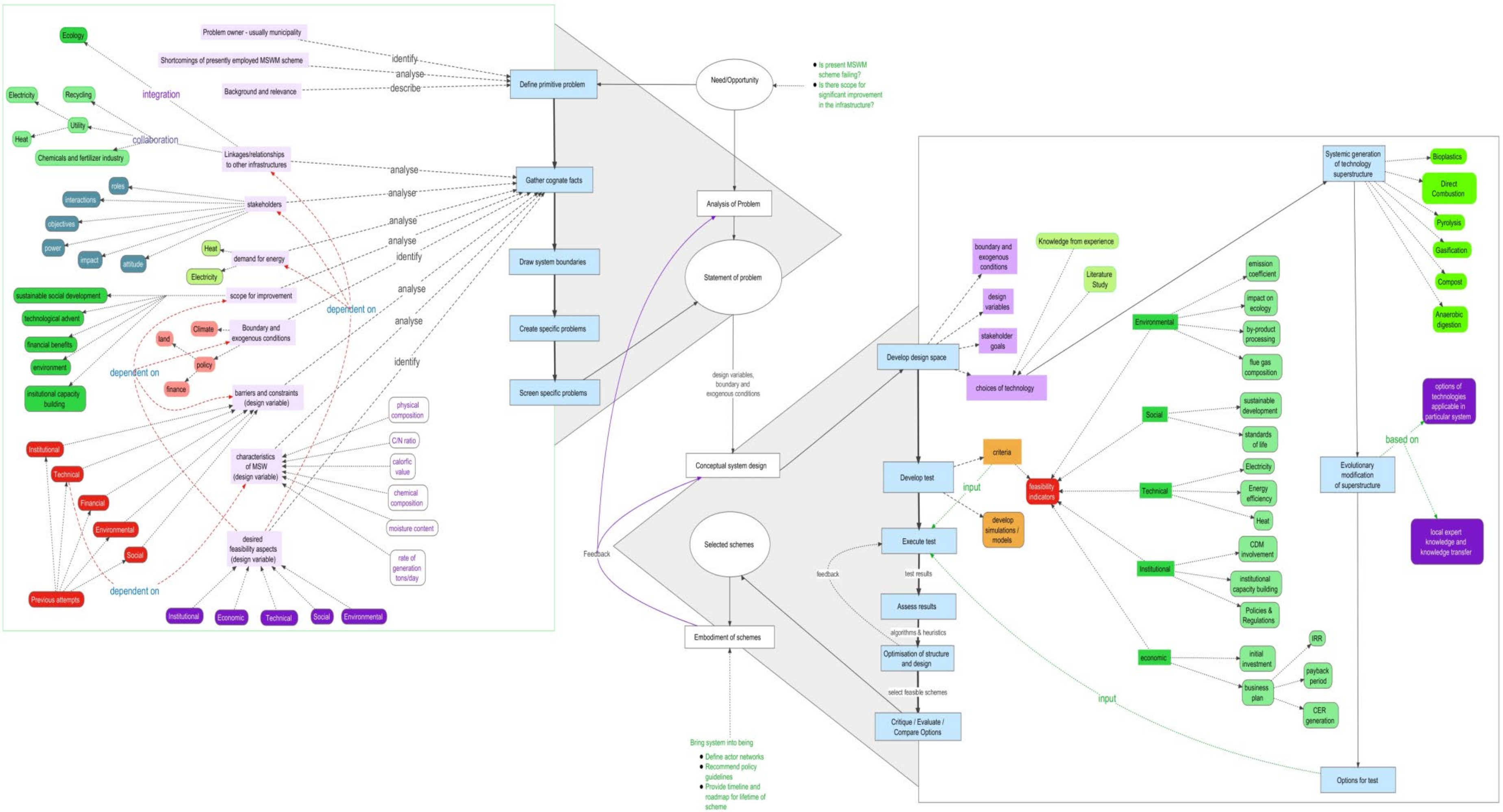

Figure 45 Evolutionary framework for feasibility studies for MSW conversion to energy

9. CONCLUSIONS & FUTURE PLANS

This chapter of the study report is dedicated to summarizing the results of the research carried out so far. It draws conclusions and gives recommendations about how MSW can be converted to energy in Kolkata's context and highlights the possible future plans that arise from this research.

9.1 Conclusions and recommendations specific to Kolkata's MSWM

After describing the problems of MSWM in Kolkata and exploring the appropriate choices of technologies, the research performed in this study led to the following conclusions:

- The existent MSWM scheme is failing because the dump site at Dhapa is unable to keep up with the increasing rates of waste generation in Kolkata and if the scheme is not changed, it will lead to reclamation of land from the farmers in the region.

