Comparative Analysis of Composting as a Municipal Solid Waste Treatment Process in India

by

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B.S. Civil and Environmental Engineering
University of California, Berkeley, 2012

SUBMITTED TO THE DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF ENGINEERING IN ENVIRONMENTAL ENGINEERING
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JUNE 2015

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Submitted to the Department of Civil and Environmental Engineering on May 21, 2015 in Partial Fulfillment of the Requirements for the Degree of Master of Engineering in Environmental Engineering

ABSTRACT

A study of composting municipal solid waste (MSW) in India compared a specific facility in Muzaffarnagar, Uttar Pradesh, India to existing standards and practices documented in literature globally and in other facilities in India. The scope of this study included an analysis of issues in various facilities around the world in light of relevant government regulations, perceptions, and social values. From these results, short term low cost improvements were proposed to increase efficiency and sustainability of the facility in Muzaffarnagar. Long term improvements were proposed to address inefficiencies within the Indian industrial municipal solid waste composting system as a whole.

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ACKNOWLEDGEMENTS

Many people helped make this project possible. I would like to especially thank the MIT Tata Center leadership (Chintan Vaishnav, Rob Stoner, Gail Monahan, and many others) for making this research opportunity possible. I also would like to extend my gratitude to my advisor, Dr. David Langseth for his helpful guidance and feedback and to my project teammates, Ellen Huang and Julie Karceski for their contributions to this project and their company. I also give thanks to A2Z Infrastructure Ltd. and Ecofil for providing me access and information to the composting facilities visited in India, Pankaj Aggerwal, Mayor of Muzaffarnagar, for being a welcoming and informative host, and the students and faculty at Shri Ram Group of Colleges for being very useful and open-minded collaborators in Muzaffarnagar. In addition, I must acknowledge my peers in the Tata fellowship and in the Course 1 MEng program that have helped me forward both academically and personally. Finally, I thank my friends and family for their love and support.

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Definitions

Composting – A process of degrading organic matter into a stabilized humus-like material called compost. This can be done aerobically (with oxygen) or anaerobically (without oxygen). For the purpose of uniformity in this report, composting will refer only to the aerobic degradation process.

Humic Matter – Otherwise known as humus, this is a black or dark brown amorphous substance made from a mixture of compounds and chemicals sourced from the degradation of plants, animals, and microbes. It is chemically stabilized degraded organic matter that is seen to have multiple benefits to plant growth.

Industrial, Commercial, and Institutional (IC&I) – A category commonly used when describing waste generation. These are waste generators that do not produce hazardous waste yet are not typically included in the municipal waste stream.

Inorganic – Although plastic materials are technically organic since they are composed of organic polymers (with carbon), due to their high resistance to degradation, they are generally considered unwanted contaminants in composting operations. For this report, organic waste is considered all biodegradable fractions of MSW while inorganic refers to all non-biodegradable fractions (plastic, metals, glass, inerts, etc.).

Kabadiwala – This is a term used to describe a person in the informal sector of India that makes a living out of conducting door-to-door collection of high valuable recyclables at the household level. They can then sell the recyclables they collect to waste material traders.

Mechanical Biological Treatment (MBT) – A form of treating MSW starting with a mechanical preparation or sorting/separation process followed by a biological treatment portion to bio-stabilize the organic fraction of the waste (such as composting, digestion, and/or combustion) (Heermann 2003; Cant 2007).

MSW – Municipal solid waste (MSW) is the main feedstock that will be of focus in this report. MSW has generally been understood to be an umbrella term that includes all municipal waste streams. For the purpose of uniformity, MSW in this report will be defined as all mixed waste (un-separated) generated by residences. This does not include medical waste, IC&I waste, or hazardous or radioactive waste.

Public Private Partnership (PPP) – This is a contractual relationship usually between a government agency or municipality and a private company that has been contracted to do some type of work for the government. In the context of this paper, a PPP refers to the relationship between a private company that collects, treats, and/or disposes of the municipal solid waste (MSW) for a municipality.

Rag Pickers – Similar to the kabadiwalas, these individuals make a living out of selling high value recyclables from waste as part of the informal waste management sector. However, rag pickers generally pick through dumpsites and are not involved in door-to-door collection. In the global community, these individuals may also be known in the global community as "waste pickers".

SSO – Source separated organics refers to the waste stream that is solely the organic waste that has been separated at the site of waste generation. This can be food waste from residential, commercial, or industrial facilities or leaf and yard waste.

Trommel Screen/Rotary Screen – Used to refer to the same thing, a trommel screen or a rotary screen is a drum with all sides made from screens with specified opening (usually circular) sizes. This drum rotates on an axis and uses sieving to sort out inputs by size. This is a common mechanical separation process utilized by MBT or other large scale composting operations.

1. Introduction

Waste management is a significant concern worldwide, particularly in countries with high population density like India. Increasingly, waste management practices are receiving enhanced scrutiny by local governments and scientific researchers alike. As of 2000, around half of all municipal solid waste in the world is landfilled, and 30 percent of that waste is the organic fraction (Mata-Alvarez, Mace, and Llabres 2000).

In many parts of the more highly developed world, waste management plans aim for zero-waste; instead of disposal and waste management planners try to find a myriad of ways to reuse and repurpose both synthetic materials and organics. In 2011, the United States generated 250 million tons of waste, which included materials that could be recycled and composted (US Environmental Protection Agency 2013). Less than 12 percent was used for energy recovery.

Landfilling waste is highly undesirable due to space considerations, especially in nations with a high population density. Incineration, or burning waste, is also frequently employed as an alternative to landfilling. However, incineration can be toxic to the environment. The content of municipal solid waste (MSW) oftentimes contains chlorinated compounds, which can form hydrogen chloride and byproducts during incineration (Hartmann and Ahring 2006).

Moving towards more sustainable waste management practices, experts envision a hierarchy of waste treatment methods: first minimization and reuse, then recycling and composting, followed by energy recovery, and treatment and disposal only as a last resort (US Environmental Protection Agency 2013). More sustainable approaches, however, oftentimes require advanced planning as well as investment and experience in technology that can make such waste management less attractive in developing nations. As such, source reduction and reuse are infrequently target programs in these areas.

In less economically developed countries, resource recovery is very difficult to implement especially as it is oftentimes proposed in the absence of an existing waste management system. Municipal solid waste can be rich in resources, and also highly varied in composition, generally consisting of food waste, paper, plastic, metal and glass; hazardous household items, such as electric light bulbs, batteries, and discarded medicines are also common (Ngoc and Schnitzer 2009). Resource recovery is both an opportunity and a challenge in waste management.

Resource recovery, particularly of organics, presents an opportunity to close the energy and nutrient loop. As Hansen *et al.* (2006) noted, "Waste treatment options allowing recycling of the content of organic matter and nutrients to agricultural land might be a method for closing the cycle between city and agriculture and simultaneously reduce the production and use of commercial fertilizers."

Additionally, improved waste management practices can lead to lower global warming emissions. (Eriksson et al. 2005) observed "landfilling of all waste contributes most to the global warming potential of the studied scenarios," and also noted that recycling of nutrients and materials led to lower global warming emissions than incineration.

The focus of this report is to address value recovery from waste within a viable financial model and efficient waste management plan. The goal is to address composting as an existing waste treatment technology and explore several methods through which it can be improved upon. An associated report will address how the resulting compost product can be marketed in India and assess the financial sustainability of compost as an alternative to chemical fertilizers (Huang 2015).

1.1 Background on Municipal Solid Waste Management in India

India is home to more than 1.2 billion people, and, with a rapidly growing economy, is finding a foothold in the developed world. Economic growth averaged seven percent per year between 1997 and 2011 (Central Intelligence Agency 2014). As a result of rapid economic growth and urbanization, lifestyle changes have been correlated to an increase in per capita waste generation of about 1.3% per year (Ambade et al. 2013). Currently, 1 out of every 3 people in India lives in an urban area and this statistic is expect to increase up to 1 in every 2 in the next 10 years (Vij 2012). Like many developing countries, India faces swelling waste management problems and currently lacks appropriate infrastructure and policies for dealing with these challenges (Annepu 2012). With a rapidly developing economy, India also has enormous opportunities in waste management.

In particular, cities in India face serious problems in the management of municipal solid waste (Kumar et al. 2009). Waste generation generally rises as population and urbanization increases. If India continues utilizing current methods of waste disposal, such population changes will require more land for the ultimate disposal of municipal solid waste. (Idris, Inanc, and Hassan 2004). The annual load of solid waste in Indian cities rose from 6 million tons in 1947 to 48 million tons in 1997. At the current growth rate of 4.25% per year, annual waste will reach 300 million tons by 2047 (Sharholy et al. 2007). Additionally, Kumar *et al.* observed that in most urban centers in the nation, waste is merely disposed of into low-lying areas and unregulated landfilling is common in most cities. Other issues include lack of proper vehicle transportation of waste, lack of coordination between civic bodies leading to poor waste management, and lack of public concern and accountability for waste disposal and littering (Vij 2012).

As a heavily agricultural nation, India creates high volumes of organic waste. Rural and urban areas of India face distinct and pervasive waste management problems, and both are ripe for improved management strategies. An overview of MSW composition in India by regions is provided in Table 1. The middle three columns (Compostables, Recyclables, and Inerts) are shown as average percentages of total MSW by weight. The moisture content percentage is shown as the amount of water in unprocessed MSW by weight. A breakdown of overall average MSW composition in India is provided in Figure 1.

Table 1: Breakdown of MSW Composition in India by Weight (Annepu 2012)

Region	MSW (TPD)	Compostables (%)	Recyclables (%)	Inerts (%)	Moisture (%)
Metros	51402	50.89	16.28	32.82	46
Other Cities	2723	51.91	19.23	28.86	49
East India	380	50.41	21.44	28.15	46
North India	6835	52.38	16.78	30.85	49
South India	2343	53.41	17.02	29.57	51
West India	380	50.41	21.44	28.15	46

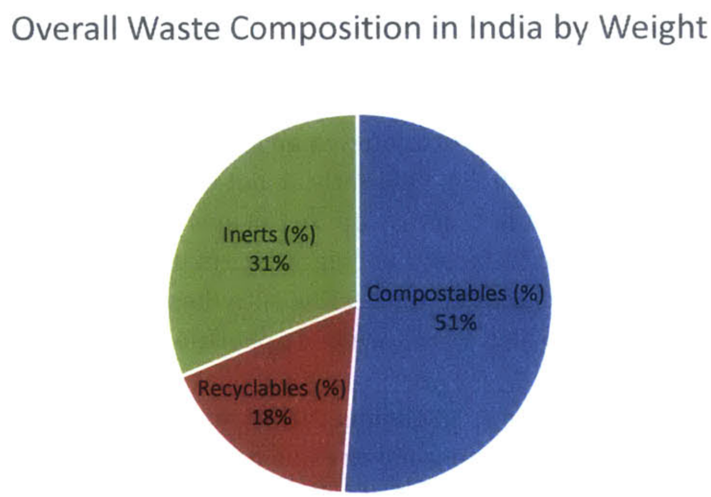

Figure 1: Overall Waste Composition in India (Annepu 2012)

1.1.1 Advancements in Municipal Solid Waste Management in India

As a response to a public interest litigation that was filed against the government of India in 1996 for failing to manage MSW properly, the Supreme Court of India appointed an expert committee called the Burman Committee to make recommendations and improve the situation (Joseph 2014). The Supreme Court made composting of biodegradable municipal solid waste mandatory based on recommendations from this Committee report in 1999. The Supreme Court then directed the government of India, state governments, and municipal authorities to take action. As a response, the Ministry of Environment and Forests issued the Municipal Solid Waste (Management and Handling) Rules of 2000 under the Environmental Protection Act of 1986, mandating specific policies and regulations regarding MSW management (Ministry of Environment and Forests 1999). Furthermore, the MSW Rules required biodegradable waste be processed by composting, vermicomposting, anaerobic digestion or any other biological processing that would effectively stabilize the waste (Ministry of Environment and Forests 1999). In 2007, the Supreme Court indicated compost and biomethanation technologies were appropriate for the typical quality of MSW found in India. Such typical traits included high organic waste content (40-60% by weight), high moisture content, and low calorific values (Rawat, Ramanathan, and Kuriakose 2013). In tandem, the Government stipulated that around 25% of all fertilizer come from composted-derived soil amendments. However, government subsidies of urea based fertilizer and common practices of bundling compost with traditional fertilizer create difficulties for MSW composting facilities to sell only compost (Kanhal 2014).

1.1.2 Waste Management Options in India

Though the wealthy are usually able to contribute their waste to recycling programs and other waste management practices, the fact remains that more than 90 percent of municipal solid waste in India is disposed of into open dumps (Silva and Naik 2007). Additionally, Kumar *et al.* 2009 noted that such open dumping is improper because "open dumps pose environmental hazards which cause ecological imbalances with respect to land, water, and air pollution." This is staggering not only in its scale, but also is a detriment to human and environmental health. It is a significant lost opportunity in reuse and repurposing of waste.

Gupta *et al.* (1998) noted that in India:

> "Uncontrolled dumping of waste on outskirts of towns and cities has created overflowing landfills, which are not only impossible to reclaim because of haphazard manner of dumping, but also have serious environmental implications in terms of groundwater and pollution and contribution to global warming."

Additionally, nearly half of municipal solid waste is comprised of organic matter. In fact, in cities with a population between two and five million, 56 percent of municipal solid waste is organic material (Sharholy et al. 2008). Organic waste, rich in energy and nutrients, can be digested aerobically (also known as composting) or anaerobically. Composting, a fast-growing option in India, produces soil amendments that can be sold as fertilizer.

Comprehensive collection of municipal solid waste is generally viewed as a first-world priority, due to lack of resources, expertise, and political will in the developing world (Silva and Naik 2007). Improvements in waste management practices developed in wealthier countries take a considerable amount of time to trickle down to the poorest. Additionally, due to lack of lack of adequate storage capacity, waste is often dumped directly on the road (Kumar et al. 2009). In Muzaffarnagar, A2Z has considerably improved cleanliness of wealthier neighborhoods, but the low-income districts are not as active in the disposal process (observation, August 12, 2014).

The mindset towards waste in poor neighborhoods may be explained at least in part by expectations and priorities. Low-income neighborhoods do not generally have municipal solid waste collection and disposal (Sharholy et al. 2008). Paying for waste disposal is not a high priority for the poor, and they also have not grown up with the expectation of clean streets.