- The existent MSWM scheme is closely linked to the local man made ecological system which includes waste water treatment, recycling of paper, plastics and metals, and garbage farming. This ecological perspective needs to be kept in mind while designing new MSWM schemes.

- The responsibility of MSWM in the city of Kolkata lies with the KMC. They have an allocated department and taskforce performing daily collection, storage and disposal of MSW. Private companies are not encouraged to enter this sector because that would render this taskforce redundant.

- The monopoly of CESC in terms of electricity generation and distribution within the city of Kolkata prevents private players from entering the market and this has discouraged previous attempts made by companies like Astonfield to set up power plants converting MSW to electricity.

- The high moisture content and low calorific value of Kolkata's MSW make it difficult for existing technologies to convert it to energy. Also the recycling of paper and plastics mean that the waste stream is unsuitable for direct combustion. The C/N ratio of the MSW points in the direction of biological processes such as composting, anaerobic digestion, pyrolysis and gasification, and bioplastics production. Also a pre-treatment facility is needed to remove moisture from the MSW and make it suitable for conversion to energy or other by-products.

- Farmers, ragpickers and scavengers who depend on the Dhapa dump site for a livelihood form an integral part of Kolkata's MSWM scheme. Their welfare needs to be kept in mind while designing a new MSWM scheme for Kolkata.

- Garbage farming practices are suffering in Kolkata because the land and surrounding water bodies in the Dhapa region are contaminated with toxins and heavy metals. This makes the vegetables and fishes coming into the consumer market unsuitable for consumption. The choice of crops to be grown in this region need to be altered.

- The technologies that have been explored in this research show positive results when it comes to energy efficiency and environmental impacts. The WGT technology in particular is attractive to investors interested in Kolkata's MSWM regime.

- KMC aims to alleviate the problems of MSWM in the city by taking on new roles and leading to institutional capacity building in terms of collaborations with CESC, research institutes and other industries. KMC is also willing to be a stakeholder in the CDM registration process.

- Financial instruments such as CDM and tipping fees are needed only by certain technologies in order to make the business case feasible for investors to enter the MSWM regime of Kolkata.

- Electrical connection to the grid needs to be established in order for a MSW to power plant to come into existence in Kolkata. The responsibility for achieving this connection is given to the IPP who constructs the power plant.

- Knowledge and information sharing amongst the stakeholders can lead to a sustainable MSWM scheme being implemented in Kolkata. NGOs and KMC can serve as knowledge and information sharing bodies to the stakeholders.

- Since all the proposed technologies are not mature and the evolution of technology is progressing at a rapid rate in the field of MSWM, the major stakeholders hesitate to implement a full-scale new scheme when it comes to the context of Kolkata. This creates the opportunity to implement small scale pilot plants in order to gain valuable information and data for the future. Also further research needs to be carried out in terms of alternatives to MSW to energy conversion.

This report has led to the design of a new MSWM scheme and the recommendations on how to implement the system and what future work needs to be done are listed below:

- Knowledge and information networks need to be set up for stakeholders to be aware of the system. The CDM network needs to have transparency in terms of the PDD, the additionality clauses and the baseline definitions. The local knowledge network needs to disseminate knowledge and information about MSWM to the local stakeholders in Kolkata.

- KMC should start institutional capacity building by collaborating with different institutions and take up the responsibility of owning and operating one pilot plant. They should also invest in logistics and vehicles in order to increase the effectiveness of the MSW collection system.

- The population of Kolkata, the industries, markets and other institutions should be more proactive with their MSW handling patterns and should start separating the

MSW at the source by segregating paper, plastics and metals. This makes the job of KMC and other IPP's much easier when it comes to MSW conversion to energy.

- Since the waste generation rates of Kolkata are increasing and because there is a shortage of land, the scope arises for research to play an important role in Kolkata's MSWM regime. Instead of having one conversion facility, multiple small scale pilot plants can be implemented in order to gain experience and information and knowledge about upcoming technologies such as bioplastics production, WGT technology and anaerobic digestion. Since by-product processing and dioxin effects have not been taken into the scope of this study, more research in this context needs to be performed in order to make the feasibility study more comprehensive.

- The monopoly of CESC can be broken if they themselves have a stake in the new MSWM regime. If they own and operate an anaerobic digestion plant, then they will be compelled to establish the connection to the grid. This means that the other pilot plants will also have access to the grid without having to invest in electrical connections. Regulations and policies need to be passed in order to make CESC comply with these plans.