The impact of reduced waste on quality of life could be significant. The portion of organic waste in municipal solid waste generally increases as socio-economic status decreases, so the poorest have the most to contribute, in terms of volume, and the most to gain, in terms of public health (Sharholy et al. 2008). Improper disposal can have an enormous effect on human health and the environment, as disposal sites tend to be located in poorer districts. Organic waste can contain pathogenic bacteria, such as *Salmonella*, *Escherichia coli*, and heavy metals such as copper, cadmium, lead, mercury, and arsenic (Shyamala and Belagali 2012).

Waste management problems in India are endemic and characteristic of poverty in developing nations. Perhaps optimistically, these problems also appear to have interesting solutions that would not only improve public health and the environment, but also empower the local community and present opportunities for small-scale entrepreneurship.

1.2 Report Structure

Section 2 provides an introduction to composting: the different types, beneficial uses, and potential markets. Section 3 delves more in depth into a literature review of the composting process, parameters that are the most important, and common issues experienced when composting MSW. Section 4 analyzes specific cases of composting MSW in India, with particular focus on Muzaffarnagar. Section 5 expands the analysis to other parts of the world, particularly the US, Canada, and Europe. Section 6 offers overarching recommendations for composting facilities in India, specifically Muzaffarnagar, based on the analysis of the other composting plants around the world. Section 7 wraps up with a conclusion that also offers potential next steps for future research.

2. Introduction to Composting

Composting MSW on an industrial scale has become an increasingly popular alternative to landfilling. If conducted right, composting reduces common landfill issues such as greenhouse gas emissions and leachate problems (Gupta et al. 1998).

2.1 Composting

Aerobic composting, vermi-composting, and anaerobic or trench composting are common composting processes (Mazumdar 1996). Aerobic composting involves microbes that utilize oxygen to degrade waste into a stable, humus-like product. Sometimes, co-composting with other waste products such as cow dung or biosolids (sludge from wastewater treatment processes) is done to enrich the nutrient content of the final compost product (Mazumdar 2007; Goldstein 2003). Vermi-composting involves the use of earthworms in addition to microbes to degrade and stabilize organic matter. Since exothermic reactions result in a high heat phase in the aerobic process (called the thermophilic phase) and earthworms are very temperature sensitive, the organic matter must be spread out to prevent a thermophilic phase in vermi-composting. As a result, vermi-composting may require more space than aerobic composting and does not reduce human pathogens as effectively (Tognetti et al. 2005). Anaerobic composting is also practiced but is more commonly known as anaerobic digestion. Anaerobic digestion has some differences when compared to composting: anaerobic processes produce biogas which can be harnessed as an energy source in addition to potential soil amendments from dried sludge. The process can be used effectively to treat wet municipal solid waste that is difficult to incinerate (Hartmann and Ahring 2006). It is, however, more expensive than land filling and requires more research before being adopted on a larger scale. As discussed in the definition section above, this report will focus on composting as an aerobic process exclusively.

Benefits of Composting

Composting is an attractive alternative waste treatment method due to its relatively simple technology; lower capital, operations, and maintenance costs; and flexibility in design when compared to other alternative waste treatment processes such as waste-to-energy and anaerobic digestion (Mazumdar 2007). Compost as a soil amendment can offer the following benefits: an increase in humus content, improved soil texture, better air circulation and moisture retention, improved resistance to pests, and plant nutrients (Mazumdar 2007). These properties make compost a potentially great soil conditioner that harnesses fertilizer value and may even contain microbes that can assist plant growth and prevent fungal disease (Otten 2001). Compost can also reduce erosion loss and increase structural stability of soil (Farrell and Jones 2009). In addition, composting not only diverts materials from landfills, increasing the lifespan of these sites but also makes landfills easier to maintain with reduced leachate, landfill gas, and odor issues (Otten 2001).

Uses for Compost

Potential applications for MSW-derived compost include agriculture and horticulture. However, there is concern that heavy metals in the compost may bioaccumulate in food crops and be dangerous for consumption (Farrell and Jones 2009). Other applications include restoration of remediated sites, as landfill cover or for landscaping (Keener 2011).

2.2 RDF

Composting MSW will have lower yields and lower quality compost than composting organic waste separated from other waste at the source of generation (also known as source-separated organics or SSO) (Keener 2011). However, source separation may require extra labor, expenses, and education and thus may not be viable everywhere. Typical compost yields from MSW composting are roughly 6% to 20% (by weight) of the organic waste feedstock (Annepu 2012; Mazumdar 2007; Rada et al. 2014). Thus, MSW composting is sometimes supplemented with other processes that will recover rejected waste from the composting operation and direct it to other uses such as energy generation. Refuse derived fuel (RDF) is one such form of utilizing compost rejects. RDF is usually processed from the rejected waste through shredding or compression to make floc/fluff or pellets, respectively (Annepu 2012). This can then be used for direct combustion as a solid fuel. RDF can help divert waste from landfill and supplement as additional revenue at a MSW composting facility.

3. Literature Review

3.1 Introduction to Aerobic Composting Processes

The main processes in aerobic composting involve fungi and aerobic microorganisms (such as bacteria) that oxidize organic compounds to carbon dioxide, nitrite, and nitrate. Carbon is utilized as a source of energy while nitrogen is recycled (Ministry of Urban Development 2000). This process is separated into two stages. The first stage, known as the thermophilic stage, is correlated with an increase in temperature (to about 50-60°C) and involves the decomposition of readily degradable compounds (e.g. sugars, fats, and proteins) into carbon dioxide, nitrite, and nitrate with oxygen as the oxidizing agent. Due to the high heat generation in this stage, pathogens (such as pathogenic microbes and helminthes eggs) are also destroyed. This process may take anywhere from 3-4 weeks or 8-12 months depending on the feedstock characteristics, type of composting technology used, climate, or level of operation and maintenance (Environment Canada 2013). As temperature decreases, the process enters the second stage, known as the stabilization or curing stage, where the organic matter is cured and increases in humic matter content. At this stage, temperature is typically around 25-30°C. This process can take anywhere from 8 to 12 months (Environment Canada 2013). The final product (after any additional processing post curing) is known as compost (Bundela et al. 2010).

Different pretreatment mechanisms may be used depending on the quality of the waste or feedstock. Shredding can reduce particle size to create more surface area for faster degradation. Mixing will help obtain a more homogeneous feedstock. Pretreatments may also include hand sorting, debagging, and/or screening to remove contaminants (Environment Canada 2013).

Typical composting technologies are separated into two different categories: static systems and turned/agitated systems. Static systems may include windrows that are aerated passively with perforated PVC pipes under the windrow piles (Epstein 2011). This is the most low-cost and low-tech option. Otherwise, air can be forced through piles actively in aerated static piles (ASP) either by a suction with a biofilter to reduce odors (negative aeration) or by pushing air out of the piles (positive aeration). To prevent odor emissions from positive aeration, the piles can be covered with fabric or finished compost. (Epstein 2011).

In turned/agitated systems, air can be circulated through windrows by turning or in agitated beds with turning devices (Keener 2011). Windrows are typically outdoors and may have a higher risk of odors emissions but will have more space and thus greater capacity than agitated beds (Epstein 2011). They are also low-tech and thus require less maintenance and operational investments. Windrow dimensions are typically 1.5 to 2.7 meters high and 2.7 to 6.1 meters wide with space between for a turning machine to maneuver (Epstein 2011). Windrows cannot be piled too high or they can become anaerobic easily. Turning is important not only for aerating the windrows but also to increase porosity and break up particles. On the other hand, agitated beds are usually enclosed or indoors. They are horizontal systems using turning machines, paddles or some other vessel that turns and provides aeration (Epstein 2011).

3.1.1 Additional Processes to Improve Composting Operations

Bulking agents may be added to feedstock to increase porosity (to increase oxygen availability) or control moisture content. Other amendments may be added to final product to improve product quality or add nutrients depending on the intended use (Epstein, 2011). Some bulking agents, like woodchips, can be recovered and reused before the curing step (Environment Canada 2013). Bacteria inoculum can also be sprayed onto windrows or curing piles to speed up decomposition or control the quality or odor of the compost (Mazumdar 2007).

Separating contaminants may be easier after curing than in the initial wet waste (Epstein 2011). Thus, post processing equipment like gravity separators, magnets, and de-stoners can be used to remove small contaminants such as glass, metals, or inerts (Mazumdar 2007). Refining cured compost will ensure a more uniform final product. This involves passing the material over a fine screen to remove oversized materials such as stones or bulking agents (Environment Canada 2013). This leads to improved quality of the final compost product.

3.1.2 Parameters Affecting Compost Process and Quality

The effectiveness of the composting process depends on various parameters as discussed below. Quality of the final product will also depend on how well organic material is processed.

Temperature

Temperature is one of the most important factors as it is directly correlated with the amount of organic material consumed by microbes. The optimum temperatures for the thermophilic stage are between 50-60°C (Epstein, 2011). However, to effectively inactivate pathogens, temperatures must consistently be above 55°C for several days. Above the optimum temperature range, microbial activity is inhibited and stabilization takes longer. Below the optimum range, stabilization can be achieved faster but pathogen inactivation will not occur as effectively (Avnimelech et al. 2004). Temperature can be affected by pile structure, dimensions, moisture, oxygen content, ambient temperatures in the environment, and turning frequency (Epstein, 2011).

Carbon and Nitrogen

Carbon to nitrogen ratio (C:N) has been seen as another important factor, since organisms involved in composting utilize carbon and nitrogen in ratios roughly 30 to 1. At too low amounts of carbon, the extra nitrogen will be converted to gaseous ammonia and lost to the air. At too low amounts of nitrogen, the microorganism growth will be inhibited by the lack of nitrogen and degradation of organic material will proceed more slowly (Environment Canada 2013). Optimum (C:N) ratios specified in literature range from 26:1 to 30:1 (Ministry of Urban Development 2000; Epstein

2011). To alter C:N ratios, carbon sources like sawdust and straw may be added when ratio is too low and sewage or biosolids (byproduct from wastewater treatment) are commonly added when the ratio is too high .

Moisture Content

Composting has optimum moisture content of around 45-55% by weight (Epstein 2011). Above 60%, pore spaces may be filled with water, thus limiting oxygen content and reducing microbial activity. Below 40%, microbial activity decreases and screening of compost may releases dust and bioaerosols which may impact worker health, increase susceptibility to fires, and corrosion of equipment (Environment Canada 2013). At about 20% moisture, microbial activity almost stops completely (Epstein 2011).

Oxygen

Due to the importance of oxygen to the rate of biodegradation of waste, composting processes must include aeration either through turning or with blowers. Insufficient oxygen levels may affect odor or phytotoxicity (Avnimelech et al. 2004). Low oxygen concentration will also decrease the aerobic degradation of organic material, turning the system anaerobic (Epstein 2011). Lack of oxygen will also lead to decreased pH, indicating the production of phytotoxic organic acids which can harm plant growth. Although the oxygen concentration of ambient air is 21%, usually an oxygen concentration of 13 to 18% in the compost piles is enough to ensure healthy microbial activity (Environment Canada 2013). The feedstock must also have sufficient pore space for microbes to access the oxygen easily. Porosity is governed by feedstock composition, moisture content, and particle size (Epstein 2011).

Stability and Maturity

Other factors include stability and maturity. Stability of the final compost product is critical to ensure that microbial activity is minimized and will not compete with plants or crops by depleting nitrogen or oxygen in the soil. Maturity of compost is suggested by the minimization of phytotoxic chemicals (such as organic acids), high electrical conductivity, or a large ammonia concentration (Francou, Poitrenaud, and Houot 2005). Organic acids in immature compost can also prevent the germination of seeds (Keener 2011).

3.1.3 Contamination in Composting Municipal Solid Waste

Contaminants that may affect compost quality include accumulation of heavy metals, inerts, and biologically or chemically hazardous materials. Toxic elements in compost applied to agricultural crops may also contaminate and concentrate in the food chain by entering food crops and affecting human health (Bundela et al. 2010). Bio-magnification of heavy metals is of particular concern. Sources of heavy metals may be household products such as soaps, detergents, cosmetics, packaging, leather, paints, electronics, ceramics, and batteries in the waste stream (Debertoldi 1993). Sources of inerts are glass or plastic fragments in MSW that will not easily biodegrade in the composting process, if at all. Biological contaminants like polynuclear aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) may also be present in compost feedstock from co-disposal with non-biodegradable wastes such as plastics and electrical equipment (Farrell and Jones 2009). Endocrine disrupting chemicals (EDCs) are also a risk to the environment and are sourced from industrial and agricultural activities. These problems illustrate the dependence of compost quality on the composition of the MSW that is used as the feedstock. Such waste varies largely between different countries, cities within a country, and even different areas within a city. Seasonal and even daily variations may also occur (Ojha 2011). This is part of what makes composting MSW so challenging.

As a result the quality compost made from MSW will generally be much lower than compost made from pure food waste or yard waste. Potential contamination in many situations can limit MSW compost to be used for specific low impact uses (non-agricultural) such as landfill cover or public landscaping (Keener 2011).

3.2 Composting Situation in India

Composting MSW in India dates back to 1934 when putting garbage in windrows just began. In the 1970s, MSW composting spread into more large scale operations with the installation of a dozen mechanical compost plants around the country (Mazumdar 2007). Compared to western societies, there is reduced waste generation per capita generation waste and also higher organic content and better C:N ratios in Indian MSW feedstock (Joseph 2014; Ministry of Urban Development 2000). This reflects differences between Indian and western lifestyles. However, source separation of waste (aside from high-quality recyclables by kabadiwhallas or ragpickers) is seldom practiced. MSW in India is thus typically mixed waste with high risk of contamination from inerts, hazardous materials, and metals.

However, MSW makes for poor quality feedstock which makes large scale mechanical composting in India a difficult challenge. Many such operations have failed because of problems in operation and maintenance, cost, and poor quality compost (Annepu 2012). Especially in the initial stages, machinery was imported and hard to maintain and the mixed waste would get stuck in the machinery or cause other problems. Lack of continuous power, lowered productivity during monsoon seasons and lack of market demand are some of the other issues compost facilities struggled with (Annepu 2012). Some large-to-medium plants, such as the Karnataka Compost Development Corporation plant in Bangalore, have been successfully operating with simpler technologies and with the help of government subsidies (Joseph 2014). Private companies have also shown interest in MSW management. Companies like Excel Industries have taken advantage of free MSW and rent-free site contracts with governments to create operational plants. However, without source separation, providing quality compost at attractive prices has proved to be a significant challenge. Issues such as thin plastic bags and household hazardous wastes in MSW are always threats to any composting operation (Joseph 2014). Unfortunately, changing MSW feedstock composition would require major changes to existing solid waste management systems and practices.

To regulate MSW composting and products, India has issued various guidelines, specifications, and regulations. Specifically, the Municipal Solid Waste (Management and Handling) Rules of 2000 (Ministry of Environment and Forests 1999) has mandated specific parameters to regulate compost quality especially to address metals contamination. Guidelines for heavy metals content, carbon to nitrogen ratio, and pH in compost quality for agricultural use (food crops) are specified in Table 2 (Ministry of Environment and Forests 1999):

Table 2: Specifications for Compost (Ministry of Environment and Forests 1999)

Parameters	**Concentrations not to exceed (mg/kg dry basis, except pH values and C:N Ratio)**
Arsenic	10.00
Cadmium	5.00
Chromium	50.00
Copper	300.00
Lead	100.00
Mercury	0.15
Nickel	50.00
Zinc	1000.00
C:N Ratio	20-40
pH	5.5-8.5

After the Municipal Solid Waste (Management and Handling) Rules were released in 2000 with specific parameters for metals, C/N ratios, and pH of compost, the Ministry of Agriculture has issued a Fertilizer Control Amendment Order in 2006 which required additional stricter stipulations for quality. These requirements are listed in Table 3 (Mazumdar 2007):

Parameters	Requirements*
Moisture (%)	15.0-20.0
Color	Dark brown to black
Odor	Absence of foul odor
Particle Size	Minimum of 90% material passing through 4mm sieve
Bulk Density	0.7-0.9
Total organic carbon (%)	16.0 (minimum)
Total nitrogen (%)	0.5 (minimum)
Total phosphate as P2O5 (%)	0.5 (minimum)
Total potash as K2O (%)	1.0 (minimum)
C/N Ratio	20:1 or less
pH	6.5-7.5
Conductivity (dsm-1)	Not more than 4.0
Pathogens	nil

Table 3: Additional Specifications for Compost (Mazumdar 2007)

*All percentages are by weight

In addition, a Manual on Municipal Solid Waste Management was prepared by the Ministry of Urban Development in 1998 to assist in proper management of solid waste in urban areas. The manual addresses two main methods of pit composting as well as windrow composting.

One pit composting process is called the Banglore Process and is described as an anaerobic method where waste is stabilized in pits with alternating layers of MSW and human excrement (also known as night soil). After filling, the pit is covered with a final soil layer to prevent fly breeding, rainwater entry, and heat loss. After a 4 to 6 month decomposition process, the stabilized material is ready to use as compost (Ministry of Urban Development 2000).

The second pit process method is called the Indore Process and is different from the Banglore method in that it is aerobic. To facilitate aerobic conditions, the material is turned at specific intervals. The first turn is done with rakes usually 4 to 7 days after filling. The second turn occurs after an additional 5 to 10 days. The material is then stabilized in 2 to 4 weeks. However, night soil is not always available in urban areas so composting of MSW usually occurs without layers of night soil (Ministry of Urban Development 2000).

Since the Bangalore method usually requires more time for stabilization (months scale) and more land space, the Indore Method is usually more attractive for urban areas. Aerobic processes also create fewer odor problems than anaerobic composting does. Compost yield from feedstock varies depending on the quality and composition of the input (Ministry of Urban Development 2000).

Another option for aerobic decomposition is open windrows especially in areas with high ambient temperatures. Specifications for these windrows include dimensions of 3m long by 2m wide and

1.5m high with total volume not exceeding 9.0 cubic meters (Ministry of Urban Development 2000). Aeration is provided by turning on the 6th and 11th days. On the 16th day, windrows can be sieved through rotary screens of about 25mm square mesh. The screen compost is then stored for 30 days in piles about 2m wide by 1.4m high and up to 20m long to accommodate the stabilization phase before the final compost is packaged and sold (Ministry of Urban Development 2000). The Municipal Solid Waste (Management and Handling) Rules of 2000 (Ministry of Environment and Forests 1999) has also issued regulations regarding windrow design. To satisfy these requirements, the compost windrow area must be constructed over an impermeable base made of concrete or compacted clay, 50 cm thick with a permeability of less than 10^{-7} cm/seconds. The base would also need to be designed with a 1% to 2% slope and encircled by lined drains for collection of leachate or surface run-off.

4. Case Studies in India

Three MSW aerobic composting facilities were visited in different regions of India for the comparative analysis to get a broad idea of industrial, centralized composting facilities in the nation. The key location of this project is the city of Muzaffarnagar, situated in the northern Indian province of Uttar Pradesh, approximately 130 km from the national's capital of Delhi. Muzaffarnagar is a traditionally industrial town, with processing faculties such as paper mills, steel recycling, and brick-making. Although municipality of Muzaffarnagar holds roughly 400,000 people (Ministry of Home Affairs 2011), the population of the greater metropolitan area has been estimated at up to a million (Kulshreshtha 2015). There has been historically a lack of infrastructure to handle the demands of the population and so waste management has long been a significant problem (Aggarwal 2015). A strong partnership has been developed between MIT and the local governing body in Muzaffarnagar. With an open mind to new changes, both the municipality and A2Z have expressed interest in improvements to the existing waste management structure (Aggarwal 2015; Saifi 2015). Therefore, this location serves as the main case study and the area where potential future improvements and recommendations will be piloted. Other facilities in India are explored to understand practices in Muzaffarnagar within the context of other MSW composting operations in the country. These other locations included Indore, Madhya Pradesh and Mumbai, Maharashtra. They were selected as additional case studies due to similarities to the A2Z Muzaffarnagar facility.

4.1 Case Study: Muzaffarnagar

Climate in Muzaffarnagar is warm and temperate. Monsoon season typically occurs July to September. The city has an average temperature of 24.2°C with an average of 32.8°C in June (the hottest month) and an average of 13.9°C in January (the coldest month) (Climate-Data.org 2015).

4.1.1 MSW Collection and Management Overview

In India, municipal solid waste is the responsibility of the local government, and Muzaffarnagar has contracted the waste management company A2Z Infrastructure Ltd., to take full control of the waste management chain (including collection, transportation, processing, and disposal). This contract is known as a Public Private Partnership (PPP). Since the system's start three years ago, it has not been exceptionally effective or profitable (Aggarwal 2015).

Muzaffarnagar citizens engage with two types of waste collectors each day. In the morning, a network of high-end waste collectors (also known as kabadiwalas) collect directly from residences. The kabadiwalas retrieve the most valuable recyclables (e.g. scrap metal and high quality plastics) with freight tricycles each morning (Aggarwal 2015). The remaining waste is collected by A2Z freight tricycles. This municipal waste is then delivered to a secondary waste site, where it is picked over by rag pickers, who retrieve plastics and other recyclables of value. Like the situation in

Muzaffarnagar, most waste management in India springs from *ad hoc* groups and individuals (such as kabadiwalas, rag pickers, and private sweepers) taking advantage of high-value recyclable items (Baud et al. 2001). Baud et al. (2001) further noted, "Little attention is given to the potential of small-scale, private operators and community-based organizations removing solid waste informally." The informal sector is not engaged in the planning process with local governments, leaving a gaping hole in connecting best practices with skilled workers (observation, August 12, 2014). D-Lab, a program at MIT that seeks to explore issues in developing countries, has been engaging MIT students and faculty to better understand and help navigate this relationship between the informal sector and the municipal solid waste management system in India.

Towards the late afternoon, A2Z trucks load what is left of the waste from the secondary waste site and bring it to the central waste processing facility (Saifi 2015). In theory, all the waste brought to the A2Z facility consists of mainly low grade recyclables (e.g. plastic bags and films), inerts (e.g. rocks, and sand), and organics (e.g. food scraps and yard waste).

The A2Z facility in Muzaffarnagar is a MBT system that processes MSW mainly with aerobic composting and RDF production. A2Z processes the waste, using an aerobic windrow system (observation, August 14, 2014). The final compost product, a soil amendment, is marketed towards farmers to be used as fertilizer. However, the cost of compost fertilizer stands as a barrier to its widespread implementation due to subsidies of chemical fertilizers (Kanhal, 2014). Revenue at the A2Z facility mainly comes from a tipping fee paid by the government per ton of waste that enters the plant. Income is also supplemented by sales of compost and RDF. A2Z also collects a nominal monthly fee of 30 rupees from all the households that waste is collected from. However, collection rate has been very low and only a small portion of Muzaffarnagar residents (mostly in wealthier neighborhoods) is paying the monthly waste collection fee (Aggarwal 2014).

4.1.2 Process Outline

At the A2Z facility in Muzaffarnagar, A2Z trucks bring MSW from secondary dump sites into an uncovered holding area onsite (observation, January 13, 2015). From here, the MSW is loaded into a rotary drum of 100mm size sieve. This is known as the presorting machine (See Figure 2). Two conveyer belts emerge out of the presorting machine. One conveyer belt carries the waste that is larger than 100mm into the uncovered RDF material holding area. The RDF material is further processed by a shredder and then compressed by a briquetting machine to become RDF briquettes. The other conveyer belt dumps the waste that is smaller than 100mm into a pile that is then used to make into windrows (See Figure 3) (observation, January 13, 2015).

Figure 2: Presorting Machine (100mm)

As the waste is formed into a windrow, it is sprayed with a proprietary bacterial inoculum that is a 1:15 ratio of inoculum to water (Saifi 2015). One liter of this solution is applied per metric ton of waste. This is called Biofertilizer Biocontrol (BFBC). There are four windrow piles onsite. Each windrow is roughly 2.5 meters high and about 3.5 meters wide. This design differs from the windrow dimensions specified by the Ministry of Urban Development (Ministry of Urban Development 2000). Length of the windrows at the facility can vary depending on the amount of waste material processed. The first two windrows are uncovered while the last two lie underneath a canopy. Every seven days, the waste in one windrow is moved to the next windrow location with a backhoe. The piles are aerated during this turning process. During the second turning, the BFBC is sprayed again (Saifi 2015).

Figure 3: Windrow Turning with Front Loader

The waste from the last windrow is loaded into the next rotary drum, of 35 mm size, after sitting in windrows for a total of 28 days (Saifi 2015). This drum and the rest of the composting process are all carried out indoors. Conveyer belts bring waste greater than 35 mm to be processed as RDF. Waste smaller than 35 mm is sent into a 16 mm rotary drum. These two rotary drums (35mm and 16mm) together are called the semi-finish line machine. Waste larger than 16mm is rejected and sent to landfill. Waste smaller than 16mm is sent through the finish line machine, which is a rotary drum sieving 4mm size. Waste larger than 4mm is also rejected and sent to landfill. Finally, waste smaller than 4mm is taken to an indoor storage area where the processed compost sits for two weeks curing before it is bagged as the final compost product. Before the compost is bagged, it is sprayed again with a different bacterial inoculum that helps stabilize and remoisten the final product. This culture is known as Enricher (Saifi 2015). The bagged compost is piled in a storage area ready to be transported out as orders come in (See Figure 4) (observation, January 13, 2015). Final compost can also be stored loose in piles for bulk orders.

Figure 4: Packaged Final Compost Product in Storage

Figure 5 provides a process diagram summarizing the total process (including RDF production) at the A2Z Muzaffarnagar facility. Materials are indicated by ellipse shapes while processes are indicated by rectangular shapes.

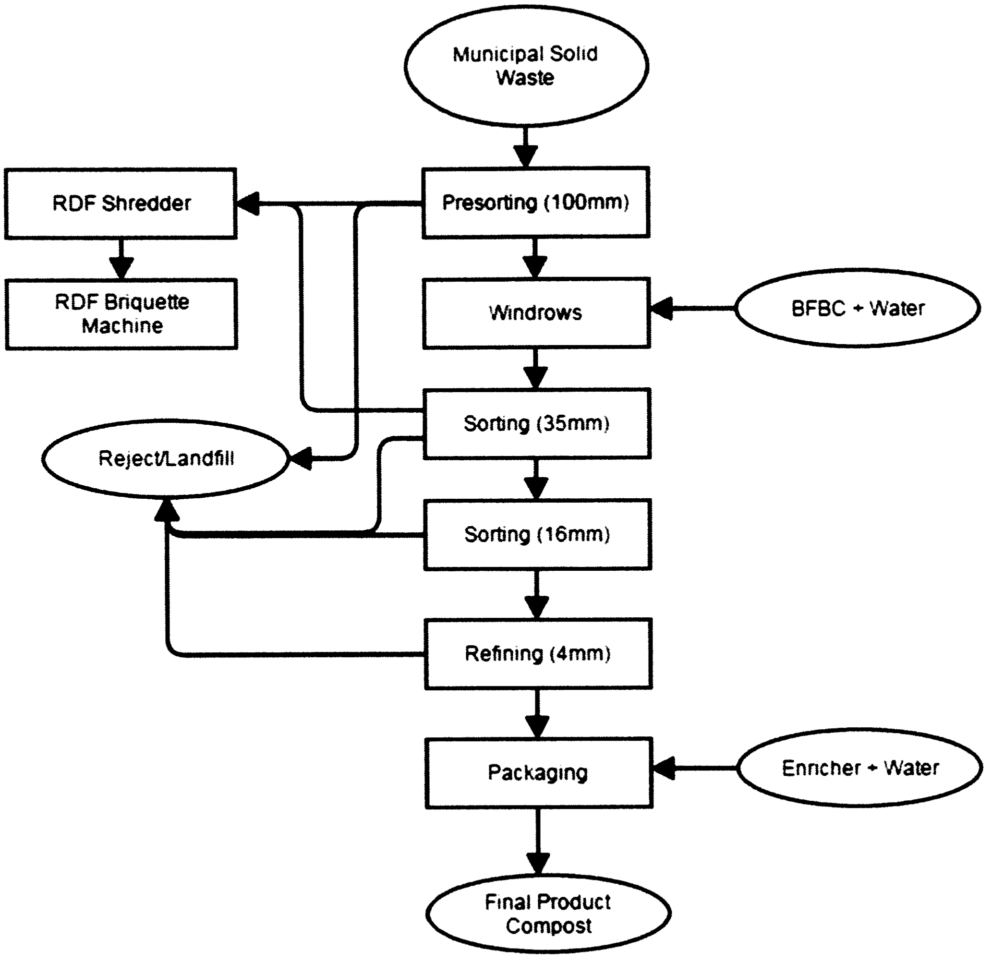

Figure 5: Process Diagram of MSW Treatment Process at A2Z Muzaffarnagar Facility

No compost was being bagged at the time of visit. No RDF was in production during the visit either. No leachate or leachate management system was observed. Vectors observed included birds, flies, and stray dogs.