- The ragpickers and scavengers need to develop the urge to improve their standards of living and working conditions. They need to realize that this MSWM scheme can benefit them and be more proactively involved in realising this scheme in reality.

- The garbage farmers should stop resisting the change of farming patterns. They need to understand that changing the crops will not lead to them losing their livelihoods. Research needs to be carried out to arrive at suitable alternatives in terms of cash crops or flowers.

- NGOs need to get actively involved in order to convince the ragpickers, scavengers and garbage farmers that this MSWM scheme is beneficial for them. These NGOs should also try to convince society and industry to start separating the MSW at the source in order to facilitate better energy conversion efficiencies.

- Financial institutions need to encourage private investors to enter the field of energy conversion from Kolkata's MSW. The interest rates and debt-to-equity ratio need to be formulated in such a way that they suit the needs of investors.

9.2 Future plans

This report can serve as a starting point for KMC to carry out further research in terms of technology implementation and social upliftment of the poorer sections who are involved directly with the MSWM infrastructure of Kolkata. The timeframe of 8-10 years when the dump site reaches complete saturation creates the scope of testing new technologies in pilot scale plants as recommended in the system design.

In this timeframe more research needs to be done in order to get more accurate data regarding the MSW characteristics, environmental impacts and other technologies that can be associated with MSWM in Kolkata's context. Also a close eye needs to be kept on the economic growth of Kolkata as a city and how the MSW characteristics evolve over time, before a concrete large scale infrastructural change is made to the existent MSWM regime. The conceptual design presented in this study derives its technological elements based on simulations which have a normalized set of data. Detailed engineering of these plans needs to be carried out in order to obtain higher levels of accuracy in terms of performance and economics. KMC have a few years in hand to indulge into obtaining more concrete evidence of the feasibility of implementing alternatives to landfill when it comes to Kolkata's MSW.

Appendix I – Interviews with stakeholders

Name : Mr. Arun Kr. Sarkar
Designation : Principal Technical Advisor (E & M)
Organization : KMC
Contact Number : +919830324302

Q & A

1. *How has KMC progressed in terms of MSWM in the city of Kolkata over the years?*

The Dhapa dumping ground has been used for decades to dispose of Kolkata's MSW. It is also a part of the Wetlands which makes it a very interesting site for the MSWM department of KMC. When the first part of the site got saturated, KMC collaborated withM/S Eastern Organic Fertilizers (India) Private Limited to set up a composting plant which would handle a part of the city's MSW. Also a part of the reclaimed land was given to garbage farmers for urban farming. With the advent of technology, KMC now employs mechanized street cleaners and other efficient vehicles to keep the city of Kolkata clean.

2. *What are the problems that KMC face with respect to MSWM today?*

Since the population of Kolkata is rising everyday and the consumption patterns of the residents are changing because of economic growth, it is very difficult to predict the MSW generation rate and its characteristics. This leads to us failing to come up with a new scheme to handle MSWM. Also, the Dhapa site is getting rapidly saturated and we have begun to look for alternatives to open dumping. A lot of waste is also left uncollected in the streets and we are looking to solve that problem by employing more personnel and vehicles. The lack of funding also creates problems when it comes to investments or changes in the infrastructure.

3. *Are you willing to let R &D play a role in defining KMC's future plans?*

Yes, of course. You are here carrying out research for pyrolysis and gasification. We are also encouraging industry players from all over the world to come and find out innovative solutions to the problems that KMC face. We are aware of the fact that new technologies are being implemented around the world and we are looking at options which best suit the needs of Kolkata's MSWM.

4. *Why did Astonfield and CESC get stuck with their plans?*

First of all, neither of them submitted a formal feasibility report for their proposed power plants. Secondly, the tipping fee that they demanded were not consistent with each other or with our calculations. We know that direct combustion of Kolkata's MSW is not the best option because of the low calorific value and also because the scavengers at Dhapa earn their living by separating the recyclable materials in Kolkata's MSW. The opposition party is also aware of these constraints and together we have decided to wait for better options as it will take around 8-10 years for Dhapa to be totally saturated.

Name : Mr. Subhasish Chattopadhyay
Designation : Executive Engineer
Organization : KMC
Contact Number : +919836536419

Q & A

1. *What are the technological options that KMC are looking at for Kolkata's MSWM?*

   We have looked at direct combustion and CESC is looking at anaerobic digestion. Composting is already being done but at a lower capacity than expected. You as a researcher are looking at pyrolysis and gasification. It is not that we are not aware of the problems. We know we need a solution. We are just waiting for the right one.

2. *Why is the MSWM service not being privatised?*

   There are over 600 people employed in the KMC to handle MSWM in the city. There are more than 1000 personnel involved directly in the collection and disposal of MSW. If the private companies take over, there is no guarantee that these jobs will still be ours and this is a major concern. Also KMC is the designated problem owner and we take pride in our work and serve the citizens dutifully.

3. *If that is the case, why are you not investing more?*

   That is something which is not in our hands. We get an allocated budget every year and we work with what we have. You have to talk to higher authorities to get a more suitable answer to your question. You as a researcher are working without remuneration because of the lack of funding. In spite of this being a prestigious institution (KMC) we still do not have proper internet access. You are a representative of the youth and more familiar with technologies. It is upto you guys to make sure that the right technologies come into the picture and the funding associated with them as well.

4. *Is it possible to test these new technologies using small scale pilot plants?*

   KMC is willing to give the land and water required by these proposed plants for free. However, we are not willing to pay tipping fees to any company unless they prove the need for it in a transparent way. We have had more than 6 proposals from different companies and none of them are consistent with each other with respect to the tipping fee. Pilot plants are always welcome but we need proof that they are not just whims of companies but actually have the potential to change the MSWM infrastructure in the future. We ourselves are collaborating with NEERI to understand the characteristics of MSW better and trying to see which technologies are suitable for test purposes.

5. *Do you think this office deserves a revamp?*

   Most definitely so. We need wireless internet for all our PCs. We need more efficient lighting systems and air conditioners. However, we need a lot, we get little.

Name : Mr. Ashim Kr. Mondal
Designation : Deputy Chief Engineer
Organization : KMC
Contact Number : +919830582969

Q & A

1. *Is KMC making any efforts to aid the economic growth of the personnel involved in its MSWM scheme?*

The people involved directly with waste collection and disposal are uneducated and poor. So are the ragpickers and scavengers in the Dhapa site. We are doing the best we can by providing them with a source of livelihood to sustain themselves and their families.

2. *Do you know that CDM can be used as a tool to generate finances if the poorer sections benefit from it?*

Yes. It is possible. If we were to implement a new MSWM scheme which would reduce GHG emissions and satisfy the additionality criteria, it can be a valid CDM project. However, it is not so simple. The scavengers will need to change their lifestyles and adapt to that of a rigorous training regime which would allow them to work in either a power plant or any other plant. This idea does not fit well with them. They need to be motivated enough to change. We cannot force them to do anything.

3. *Why don't you collaborate with NGOs to take care of this?*

We do try to bring in NGO participation when we can. However, very few NGOs are willing to take up the responsibility of changing the patterns of this class of people. If we find a dedicated NGO we will surely go for it.

Name : Withheld
Occupation : Scavenger at Dhapa site
Age : 14 years

Q & A

1. *What is it that you do here in this dump site?*

I take out all the thermocol that is present in the waste stream. I collect them and then hand it over to the person who takes the load to the recycling company.

2. *How much do you earn from this?*

Just about enough to make sure that I have two square meals on my plate everyday. Realistically that is all that someone like me can hope for.

3. *Have you ever thought about going to school and getting an education?*

Who doesn't? However, it is not simple. If I goto school, I will probably have to pay for it. I know there are some schools that teach kids for free. If I go to a school, it will mean that I can work here only on weekends and holidays. This means that I will not earn money. Either I will starve or someone in my family will starve.

4. *You do realize that I am trying to help you out here?*

This is not the first time that someone like you has come along and said these things to me or the other kids. It never materializes. We are used to it by now. I do not mean to offend you but you have no idea how we live and you have no clue how hard it is for our families.

5. *What is it that you need or want in order to make your life less difficult?*

As you can see, this dump is not the most hygienic place to work in. Personally, I would like a set of clothes which would prevent the toxic streams from touching my bare skin. Also I would like to have a mask which would help me breathe without wanting to throw up everytime I dig into a dump. People say we are immune to these conditions. Truth is, we tolerate it because we do not have a choice.

Name : Withheld
Occupation : Door to door waste collector
Age : 56 years

Q & A

1. *How long have you been working as a waste collector?*

Around 40 years now.

2. *Did you ever think about changing your profession?*

No. I took over from my father when he passed away. This is the only thing that I can do in society and this is the only thing that society will let me do keeping in mind my caste.

3. *How much do you earn per month?*

Around Rs. 5000.