Much of A2Z's composting procedures is summarized in the company document: "Windrow Management: Standard Operation Procedure" (See Appendix A).

Quality Control

Seasonal variations necessitate adjustments to the composting process. This includes adding additional water to the windrows during the dry season and storing windrows in a monsoon shed during the rainy season (Saifi 2015). The monsoon shed is a canopied area over a concrete slab. The moisture content of the windrows is checked weekly through hand-feel and the targeted moisture content is around 45%. Samples of the windrows are also taken periodically and tested for moisture content in a more precise manner. The testing is conducted at the company laboratory in

Kanpur (Saifi 2015).

Temperature of the composting piles can vary between 18°C and 45°C (Saifi 2015). Temperature in each windrow is measured daily by a temperature probe in three locations: at both ends and at the middle. Each measurement is taken at approximately halfway up the full height of the windrow. The windrows are moved to the monsoon shed to cool down if the temperature is too high. This usually only occurs during the summer months. In addition, the dimensions of the windrows are adjusted according to temporal variations. Colder temperatures will lead to increased height of the windrows and hotter temperatures will lead to decreased height of the windrows (Saifi 2015).

According to Mr. Saifi, samples of the final compost are taken every 1 to 2 months or as required by the government (Saifi 2015). These samples are sent to the company laboratory in Kanpur, Uttar Pradesh or sent to be tested by a third party. Compost that does not meet government standards is sent through the process again. According to results found at the Kanpur laboratory, the compost is around 0.8% nitrogen and 12-15% carbon (by weight). Cow dung can be added to improve the fertilizer value of the compost if it is nutrient deficient. A2Z did not make sampling data available for analysis under the scope of this project.

Mr. Saifi estimates average production of compost at 1,000 metric tons/month or 30 tons/day (Saifi 2015). However, this number varies seasonally. January to March is considered the low production period at around 500 to 600 tons/month whereas March to December are considered the high production period at around 1,200 tons/month.

4.1.3 Preliminary Assessments of Process Drawbacks

Table 4 presents an averaged mass balance of materials that flow through the facility at each stage of the composting process. For example 72% of the initial waste feedstock passes through the presorting 100 mm rotary sieve to be piled in windrows while 26% is rejected from the presorting machine as feedstock for RDF production and 2% is rejected as debris (to be landfilled). The 72% is then further reduced to 37% while 35% is lost as evaporated moisture and dust in the windrows. Final compost product averages at 17.95% of initial waste feedstock.

Table 4: Composting Mass Flows at A2Z Muzaffarnagar Facility (Saifi 2015)

	Composting Mass Balance (% by weight of total waste feedstock)				
	Pre Sorting 100 mm	**Windrows 1-4**	**Pre Sorting 35 mm**	**Pre Sorting 16 mm**	**Pre Sorting 4 mm**
Compost	72	37	29.75	24.25	17.95
RDF	26	0	2	0	0
Debris	2	0	0	5.25	6.3
Normal Loss	0	35	5.25	0	0
Total	100	72	37	29.5	24.25

Table 5 presents an averaged mass balance of materials that flow through the facility at each stage of the RDF production process. For example, 28% of the initial waste feedstock that has been diverted to RDF production is further reduced to 8.4% from the shredder process before it is compressed in the briquette machine to produce the final product RDF which is 7% of the initial waste.

Table 5: RDF Mass Flows at A2Z Muzaffarnagar Facility (Saifi 2015)

	RDF Mass Balance (% by weight of total)	
	Shredder Process	**Briquette Machine**
Compost	0	0
RDF	8.4	7
Debris	0	0
Normal Loss	19.6	1.4
Total	28	8.4

A summary of the averaged final mass balance distribution is presented in Table 6. This gives an idea of how much of the initial MSW is processed as final compost, RDF, landfill material, or normal loss.

Table 6: Final Mass Balance Breakdown at A2Z Muzaffarnagar Facility (Saifi 2015)

Final Mass Balance (% by weight of total)					
		Losses			**Reject/**
Compost	**RDF**	**From Composting**	**From RDF Production**	**Total**	**Landfilled**
17.95	7	40.25	21	61.25	13.55

The data provided in the three mass balance tables have been collected from a preliminary mass balance table provided by A2Z and additional modifications developed through interviews with A2Z facility operator, Mr. Ahsan Saifi (Saifi 2015). Discussion with Mr. Saifi suggested the data was collected from a single sampling event which may cast doubt on the validity of the numbers as a representation of the mass balance flows of the entire facility. However, the data collection method was not clearly confirmed. There is also a lack of information on process variability at the plant (from seasonal variations, temperature, feedstock variability, etc.) from this set of data. Nevertheless, analyzing this data is still useful in providing an understanding of process flows and efficiencies within the MSW treatment system. Section

6.0 Discussion and Conclusion will delve into a deeper analysis of the mass balances at this facility in relationship to rough averages at other facilities in India and around the world.

Losses

According to the data presented in Table 6, over half of the incoming MSW feedstock (61.25%) is lost from the system. Pathways for this loss include moisture evaporation from the windrow piles into the air, losses from equipment leakages, and fine particle movement to other parts of the facility and vicinity as dust. This high percentage of losses may indicate a lack of efficiency in processing incoming waste and is worthwhile to explore further. However, at this time, the losses have not been physically measured; they have been calculated as the difference between the total weight of the incoming feedstock and the weight of the resulting processed materials (Saifi 2015). Therefore, there may also be other portions of the process that have not been calculated correctly or have been underestimated. This may also contribute to the high losses generated at the facility.

Temperature in Windrows

According to interviews with Mr. Saifi, the windrow temperatures range between 18°C and 45°C. However, temperatures must be between 50°C to 60°C for several days to effectively inactivate pathogens in MSW (Epstein 2011). If the windrows are not raised to these higher temperatures, pathogen inactivation will not occur sufficiently which may affect the health of the workers managing the composting process as well as any users of the compost coming into direct contact with the product.

In addition, the ambient temperature in the winter months is much colder than in the summer months, making it more difficult to maintain a high enough temperature in the windrows for optimum microbial activity (Saifi 2015). As a result, degradation occurs at a slower rate which is reflected in the lower estimates for the low production period (January to March). There is a drop of about 30% in productivity during these winter months (Chauhan 2015).

Bottleneck: Moisture Content

Interviews with Mr. Saifi also indicated issues with moisture in the summer/monsoon season (Saifi 2015). During this time, moisture content is higher than desirable, particles clump together, and as a result the rotary drums are clogged much more frequently. This leads to more frequent cleaning of the drum screens which hampers the production rate of compost (Saifi 2015).

Potential Contamination Issues

A2Z facility staff did not specify any particular issues with contamination that they needed to address, aside from minor glass bits that are sorted out of the system by hand. Mr. Saifi indicated that all compost produced met government specifications (Saifi 2015). However, without a mechanized metals or glass removal process such as a gravity separator, deriving clean and uncontaminated compost from mixed waste is nearly impossible. Therefore, there is a very real risk of contamination from heavy metals, glass pieces, or inerts. This may contribute to the low demand for compost product. However, due to lack of physical data, this issue cannot be formally evaluated.

Electricity Availability

Electricity outages within the city has also created problems for the facility. It hinders the processing rate by stalling machinery and interrupting process flow. Mr. Saifi expressed concern over this issue (Saifi 2015).

4.2 Case Study: Indore

Indore is a city within the Indore District and Indore Division located in the central portion of India, within the state of Madhya Pradesh (MP). As the largest city in MP, Indore is home to over 2 million people (Ministry of Home Affairs 2011). Summers (March, April, and May) are typically very hot with temperatures reaching up to 40°C on average although humidity is low (National Oceanic and Atmospheric Administration 2015). Overlapping with the summer months is the monsoon season that picks up in June. Here, Indore receives the majority of its annual rainfall of 32 to 35 inches. Winters are moderate and dry with temperatures ranging from 8°C to 26°C (National Oceanic and Atmospheric Administration 2015). Overall, Indore is closer to the equator and has a warmer climate than Muzaffarnagar. Winter in Indore are also drier and less foggy than the winter season in Muzaffarnagar.

4.2.1 Process Outline

In Indore, A2Z Infrastructure, Ltd. has entered in a PPP contract with the Indore municipal government. However, the waste collection process is slightly different. Municipal workers collect household waste door to door and drop the waste into secondary collection bins in designated areas (Chauhan 2015). From there, A2Z collects the bins and transports to the waste processing facility. Unlike in Muzaffarnagar, A2Z in Indore does not collect from households and only collects from the secondary areas, which allows the government to pay A2Z a lower tipping fee. About 750 to 800 tons of waste are collected per day from these secondary collection bins (Chauhan 2015).

Much of the process at Indore is similar to the A2Z facility at Muzaffarnagar. All waste is processed in the same day to avoid spoiling (Chauhan 2015). Whereas much of the operations in Muzaffarnagar is uncovered, all of the composting machinery in the Indore facility are within sheds (observation, January 19, 2015). There are four sheds total: one for the presorting machine and the RDF processing; one for the semifinish line; one for the finish line; and one to store the final compost. There are seven sets of four windrows, one for each day of the week. Already it is evident by the number of windrows that the Indore facility has a greater capacity than the older facility in Muzaffarnagar. However, the windrows are turned the same way and also take 28 days. New windrows are also sprayed with bacteria inoculum comprised of a 1:9 ratio of bacteria to water. 1 liter is sprayed per metric ton of waste. Windrow dimensions are normally 1.5 to 2 meters in height and 3 meters wide. Length of the windrows can vary depending on the amount of waste material processed. However, at the time of the author's visit, some windrows were higher than others due to mechanical problems in the loading trucks. There was also a concrete paved monsoon shed that was not in use. The rest of the composting process is exactly the same as the facility in Muzaffarnagar except for a curing phase between the 16mm rotary drum and the 4mm rotary drum. Here, the immature compost is placed into one of 24 sheds and kept for 15-20 days for further decomposition (See Figure 6). At this time, the same inoculum solution is sprayed in the same dilution ratio but the dose is 1 liter is distributed over 3 to 4 tons of the immature compost. Before packing, the compost is sprayed with a different inoculum and water solution to stabilize and maintain the moisture level at 15-20%. In offseason times (when crops are not being grown), the finished compost can be stored up to 4 months (Chauhan 2015).

Figure 6: Curing Sheds

Figure 7 provides a process diagram summarizing the total process (including RDF production) at the A2Z Indore facility. All processes and materials different from the A2Z Muzaffarnagar facility are outlined in blue. RDF processing at the A2Z Indore facility also differs from the Muzaffarnagar facility but an exploration of this comparison is outside the scope of this report.

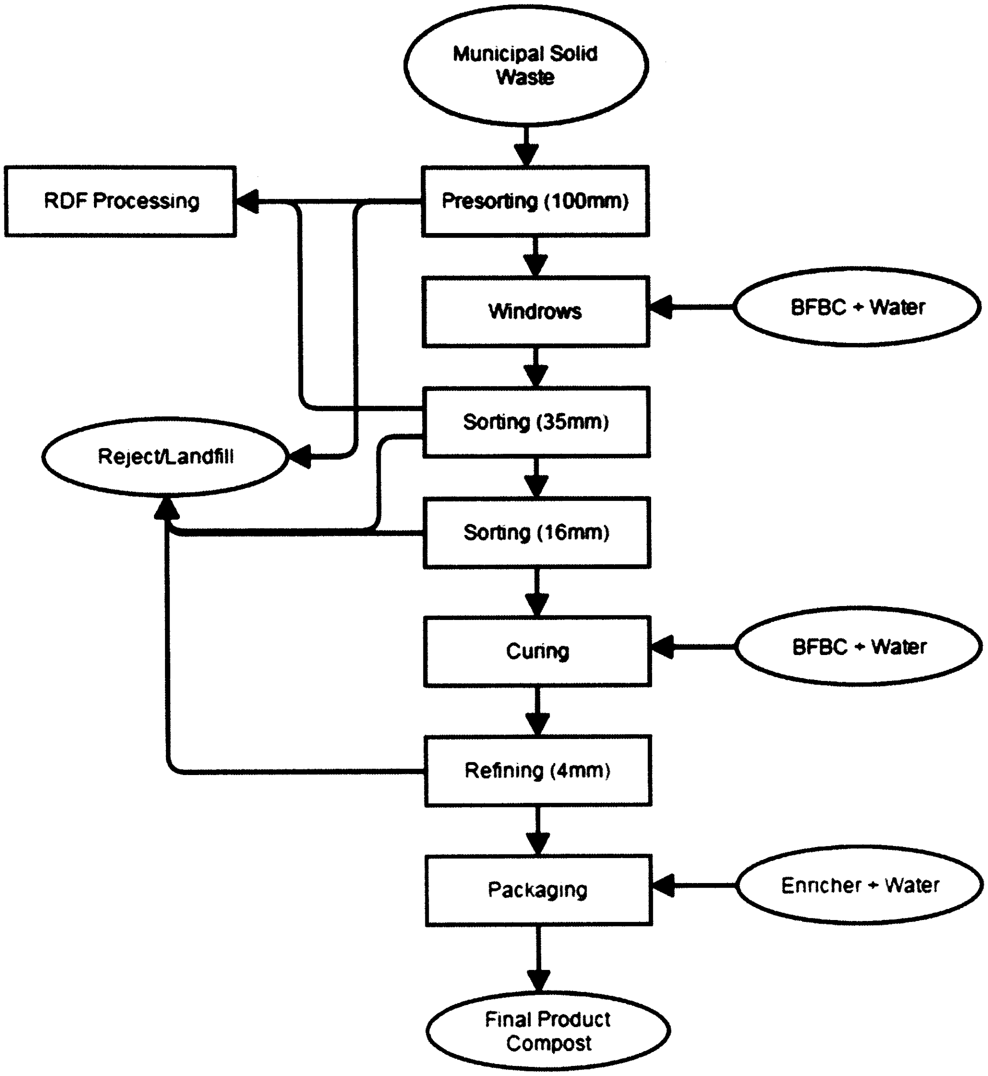

Figure 7: Process Diagram of MSW Treatment Process at A2Z Indore Facility

Quality Control

In-situ temperature sampling is conducted every 1 to 2 days in the windrows (Chauhan 2015). Additionally, a sample from each batch of final compost product is collected and analyzed at a small onsite laboratory (See Figure 8). Each sample is tested for moisture, carbon content, and nitrogen content. Batches that do not pass government specifications (approximately 1% of the compost produced by weight) are sent back through the production process again. More complex or thorough analysis of samples is conducted a full scale laboratory in A2Z's main facility in Kanpur (Chauhan 2015).

Figure 8: Laboratory Equipment in On-site Testing Lab

4.2.2 Discussion

Similar to Muzaffarnagar, the monsoon season raises the moisture content of the windrows (even with monsoon shed storage) which affects the processing rate of the compost. Plans are being made to make a completely indoor storage facility for the windrows (Chauhan 2015).

In the winter season, the fog and the cold temperatures will also lower productivity due to heightened moisture and lowered ambient temperature (Chauhan 2015). However, this is less of a problem than it is in Muzaffarnagar where fog is more common in the wintertime.

Mr. Rohit Chauhan, Operations Manager, indicated that there are issues with hiring workers in the waste sector because it is heavily stigmatized (Chauhan 2015). Approximately 50% of the revenue is used to buy diesel fuel. However, unlike Muzaffarnagar, Indore does not suffer from electricity service interruptions and can run continuously (Chauhan 2015).

4.3 Case Study: Navi Mumbai

Navi Mumbai is a township of Mumbai along the west coast of the state of Maharashtra. As of the 2011 census, Navi Mumbai is home to over 1 million people (Ministry of Home Affairs 2011). Monsoon season is typically June to November with other months being relatively dry but still hot. Average maximum temperature is 31.2°C while average minimum is 23.7°C (National Oceanic and

Atmospheric Administration 2015). Overall, Navi Mumbai is much warmer than Muzaffarnagar and more humid. Navi Mumbai also does not experience as distinct a winter season as Muzaffarnagar or Indore do.

4.3.1 Process Outline

Much of the composting process at the MSW facility in Navi Mumbai is similar to the ones at Muzaffarnagar and Indore. However, as the plant is operated by a separate company, EcoFil, the processes are slightly different. The facility has a capacity of 500 metric tons per day (Verma 2015).

Most obvious difference is the drainage collection system and treatment facility for the leachate generated on site. The leachate is treated with alum and is then reused to spray onto the windrows to add moisture and microbes (Verma 2015).

The waste sits in windrows for roughly 30 days and turned for a total of four times. Bacteria inoculum is sprayed after the initial windrow is formed and after the first turning. All subsequent turnings are followed by spraying with treated leachate water to maintain the proper moisture content. The first window has roughly 75% moisture content and by the last windrow, moisture content decreases to about 40-50% due to evaporative and leachate losses. First windrow typically maintains a temperature of about 40-45°C. After seven days, the temperature increases to 55-65°C due to enhanced microbial activity (Verma 2015).

The sieve sizes for the sorting process are also slightly different than in the composting facility at Muzaffarnagar. Instead of 35mm and 16mm rotary drums, 50mm and 14mm drums are used instead. The last mechanical sorting rotary drum is still 4mm. Sieve sizes have been chosen based on studies of the local MSW composition. Rejects from the 100mm drum and the 50mm drum are used to make RDF products. All other rejects from other drums are sent to landfill (Verma 2015).

Discussions with Mr. Anil Verma, Operations and Maintenance Manager, indicated the facility received higher than average organic waste fraction in the MSW due to the food and vegetable waste collected from a nearby market (60-65% organic waste total, by weight) (Verma 2015).

Figure 9 provides a process diagram summarizing the total process at the EcoFil facility in Navi Mumbai. All processes and materials different from the A2Z Muzaffarnagar facility are outlined in blue. RDF processing at the EcoFil facility also differs from the Muzaffarnagar facility but an exploration of this comparison is outside the scope of this report.

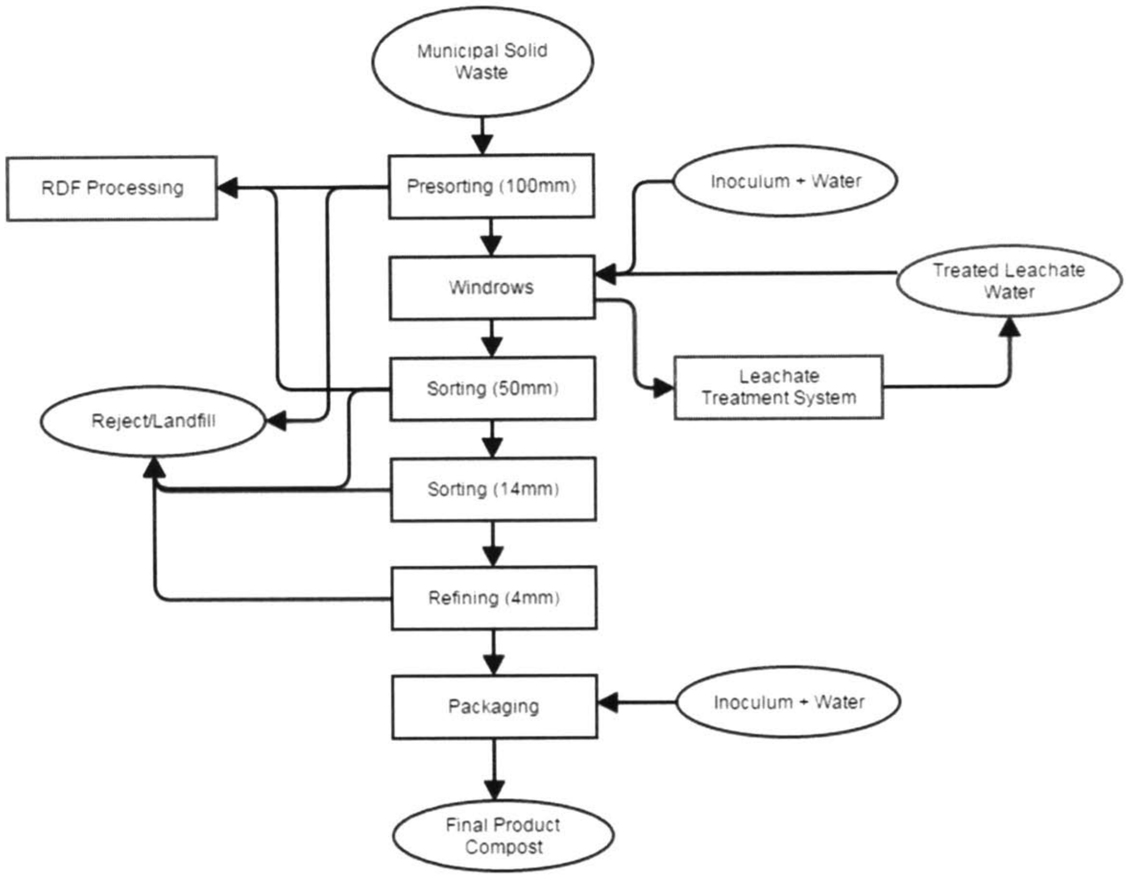

Figure 9: Process Diagram of MSW Treatment Process at Ecofil Navi Mumbai Facility

4.3.2 Discussion

The main issues with this facility are also seasonal variations in moisture. Discussions with Mr. Verma indicated high moisture during the monsoon season can hinder productivity by roughly 50% (Verma 2015). No mention was made of issues with glass or metal contamination.

The existence of the leachate treatment system in the Navi Mumbai facility may be due to specific conditions in the windrows that are more favorable towards leachate generation. Problem with leachate may be due to higher ambient temperatures and humidity in Navi Mumbai in comparison to Muzaffarnagar and Indore. This contributes to higher microbial activity depleting oxygen in the pore spaces of the piles. Higher humidity also increases moisture content in the windrows, reducing pore space for air/oxygen. As a result, these conditions are more favorable towards anaerobic conditions which is then conducive to the generation of leachate as pollution (Environment Canada 2013). Although recycling the treated leachate back in the windrows is a resourceful way to conserve nutrients, since leachate is generated from anaerobic processes, there will most likely be anaerobic bacteria in the treated leachate that then continues to promote anaerobic activity within the windrow piles when the leachate is sprayed on. This perpetuates the issue of leachate generation.

4.4 Common Issues

One of the main issues experienced by all these facilities is a lack of source separation. Two-bin systems for wet and dry waste can be seen all over Mumbai, yet Mr. Verma pointed out there is a lack of interest in adopting the system so the separate waste stream bins are largely ignored. Discussions with Mr. Aggarwal indicated A2Z also attempted to encourage source separation with four separate bins during door-to-door waste collection in Muzaffarnagar (Aggarwal 2015). However, this also failed as households and waste collectors alike ignored source segregation. All four bins were used to hold mixed waste instead. Without source separation, it is harder to extract high quality compost product from MSW feedstock due to high risk of contamination from metals, glass, and plastics.

In addition, low profit margins make composting MSW a difficult business to thrive in. This is due to a variety of factors including lack of high demand for compost product and lack of subsidy for compost. These two go hand in hand and is especially important since Mr. Chauhan has indicated A2Z is trying to petition the government to provide subsides for compost product which can better level the playing field in soil amendment markets. Also, lack of adherence to government laws and regulations is a problem. Despite the Municipal Solid Waste Management Rules of 2000, landfilling and open dumping have been long held practices and are hard to stop especially when costs are low.

Another important issue is high seasonal ambient humidity that can contribute to higher than desired moisture levels in compost piles. This seems to be an issue across the board in India as the monsoon season is experienced in most areas of the country. Heightened moisture levels appear to take a serious effect on productivity (up to 50%) and increases operations and maintenance costs as well.

5. Comparative Analysis: North America and Other Regions

Much of the developed world has already experienced many of the issues current MSW processing facilities in India are experiencing today. Lessons can be drawn from other nations, especially ones that have already made a lot of progress in addressing landfill alternatives.

5.1 Centralized Composting in United States

In the United States, industrial scale composting utilizing mixed waste is much less common than in India. Most composting facilities process SSO and often also take in organics from commercial facilities as well (Goldstein 2005). Thus compost quality is much higher with less risk of contamination. However, some facilities process MSW (11 facilities as of 2010) and co-composting with biosolids is commonly practiced (Sullivan 2010). This is more common in rural areas or tourist destinations such as Yellowstone National Park that have limited landfill capacity and limited ability to train tourists to separate waste (Goldstein 2003). Other system variations may include curing outside verses covered curing and reducing particle size by shredding and grinding verses screening with rotary drums (Spencer and Goldstein 1990).

Compost derived from MSW typically has trouble finding a viable end-market due to potential contamination from metals and other non-biodegradable materials. Instead of an agricultural soil amendment, it is usually marketed for landscaping uses or as landfill cover (Giannone 1998). There are no national regulations in the US for organic materials like compost. Instead, each state has its own specific regulations regarding composting (US Environmental Protection Agency 2014).

As of 2014, 4914 composting operations were identified in the US (Platt and Goldstein 2014). The breakdown of the composting facilities and the feedstock they process is shown in Figure 10.

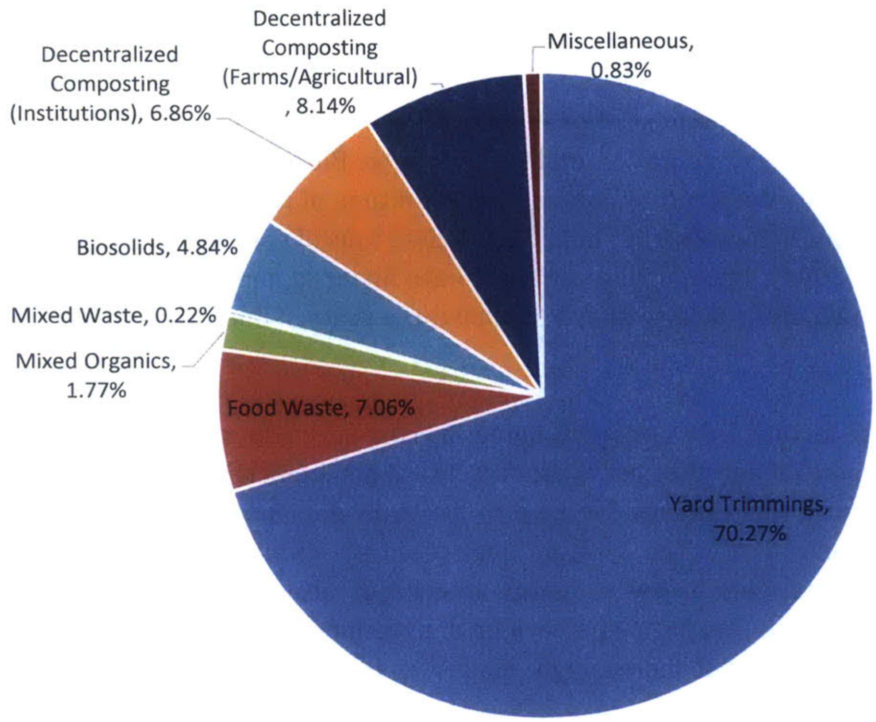

Figure 10: Breakdown of Composting Facility Feedstock in US (Platt and Goldstein 2014)

The WeCare Organics composting facility in Marlborough, Massachusetts has been selected as a representative case study to compare to the facility in Muzaffarnagar, India. The Marlborough facility also processes municipal solid waste and similarly struggled with a myriad of issues in the early years of operation. Important lessons can be drawn from an analysis of what succeeded and what became problematic.

5.1.1 Case Study: Marlborough, MA

Marlborough is a city within Middlesex County, Massachusetts. The city is serviced by a co-composting plant managed by WeCare Environmental LLC that processes both municipal solid waste and biosolids (Spencer 2004). The facility includes two rotary Eweson digesters that process 90 tons per day of solid waste and dewatered biosolids. After 2-3 days in the digesters, the raw compost is discharged and processed through a trommel screen of 2in size. The screened compost is left in a designated area (called the aeration floor) that allows the compost to cure for another 21 days. An Allu screening bucket is used to turn and provide aeration to the pile during this time. This bucket has screens at the bottom and is mounted onto a loader to sieve, aerate, and mix the pile material picked by the loader (ALLU Finland Oy 2015). The material is processed one final time through either a 1/2 or a 3/8 inch sized Bivitech vibrating deck screen (depending on final use) and a destoner before it is considered the final compost product. A Bivitech vibrating deck screen provides two vibration movements on a screening bed to sort very fine material (Binder + Co

2015). All of the facility is enclosed in buildings that are sealed and maintain a negative air pressure to prevent odor issues in neighboring areas (Spencer 2004).