4. *Is that enough? Do you not want to earn more?*

It is never enough. I have a daughter and a son. My wife works as a maid servant. Together we make enough just to make sure that my son goes to school. My daughter on the other hand has to sacrifice her ambitions and follow in her mother's footsteps.

5. *Would you prefer it to be otherwise?*

She is my own daughter. I obviously want a better life for her. Circumstances are not kind to us and our caste. We have been pushed down to the lowest rung of society and it is extremely difficult for us to climb higher. I definitely would want my daughter to goto school and live a better life, but what can I do without money?

6. *If you were to be paid more, would you take the responsibility of separating paper, plastics, metals and other recyclable materials from the organic waste in domestic households and temporary storage bins?*

Well, most of the time, people put all their waste into one plastic bag. My job is to collect it and transfer the load to a bin. I collect waste from about 400 households every day and to separate the garbage at the source does seem a good idea. It will be a painstakingly long process and the money better be worth it. A better idea is to ask the people themselves to be more responsible and use separate bags for organic waste and recyclables. This way your objectives as well as mine are satisfied.

Name : Withheld
Occupation : Garbage farmer
Age : 34 years

Q & A

1. *What crops do you cultivate?*

Me and my family grow cauliflowers in the plot of land that has been allocated to us.

2. *Are you aware that there are toxins entering the vegetables grown in this region?*

Just because the vegetables from here are cheap does not mean that they are poisonous. This practice has been prevalent for a long time now. The poorer sections of society in Kolkata rely on these vegetables and the fish from the Wetlands and there is nothing wrong with the quality. We have been told so by the authorities.

3. *If I were to tell you otherwise, would you believe me?*

You are young and naive. You do not have a grasp of the politics surrounding this region. However, for the sake of my family and my people, I will choose not to believe you. I know you have good intentions, but so do we. It is alright to have a few toxins in your food than to have no food at all.

4. *If you were given the option to grow some other crops instead of edibles, would you do it?*

As I said before, we do not dictate what we can grow. It is the demand of the downstream market that allows us to grow these vegetables and earn our livelihood.

We are used to these farming patterns. However, if you can prove that flowers or other crops will benefit not only us farmers but also the downstream consumers who rely on us, then our community can think about it.

Name : Mr. P. K. Basu
Designation : Executive Director (Generation)
Organization : CESC
Contact Number : +919830054935

Q & A

1. *Is CESC planning to enter the MSWM sector?*

We have been planning to help out KMC for a while now. We do not want to enter the sector. We want to let KMC do its job. We just want to receive the MSW from KMC and convert it into electricity.

2. *What technologies are you looking at?*

We have looked at direct combustion but the results are not very encouraging. Presently we are looking at anaerobic digestion which seems to be a better option.

3. *Why have there been no plans for implementation?*

First of all, the technology is still not proven. Secondly, there is no feasible business case. Taking into account that the characteristics of Kolkata's MSW allow to derive only 1 kg of RDF from 4 kg of MSW, it is not possible for us to design a scheme that gives us a suitable IRR (12-13%). We want a tipping fee of Rs. 300-400/ton of MSW. Lastly, the social aspects have to been given more attention. We as a private company are not the right people for this job.

4. *If CDM were to be involved, would the business case make more sense?*

As of now, no. This is because the AEB and the emissions resulting from the open site cannot be calculated accurately. The only accurate measure of GHG mitigation is from displacement of coal based electricity. For a pilot scale project, this is not much of a difference if we take the business case into account. A proper methodology to measure GHG mitigation, in terms of emissions from landfill site, needs to be implemented for CDM to make a difference to the business case.

5. *CESC has a complete monopoly in the generation and distribution sector in Kolkata. Why is it not willing to take a small drop in profits by not relying on a tipping fee and going ahead with the pilot plant anyway?*

You have to realize that we are not a charity. We do not enter into ventures unless we are sure we can make a profit. At your age, this might seem untowardly, but this is how the corporate world works. If we makes investments in terms of crores, we expect a suitable IRR.

6. *If that is the case, would you prevent an IPP from entering the market if they choose to implement a pilot plant without asking for a tipping fee?*

Ideally we would not want any other company to enter the market. However, WBERC has come up with regulations that force us to incorporate renewables in our mix. So we are also investing in renewables such as MSW to electricity. If some other company has a solution that is more feasible than ours, then they can go ahead with it as long as they pay for the electricity connection to the grid.

7. *Are you willing to enter into joint ventures with foreign companies?*

We already have done so in some of our coal-fired power plants. If the foreign company is interested they can always approach us to make some sort of a deal which benefits both parties.

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