Initially, the facility was plagued by a host of problems. Prior to WeCare's management, the plant was constructed in 1999 and began operation under Bedminster Bioconversion Corporation (BBC) (Spencer 2004). It was initially designed to handle 1,980,000 tons of residential waste and 22,500 tons of digested sewage sludge (biosolids) to produce 125,000 tons of compost per year, a net yield of 6.2% by weight (Otten 2001). Issues including inaccurate financial and engineering predictions led to a temporary shutdown of the facility after less than three years of operation in 2002 (Spencer 2004).

During the planning of the facility, BBC underestimated the cost of residues to be landfilled both in the amount of residue produced and the cost to landfill. These heightened costs added expenses to the operation. In addition, it was difficult for BBC to generate demand for the compost due to contamination from glass and plastic. The aeration floor could not reduce moisture content to the targeted 40% quickly enough. This excess moisture clogged or broke down the final screening system which slowed the process and created a backlog of unrefined compost on the aeration floor (Spencer 2004). This pile-up made it increasingly harder to reduce the moisture content which reinforced the clogging issue.

In addition, the final compost product had not been stabilized and matured properly which led to anaerobic conditions and odor issues after the product was taken off-site and stored. Employees needed to travel to the off-site locations to remediate situations, which also attributed additional unforseen expenses. Also, the buildings were not properly sealed and thus, odors leaked out and led to neighborhood complaints (Spencer 2004).

After the facility was sold to WeCare Environmental LLC, major repairs and upgrades helped restart the plant more successfully in 2004. The City of Marlborough also worked with WeCare to improve residential curbside recycling program to divert inorganic waste streams from the facility and decrease risk of contamination (Spencer 2004).

After WeCare took charge of the facility, costs to landfill had increased due to diminishing landfill space. This allowed WeCare to charge higher rates for incoming MSW and biosolids in tipping fees than BBC previously could, increasing profit margins for WeCare. The facility also began to take SSO from 15 supermarkets to supplement the MSW with an (almost) pure organic waste stream and increase compost yields (Spencer 2004). As of 2010, the facility has been seeing a decrease in contamination and a higher percentage of organics in the MSW entering the facility. This is most likely to diversion programs mandated by the Massachusetts Department of Environmental Protection (Sullivan 2010).

5.1.2 Analysis

Initial problems with composting facilities in the US included ambiguity or lack of regulation for compost product, which led to difficulties in marketing the compost (Spencer and Goldstein 1990). In addition, operational problems for many new plants included bottlenecks in equipment processing. Certain processes would take longer than the rest of the equipment which would limit the rate of processing. This led to investments in better equipment and process controls as well as the use of more sophisticated design and operations (Spencer and Goldstein 1990).

One of the main problems with composting facilities in the US (not just the WeCare facility in Marlborough, MA) has been odor. Neighborhoods surrounding these facilities can be very active with complaints which then push governing bodies into action (Spencer and Goldstein 1990). This makes odor management systems such as air scrubbers almost a necessity. However, compost facility operators in India have not indicated that this is a major problem. All of the composting operations visited in India were in more remote areas that did not have many of residential neighborhoods in the vicinity (observations, January 13, 19, and 25, 2015).

Similar to the composting facilities in India, higher than desired moisture content was a big problem for the rotary drums at Malborough, leading to higher operations and maintenance costs as well as less efficient production. WeCare tackled this problem by investing in upgrades that would help alleviate this problem.

Another major factor for the eventual success of the WeCare composting facility was the collaborative efforts with the Malborough municipality on improving residential curbside recycling programs that would help divert non-biodegradable waste from the facility and reduce contamination. Also, WeCare's agreement to take SSO from supermarkets (in addition to the MSW from the city of Malborough) helped increase the organics content of the feedstock, thus increasing the compost yield from waste in addition to reducing contamination.

Lastly, the market timing was suitable for the WeCare composting facility to be financially viable. Increasing costs associated with landfills allowed for the facility to charge higher rates for intake of MSW and have a more profitable business model. These factors do not yet have a strong foothold in India, which makes composting difficult to make economically viable.

5.2 Centralized Composting in Canada

Interest in composting programs is usually motivated by high landfilling costs or limited landfill access (van der Werf and Cant 2006a). In areas where waste disposal fees are low, it is much more difficult to utilize composting as a viable alternative for MSW treatment. As of 2006, there are an estimated 350 to 370 composting facilities in Canada. Most of these composting programs (about 130) are small scale operations that process leaf and yard waste. A small portion of composting facilities (around 50) accept food waste or SSO waste. However, source separation is still uncommon in municipalities, although landfill diversion goals have been increasing interest in source separation programs (van der Werf and Cant 2006b). Composting mixed MSW is even less common. However, viewing composting as a contribution to carbon management is also increasing interest in composting as MSW treatment for municipalities (van der Werf and Cant 2007). Results from a study conducted in 1996 show the breakdown of waste feedstock processed at composting facilities in Figure 11.

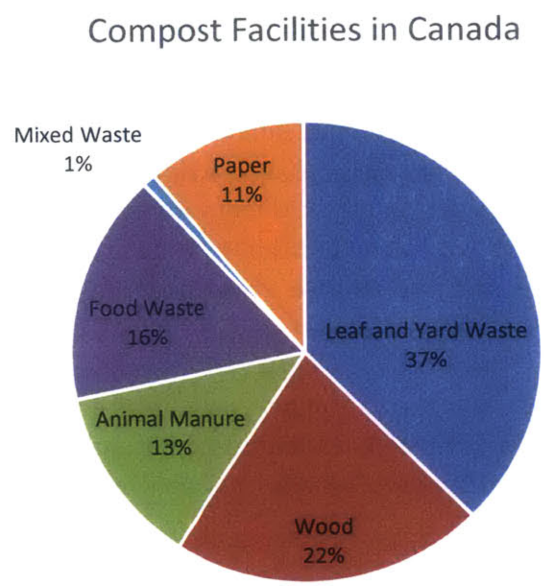

Figure 11: Breakdown of Composting Facility Feedstock in Canada (Antler 1997)

Standardized national compost quality standards were developed in a consortium of federal, provincial and territorial governments and published as in a document, *Guidelines for Compost Quality* in 1996 that was later updated in 2005 (CCME Compost Guidelines Task Group 2005). This document specifies two grades of compost, Grade A which is authorized for unrestricted uses, and Grade B which has restricted uses based on elevated presence of trace elements or sharp foreign matter (CCME Compost Guidelines Task Group 2005).

5.2.1 Case Study: Edmonton, Alberta

The Edmonton Composting Facility (ECF) began operation in 2000, handling both MSW from the Edmonton residents and biosolids from the city's wastewater treatment plant as a PPP between the City of Edmonton and TransAlta Corporation. In 2001, the City Council of Edmonton purchased ECF from TransAlta for $97 million (Spotowski 2001). From here, Earth Tech Inc, took over the operation of the facility under city ownership.

At ECF, everything is processed in negatively pressured buildings except for an outdoor curing area. Waste is first brought to the tipping floor by collection trucks. Then oversized and non-compostable objects are manually sorted out. Seasonal variations in the waste composition and amount affect this manual process. For example waste tonnage increases by 50% or more in summer due to grass and yard trimmings. This leaf and yard waste will bring in over 1,000 metric tons to the facility daily. Sorting by hand becomes tedious and dangerous at such high MSW amounts. Also variations in volume will also occur with seasonal differences. For example, density changes in waste composition (the addition of dry grasses and leaves) can lead to volume increases by 100% in the spring and fall even if tonnage is same. If the facility reach daily capacity before collection trucks are done, they must be rerouted to landfill (Gamble 2005b).

After sorting on the tipping floor, the waste is loaded into five rotary mixing drums that mix and condition MSW and dewatered biosolids together for one to two days. Waste from the drums is screened through an 80mm trommel screen to remove oversized material and loaded into conveyer into one of three aeration bays. Each aeration bay is equipped with an auger-type turner, moisture addition system, and negative aeration controls system. Here the waste is processed for 20 to 30 days. Highly automated machinery reduce the need for operators but requires more on-site electricians and instrumentation specialists (Gamble 2005a).

The buildings are kept under negative pressure to trap odors. The foul air is directed from composting processes into odor treatment system where air is cooled, scrubbed, and routed through biofilter (Gamble 2005a).

The Edmonton facility produces Grade B compost which has certain restrictions on usage. Critics believe the compost produced at Edmonton will never be Grade A due to the MSW feedstock (Vitello 2000).

5.2.1 Analysis

Manual sorting has been recognized to be a significant bottleneck to the composting process. To deal with these challenges, the City has considered installing a mechanized sorting system with a combination of trommel and finger screens which will help the facility handle higher daily tonnages (Gamble 2005b).

The Edmonton composting facility is also an excellent example of how more complex equipment in compost processing did not necessarily lead to better results for the facility. Although the plant has much more automation than a standard low technology compost facility in India, lowered labor costs are counteracted by higher maintenance and operational costs. In a country like India where the gap between generation of non-agricultural employment and supply of workers creates a labor excess, automation of processes may not be as economically attractive as it is in Canada (Thomas 2014).

5.3 Centralized Composting in Europe

Europe has been much more progressive in encouraging composting programs than either the US or Canada, by using aggressive policies like the European Landfill Directive that not only banned the landfilling of specific waste streams but also set goals for reducing the biodegradable portion of landfilled waste (Heermann 2003). In 1992, the European Commission developed guidelines for a seal of quality to measure natural soil amendment quality by (Brinton 2001). In 1998, these guidelines were updated with specific parameters for compost. Many individual European countries have also instituted their own regulations for compost quality focusing on specifying parameters for higher quality compost for agricultural application and lower quality compost for parks or ornamental plants (Gies 1997). These countries may use multiple standards or grades and are often revising and reissuing updated standards (Brinton 2001).

MBT systems are gaining traction in Europe, especially innovative ones with multiple processes that utilize different waste streams to create value. However, low-grade compost produced from MBT plants (sometimes considered "compost-like outputs") do not usually meet country specific requirements for typical compost products suitable for agricultural application. Thus, potential uses are limited and there has been more interest in facilities that process SSO which would provide a much higher quality compost product. Countries taking the lead in MBT infrastructure capacity include Italy, Germany, and Austria (Cant and Wilson 2007).

In Germany, composting MSW at a large scale has been practiced since 1953 (Runge and Hofmann 2008). However, these facilities had trouble making compost with acceptable quality for agricultural use. SSO composting began 20 years later in 1983. As of 2008, nearly half of German households source segregate their organic waste for composting facilities that are able to provide high quality compost from the favorable input feedstock. However, despite widespread source segregation, the majority of organic waste is still lost in the mixed waste stream. This issue has been addressed, in part, by the utilization of MBT facilities. There has been a growing interest in MBT plants from regulatory pressure to pretreat waste prior to landfilling. Despite using compost processes or technologies, these MBT facilities generate end products called "compost-like outputs" (CLOs) that are landfilled rather than sold and used like regular compost products. Initial problems included higher than expected operational costs due to machine overloads and breakdowns requiring maintenance and servicing. However, these issues were solved and almost all MBT facilities are running near capacity (Runge and Hofmann 2008).

5.3.1 Case Study: Athens, Greece

One of the largest MBT facilities in Europe is located in Athens, Greece. It is completely enclosed and receives MSW from residents but also from some restaurants and commercial generators (Spencer and Kalogeropoulos 2007). The facility recovers RDF, compost, ferrous, and aluminum. Waste is brought via garbage trucks to a discharge position in the reception hall. From there, the MSW is loaded into a conveyer in one of three processing lines. Above this, a bag-opener slashes plastic bags and bulky items are removed. The ferrous items are separated from the process lines magnetically while aluminum cans are removed via hand-sorting. These are then sold to local metal recycling facilities (Spencer and Kalogeropoulos 2007).

The waste then enters a primary trommel screen with 7 by 10 inch rectangular holes (Spencer and Kalogeropoulos 2007). The "overs" (waste larger than the holes) are sent to a shredder for further processing as RDF. The "unders" are sent to a second trommel screen with 4-inch diameter holes. The unders from this screen pass under a magnet before they are put into rotary digesters for 24 hours. After this, the material is passed through a trommel screen with 1-inch holes. The unders from this proceed to agitated bays where they are mixed with shredded yard waste and biosolids from Athens wastewater treatment plant. Here, active composting and stabilization takes eight weeks of retention time in the bays. Each bay is turned every two to three days with mechanical turners that move on rails along the concrete walls. Based on monitored moisture data, water is sprayed on during turning if the material is too dry. The floor is paved with slotted concrete slabs that provide aeration and collect leachate from the bays. The leachate collected is then treated at the facility's wastewater treatment plant. To maintain temperature ranges within 55°C to 65°C for more than three weeks (for pathogen inactivation), infrared temperature sensors monitor aeration bay temperature profiles (Spencer and Kalogeropoulos 2007).

After the bays, the compost is passed through a trommel screen with 1/2 and 1 inch holes. The overs are sent back upstream in the system to receive additional processing. The unders are sent through a gravimetric system to remove glass and small foil pieces before they are added to the final product. There is also a complex odor control system on-site with 12 treatment units. The compost is used mainly as a vegetative cap for closed landfills or for landscaping (Spencer and Kalogeropoulos 2007).

5.3.2 Analysis

In Europe, MBTs are used mainly to produce CLOs instead of compost due to issues with contamination and concerns about effect on agriculture. CLOs have different non-agricultural applications including landscaping, landfill cap. In some cases, if it does not meet regulatory requirements for usage, it is simply landfilled directly as a stabilized waste product (Donovan et al. 2010) thus decreasing potentially explosive greenhouse gas (methane) production and leachate generation (Harrison and Richard 1992). These usage limitations on the outputs of MBTs and other MSW processing operations have created a push to separate biodegradable waste at the household level where the waste is being generated. SSO composting facilities are able to produce a much higher quality compost product that can be expanded into larger and more consistent markets like commercial agriculture (Brinton 2005). MSW compost, on the other hand, is subject to higher risks in economic performance due to variations in marketability.

The future for India's waste management is also source separation but getting there has been a difficult struggle that is still in the early stages.

5.4 Decentralized Composting

In areas where municipalities have difficulty serving all city populations with centralized waste management and treatment services, decentralized systems have come in to fill the gap. Waste management problems in India are endemic and characteristic of poverty in developing nations. Perhaps optimistically, these problems also appear to have interesting solutions that would not only improve public health and the environment, but also empower the local community and present opportunities for small-scale entrepreneurship.

Interviews with local farmers around Muzaffarnagar, India, indicated some farmers practiced vermi-composting at their own farms (Muzaffarnagar Farmers 2015). Backyard and smaller at-source composting operations or decentralized waste management businesses help reduce the overall amount of waste that needs to be collected and transported (and most likely landfilled) by municipalities (Otten 2001). This also cuts down on emissions, increases local jobs, improves local soils, and encourages community participation and education (Platt and Goldstein 2014).

5.4.1 Sampurn(e)arth

Sampurn(e)arth is an example of a commercialized venture within the decentralized waste treatment space. The company offers on-site biodegradable waste processing services and off-site recycling of non-biodegradable waste to institutions such as schools or housing societies (Banerjee 2015). Sampurn(e)arth will help their clients conduct a waste audit first to determine the right solution. This is followed by the design and installation of a waste management and treatment system (See Figure 12). Finally the company hires operators and monitors the performance of the system. Treatment of the organic fraction of the waste involves either aerobic composting for institutions with low (less than 200 kg per day) waste generation or biogas plants for institutions with high (more than 200 kg per day) waste generation. Products generated from both of these treatments are utilized onsite or nearby. The compost product is used for on-site landscaping, methane from the biogas plant is used as cooking fuel, and sludge from the biogas plant is dried then used as a soil amendment for landscaping as well (Nataraju 2015).

Figure 12: Onsite Composting Pits at Institution (Banerjee 2015)

5.4.2 Analysis

Successful source segregation in a small-scale operation is a much easier task than in a large municipality. This is one of the advantages of decentralization that Sampurn(e)arth has taken advantage of. At this scale, operations and maintenance are also easier to handle. Although there is no direct revenue from sales of the biodegradable materials/energy recovery, using the products on-site helps save on costs for soil amendments and/or for fuel. When institutions are able to see the direct impact of segregation their waste on a local level, it increases accountability and makes the system more effective.

6.0 Discussion and Conclusion

Figure 13 provides a comparison chart between the different material recovery efficiencies of different MSW composting facilities. Facilities compared include the A2Z facility in Muzaffarnagar, the A2Z facility in Indore, general numbers for an aerobic windrow composting facility processing 500 tons per day in India derived from Infrastructure Leasing & Financial Services (IL&FS) facilities processing data (Mazumdar 2007), and information about the MBT in Athens from literature (Spencer and Kalogeropoulos 2007). Mass balance data about the Muzaffarnagar facility is presented in greater detail in Section 4.1.3.

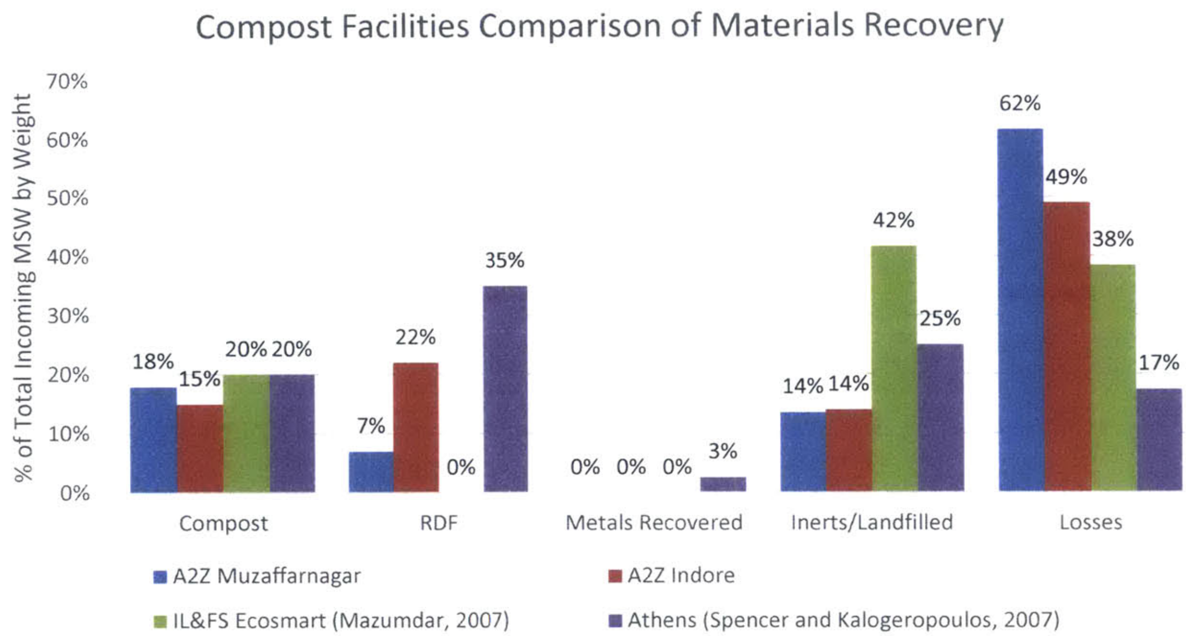

Figure 13: Compost Facilities Mass Breakdown

Although comparisons are limited for facilities that have such different practices, a few important points can be drawn from Figure 13. A major difference shown above is the contribution of RDF production to diverting waste from landfill. In the three facilities that produce RDF from compost reject (the two A2Z facilities and Athens), there is much less material left over that must be landfilled than the typical aerobic composting facilities that do not have RDF production in India (IL&FS). These trends give an idea of where the waste processing industry in India is headed. As landfill space in India shrinks and waste generation increases, market forces and government regulations will push landfilling costs up and make alternative waste treatment processes (like aerobic composting with RDF production) more financially attractive for facilities to adopt. This will make waste processing plants become more efficient and reduce total material to landfill.

Another major difference represented in Figure 13 is that none of the MSW composting facilities in India were equipped to recover metals. The facilities in Athens that recovered ferrous and aluminum metals did so via magnetic sorting and hand sorting respectively. Incorporating such practices in Indian facilities would require more capital investment and labor. Although labor is an abundant resource in India, facility operators have expressed concern over difficulty in hiring individuals in the waste management sector due to stigmatization (Chauhan 2015).

Furthermore, metals recovery is practiced at the source in many cities and towns through the informal sector (Ojha 2011). In Muzaffarnagar specifically, metals and high value recyclables are collected door-to-door daily by kabadiwalas on freight tricycles (Aggarwal 2015). Since these kabadiwalas pay the households for the metals and recyclables collected, there is monetary incentive for households to segregate these high value waste products from the rest of the MSW that is eventually collected by A2Z. Thus, the final MSW waste stream that enters the A2Z facility as feedstock is reduced in metals content from what is generated at the household. This may contribute to a reduced risk for metals contamination in the Indian facilities as compared to their US and European counterparts. Testing results for heavy metals in various MSW compost samples generated from different composting facilities in India support this claim (Saha et al. 2008). In addition, lack of infrastructure in these facilities to sort out and manage metals content is more likely due to the prioritization of other issues and problems in operating the composting plants. Problems such as lack of reliable payment from municipalities and households limit the capacity of the facilities to invest in capital improvements and equipment upgrades for more efficient practices (Aggarwal 2015; Chauhan 2015). These are issues that are largely out of the control of the plant operators and rely more on systematic changes in municipalities and payment collection mechanisms to promote more timely payment.

More efficient practices also allows for fewer losses in a system. Overall, the MBT in Athens, Greece produces the fewest losses and also has the most advanced system. The A2Z facility in Indore also produces fewer losses than the facility in Muzaffarnagar. Having been constructed after Muzaffarnagar, Indore has more updated equipment and better management practices that A2Z has learned from operating the Muzaffarnagar plant (Saifi 2015). This correlation is not surprising but can easily lead to conclusions that more sophisticated equipment and high-tech is always better in waste treatment facilities. As shown in the Edmonton, Alberta composting facility, however, using complicated equipment and higher automation may come with its own set of problems including higher maintenance and operational costs and investments (Thomas 2014).

Finally, the data presented cannot be accurately evaluated without some caveats in mind. Mainly, there may be some issues with how well the data presented represents typical operations at the facilities. Especially with regard to the Muzaffarnagar and Indore facilities, the method of data collection is not clear and may have high degree of uncertainty. There is also likely to be process variability that is not reflected in the data.

A study conducted by Jakobson (1994) evaluated air requirements in aerobic composting. In this study, it was determined that organic matter with 25% dry matter content (where 50% of the dry matter decomposes into carbon dioxide) would require 50% water content loss (through evaporation) in order to preserve a consistent dry matter content (Jakobsen 1994). From here, it can be seen that the percentage losses presented in Figure 13 are still within a reasonable ballpark as accepted by literature, despite potential inaccuracies due to variations.

7.0 Next Steps

Based on the analysis of various composting facilities in India, United States, Canada, and Europe, several recommendations have been made to improve on operations in the A2Z facility in Muzaffarnagar. Comparisons between these different facilities and management policies in the countries explored also sheds light on the kinds of regulatory changes that are needed for India to improve landfill diversion and grow composting as a waste management treatment.

First and foremost, additional data collection should be conducted at the Muzaffarnagar facility to validate existing data and estimates. The data collected should be over an extended period of time to account for seasonal variations that may affect the MSW feedstock and the processing efficiency. Metals analysis of the samples collected (both from the feedstock and the final product) will help determine whether metals recovery will be needed during the composting process enhancement. However, issues can arise with too complex equipment especially in a facility already struggling with generating profits. Thus, a study of available resources and finances should be evaluated for the facility to ensure it can accommodate the additional operations and maintenance requirements for more complex equipment. This may not be an immediately available option for the Muzaffarnagar plant so simpler solutions can be implemented on a shorter time scale.

Short term actions could be implemented to improve efficiency and quality of the composting process thereby influencing the marketability of the final compost product. Like other facilities presented in this paper, supplementing the MSW feedstock with other sources of organic material such as biosolids or food waste from supermarkets can be used to improve the final quality of compost product (also known as co-composting). These other streams can dilute the contamination effect of metals and glass in the MSW. A way to incorporate such practices in Muzaffarnagar include introducing bulk generators in the waste collection conducted by A2Z. Bulk generators in this context are commercial facilities that produce large quantities of food waste such as wedding banquet halls, hotels, and restaurants. A pilot study to assess the steps required and effectiveness of such a change utilizing Shri Ram Group of Colleges (SRGC) campus cafeteria as the pilot bulk generator has been detailed in Appendix F.

Another simple solution that can be implemented at the Muzaffarnagar facility is a more fully covered area to replace the monsoon shed. The monsoon shed currently utilized at Muzaffarnagar is little more than a large, structured canopy. Adding side walls to better enclose the shed would provide more moisture control for the windrows during monsoon seasons. This will also reduce problems with vectors (such as rats and stray dogs) although a dust management system may need to be installed to regulate indoor air pollution from dust and particulates.

However, a long-term plan for not just the plant in Muzaffarnagar but for waste facility operations generally throughout India should also be considered. As exhibited by previous issues encountered by early stage operations in the US, productive collaboration with government is important to sustainable and effective MSW management. Especially since source segregation offers a way to provide higher quality compost more easily than can be produced from mixed waste, instituting programs for source segregated waste collection should be incorporated into the trajectory for waste management in India. However, even developed nations are still struggling with implementing source segregation in households. As of a study conducted in 2006, 11% of MSW is composted in Europe but only about 5% of MSW in US and 4% in Canada is composted (van der Werf and Cant 2007). Of those small composting percentages, leaf and yard waste recycling programs have also been much more successful than food waste segregation (Platt and Goldstein 2014; van der Werf and Cant 2007). Both developed and developing nations still have a long way to go before considering composting a common alternative to landfilling. However, stricter regulations like the Landfill Directive in Europe and the organic waste stream bans in Vermont, Connecticut, and Massachusetts have been instrumental in providing motivation for both stricter source segregation regulations and the development of alternative waste management programs such as composting (Heermann 2003; Platt and Goldstein 2014). Segregated feedstocks will also create more opportunities for more scientific processing of waste and higher quality products from waste (Gupta et al. 1998).

Although similar regulations are already in place in India (Ministry of Environment and Forests 1999), governing bodies need to better enforce these policies and create more economic incentive for households to segregate waste and for business owners to operate MSW composting and other waste treatment practices in a financially sustainable manner. This can be exponentially beneficial by making compost more convenient. One of the greatest barriers to separation of food waste in households is lack of infrastructure to participate (Bernstad 2014). Tactics to increase adoption of household food separation include providing households with source-segregation equipment that can be placed in an easily accessible area that will not interfere with existing household practices. This kind of support to households may help reduce the perceived additional labor required for households to source segregate and thus increase uptake of such recycling practices (Bernstad 2014).

In addition, regulatory bodies in India can look towards expanding requirements for different classes or grades of compost to better categorize varying levels of quality in compost production. Depending on the class or grade of the compost, there could be specifications or restrictions placed on usage. Canada and many countries in Europe are already practicing this kind of regulation (CCME Compost Guidelines Task Group 2005; Brinton 2001). This is an alternative to the current regulations in India that specify a particular set of parameters that are either met or not (Ministry of Environment and Forests 1999). Updated government regulations can more clearly detail compost facility design parameters and expand possible markets for compost usage.

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Appendix A: A2Z Windrow Management Standard Operating Procedure (SOP)

Windrow Management

Standard Operating Procedure
A2Z Infrastructure

Content

Introduction

A2Z Infrastructure (P) Limited has developed an effective and eco-friendly technology for bioconversion of organic fractions in Municipal Solid Waste into a useful end product i.e. BioOrganic Soil-enricher. There are a few other methods like vermi-composting, anaerobic digestion etc for composting. **Municipal Solid Waste (MSW)** in India is highly heterogeneous in shape, size, density and texture. It is next to impossible to separate the organic fractions from the heterogeneous MSW by any mechanical process. Besides by the time MSW reaches the project site, the decaying process might have already set in, making MSW unhygienic and foul smelling. Manual separation of organic fraction is difficult and unhygienic. Vermi-composting and anaerobic digestion can be adopted in case of segregated organic waste free from non-biodegradable impurities, whereas A2Z Technology is adaptable for both segregated and non-segregated MSW.

A2z Technology consists of a controlled biological process and mechanical screening thereafter. The biological process is the most critical component. Hence it is to be properly understood and regularly monitored to derive maximum benefits from A2Z technology. The main objective of this **Standard Operating Procedure (SOP)** is to enable the technology user to get optimum results. Whole team in general and the windrow management team in particular should study and follow this SOP religiously. The team leader should ensure that the team members entrusted with the responsibility of windrow management follow the procedures without fail. For windrow management, a team consisting of a yard supervisor, two assistants and operators of turning equipment should be formed and trained. The yard supervisor should have scientific aptitude to understand the basics of microbiology and commitment and dedication to follow SOP religiously. He is the most critical player in the whole process and his omissions can lead to irreparable losses in the project economics.

Composting process

Composting is a process involving bio-chemical conversion of organic matter into humus (Lignoproteins) by mesophillic and thermophillic organisms.

A composting process seeks to harness the natural forces of decomposition to secure the conversion of organic waste into organic manure.

There are two main groups of organisms, which decompose organic matter.

Anaerobic bacteria, which perform their work in the absence of oxygen.

Aerobic bacteria, which perform their work in the presence of oxygen.

The main characteristics of anaerobic composting are :

- The process is a lengthy one extending over a period of 4 to 12months.
- It is a low temperature process and the destruction of pathogens is not fully accomplished.
- The gaseous products of reduction like methane, hydrogen sulphide etc produce offensive odours.
- Nutrients are lost.

Aerobic composting is characterized by:

- Rapid decomposition normally completed within 8-10weeks.
- During this period high temperatures are attained leading to speedy destruction of pathogens, insect eggs and weed seeds.
- Production of foul smelling gases like methane, hydrogen sulphide is minimized.
- Nutrients are fairly preserved.

A2Z adopts the route of aerobic composting. In order to accelerate and control the aerobic composting a specially formulated biological innoculum is used to treat the organic waste, which is the key element in A2Z Technology.

Factors affecting composting process

Following factors affect the rate of successful composting.

Moisture content

Moisture content of the waste should be between 40–45%. Lesser moisture will lead to mortality of microbes. Whereas more moisture will lead to anaerobic conditions making the inoculated microbes ineffective in the process of composting and emission of green house gases with foul smell will also start.

Temperature

Thanks to the exothermic biological activities of aerobic bacteria temperature rises to 65-70°C within a couple of days. This temperature has to be maintained throughout the biological cycle.

Proper aeration

Since aerobic bacteria are used in the biological process, proper aeration is required to ensure availability of oxygen.This is very important. Regular turning of the heaps will provide adequate aeration.

Carbon & Nitrogen Ratio (C:N Ratio)

CN Ratio should be maintained below 50 for speedy composting. If it is high, the decomposition process will be slow. If CN Ratio is very high, Nitrogenous material like cow-dung may have to be added to bring down CNR to the desired level. At the end of biological process, CN Ratio should come down below 20.

Importance of close monitoring

Mechanical screening follows the biological process. The screening system will be screening whatever is fed on the basis of size and specific gravity. The texture and quality of the end product as well as recovery percentage solely depend on completion and perfection of the biological process. Hence, it is very important to closely monitor the biological process so as to have maximum output of desired quality. Unit cost of the end product heavily depends upon the recovery percentage. Hence, slight reduction in recovery percentage can increase cost of production substantially. The whole economics of the project depends on unit cost of production, which is dependent on the recovery percentage. Screening system will not be able to correct and cover up omissions in the biological process to improve recovery percentage and quality.of end product Hence biological process is the critical element in this technology, and has to be clearly understood, closely monitored and optimally controlled. Properly trained and fully devoted team should be engaged for windrow management. Success of the project wholly depends upon perfect windrow management.

Biological activity is a batch process. Hence micro level monitoring of each batch is very essential to find out abnormality if any and to take remedial action soon on observation. In this case each day's arrival is to be considered as a batch. Such batch should be given a code for reference. It would be better to use date and month to form the reference code for easy recognition. For example, the batch formed on 1st January may be christened as JAN-1.

Most important format in this SOP is keeping the case history of each batch from date of arrival through biological cycle till first screening. This format is at Annexure-D

Following factors are to be closely monitored

- **Quality and quantity of incoming garbage**
- **Treatment with innoculum**
- **Windrow formation**

- Moisture level
- Leachate formation
- Temperature
- Timely turning
- Maturity
- House keeping

Quality of incoming garbage

Importance

The composition of incoming garbage is very important. If organic fraction in the incoming garbage is less, naturally recovery of the end product will also be very less. Hence, quality of incoming garbage will have to be periodically inspected and monitored. Garbage coming from different sources will be different in composition. It should be ensured that garbage generated from vegetable markets, fish markets, fruit markets etc which is very rich in organic content should invariably be brought to the project site without getting siphoned off. Initial survey of the collection methods, routes of transportation, and location specific characteristics should be done and mapped. This data should be updated periodically every year. Composition of garbage at different localities could also be analyzed so that qualitative grading can be done for various collection points.

How to find out composition

- Collect a representative sample of garbage not less than 500kg from the arrivals from each collection point and spread the same on the floor.
- Sort the garbage manually into different components like wet vegetable and food waste, garden pruning, hard wooden material, dry leaves, fibrous material like coconut shell, paper, plastic, rubber, glass, metal, rags and other non-degradable items.
- Weigh each component separately and find out the percentage.
- Initially, the exercise should be done continuously for a week for one consignment from each collection point so that the average composition can be computed. Thereafter, this exercise should be done every month to confirm whether there is any

change in the composition which was recorded earlier. Efforts should be made to locate such sources from where good quality garbage is receivable and such sources should be fully tapped.

Carbon nitrogen ratio

Another important factor to be seen is the CN ratio. If the incoming garbage contains more of dry leaves, straw, bagasse etc. heavy dose of cow-dung or any Nitrogen rich organic waste will have to be applied to make the CNR to the desired level. Otherwise, the biological cycle may take longer time than anticipated.

pH value

pH value of the degradable fractions should also be ascertained. It should be in the range 6 to 8, otherwise biological activity will be considerably slowed down. If pH is more than 8, it suggests that Municipal Authorities are using lime or bleaching powder at the collection/storage points. This practice should be discouraged as it detrimentally affects the biological process. They should be advised to use non chemical herbal formulations instead, to control bad odour and flies.

Optimum condition

CN ratio not greater than	**50**
pH	**6 to 8**
Organic fraction not less than	**50**

Corrective action

If the organic content of the incoming garbage is less than 50%, that lot should be rejected and sent to landfill site directly. Otherwise, recovery of end product will be very less and unit cost of production will be very high.

For improving the CNR, cow-dung / poultry manure etc can be added, depending upon availability and affordability. Quantity to be added will have to be worked out through trials at site. If quantity of banana leaves, wheat/paddy straw, bagasse etc are more and separable without much cost and effort, they should be separated and shredded and soaked in cow dung slurry for at least 48hours and thereafter mix with the rest while forming windrows. Power driven or manual chauff cutters can be employed for shredding.

Frequency

This exercise of analyzing incoming garbage should be done regularly once in a month. Format at **Annexure-A** may be used for this purpose.

Quantity of incoming garbage

Importance

- Proper assessment of quantity of incoming garbage is very important from two angles.
- To estimate adequate dosage of biological innoculum for treatment and
- To estimate and monitor overall recovery percentage of the end product.

Procedure

It is always advisable to have a weighbridge installed at the facility where all the incoming vehicles can be weighed and recorded. In the absence of a weighbridge, quantity of incoming garbage can is assessed empirically as described below.

- Prepare a list of incoming vehicles along with dimensions of the body (length, width and height).

- Spread the garbage evenly in the vehicle and measure its volume.

- Weigh the vehicle after measuring the volume in a nearby weighbridge and record the weight.

- Weigh the vehicle after emptying the garbage in the same weighbridge to find out the tare weight.

- Compute the net weight of the garbage by deducting tare weight from the gross weight.
- Divide the net weight by the volume to find out the Bulk Density (BD) of the incoming garbage.
- Once the above exercise is done for each type of vehicle and bulk density of incoming garbage is assessed through actual weighment and measurement of actual volume, later on weight of each consignment can be found out by measuring volume and multiplying the volume by bulk density. While doing calculations, volume may be considered in liters (1cum = 1000 litres) and weight in kg. Normally, the BD will be ranging from 0.5 to 0.7. Higher BD. indicates more non-degradable in the lot. Format at Annexure-A may be used for this purpose.
- Assessment of BD should be done once in 2months because seasonal variation in the composition of incoming garbage may change BD periodically.
- Proper record should be kept in the format Annexure-B for the consignments received daily.

Treatment with innoculum

Importance

Incoming garbage may have native microbes, which might have started decaying process. They could be of anaerobic and aerobic varieties. In order to have an end product of desired quality and also to accelerate the process of decomposition, inoculation with selected strains of effective microbes is very essential. Otherwise the decomposition process will be erratic creating problems for the operation. Purpose of biological treatment could be summarized as below:-

- To accelerate biological process
- To ensure optimum decomposition.
- To make the end product of desirable quality.
- To suppress the activities of anaerobic microbes to minimize production of offensive odours.
- To ensure exothermic biological activity to destroy pathogenic organism.
- To reduce loss of nutrients
- To avoid propagation of insects and disease carrying vectors.

The biological innoculum developed by A2Z is a mixture of effective strains of microbes (fungi and bacteria) identified to be responsible for natural decomposition process. These microbes are isolated and cultured in our R & D microbiological laboratory with utmost care. Since the biological process has to be completed within a limited time period owing to lack of space in the yard, utmost importance has to be given to biological treatment with proper dosage to have maximum recovery of an optimum quality end product. Any laxity in application and dosage could lead to losses, which may become noticeable only after mechanical screening is over. At that stage no corrective step is possible. Hence, treatment of incoming garbage should be done religiously using correct dosage to derive optimum benefits.

Treatment procedure

Preparation of Slurry

The biological innoculum is in powder form. For better spread, it should be mixed with water to form slurry. pH of the water should be 7±0.5. Quantity of water to be used will depend upon the moisture level of the incoming garbage. During rains, the incoming garbage may be very wet as visible from dripping of water. During summer, the incoming garbage may be very dry. The following table indicates the quantity of water to be used during different seasons.

Sr No.	Period	Water/1kg of innoculum
1	summer	80 liters
2	winter	40 liters
3	monsoon	20 liters

Dosage

- 1kg of innoculum should be used to treat 1MT of incoming garbage. The dosage has to be made into 2splits.
- 700gms per MT of incoming garbage on the day of arrival.

- **300gms per MT fresh garbage at the time of second turning**

The culture to be used for mixing at the time of packing will be different from the culture to be used for 1 & 2 splits and is called as **Enricher**. It is recommended to use 1kg of the culture (Enricher) per MT of finished product at the time of packing. This culture consists of effective microbes capable of biological Nitrogen Fixation and Phosphate Solubilisation and improves the efficacy of the end product manifold.

Application

The slurry may be prepared in 200liters capacity drums kept near the area where the garbage is accepted daily. Where slurry tank is constructed, slurry could be prepared in it every day for the day's usage. After the slurry is made depending upon dosage, the same may be sprayed on to the incoming garbage while unloading from the vehicle. This will ensure uniform mixing at the time of windrow formation. For the 2nd split also the application should be done during the turning operation so that the slurry spreads and reaches even the inner core of the windrows.

Recommended dosage as above has been worked out based on extensive field trials of different types of incoming garbage under different climatic conditions. Hence, one should strictly adhere to the dosage for fast and effective decomposition.

Record of culture consumption should be maintained

Symptoms of erratic process

- Inadequate dosage and improper application method will result in following symptoms

- No or slow rise in temperature inside the heap

- Excessive flies around the heap

- Unbearable foul smell

Corrective action

- Above symptoms clearly indicate under dosage and non-uniform mixing. Corrective action should be taken immediately as below.

- Break open the defective windrow

- Inoculate with supplementary dosage @ 300gms/MT
- Adjust moisture level to 40%
- Remake the windrow
- Clean the area around the windrow
- Sprinkle Rockphosphate powder over the windrow using a duster to suppress bad odour quickly

Windrow formation

- Windrow means a long heap of regular shape and cross section.

Formation of windrow is very important from following angles

- Available space is optimally utilized
- Natural airflow is not obstructed
- Movement of incoming and outgoing vehicles is hassle free
- Turning machines have easy access to each windrow.
- Leachate overflow is controlled and
- Overall appearance of the yard is aesthetically improved.

Following patterns are normally adopted

Circular / octagonal	**(Annexure E)**
Horse-shoe shape	**(Annexure F)**
Rectangular	**(Annexure G)**

Total platform area has to be properly earmarked for a peripheral road for incoming and outgoing vehicles, daywise formation of windrows and subsequent turnings, and common area for natural drying.

Movement of incoming vehicles should be restricted to the periphery of the windrows. Movement of vehicles should be unidirectional to avoid traffic problems clockwise movement is preferred, keeping in tune with the common traffic style of **'keep left'**.

Outer ring should be dedicated to fresh garbage being received daily. It may be divided into 8 distinct blocks for receiving garbage for 8days. Cross section of windrow may preferably be kept as a trapezoidal with 6 to 8meter base, 2 to 4 meter top and 2.5 to 3.5 meter height. Depending upon the average daily inflow, length of the windrow can be determined as below

Daily in flow of garbage X MT.
Bulk Density of garbage Y
Volume of garbage received daily X ÷ Y CUM

Cross sectional area of windrow

(A + B) H ÷ 2SQ.M

where A = **Base width; B = Top width, H = height, all in Meters**

Length of windrow = Total volume ÷ Cross sectional area in MTR.

Between each windrow, alleys of minimum 1 meter width may be kept for natural airflow. The outer most windrow may be designated as to A1 to A8. Successive windrows towards the center may be designated B1 to B8, C1 to C8 and D1 to D8. Thus there will be 32 designated cells on the platform. It would be better to earmark the spaces by painting so that formation and successive turning of windrows becomes easy and streamlined.

Once the incoming garbage is treated with innoculum, it may be formed into a windrow in the designated space with the use of Backhoe Front End Loader or suitable turning equipment. At the time of windrow formation, heavy non degradable items like big stones, rubbles, tyre, sacks etc may be hand picked as far as possible and should be separately stored in designated areas for disposal. This will help in reducing handling volume and damage to the processing machines. If garbage is received in closed polythene bags, it may have to be torn open. Care may be taken to keep slaughter House, Fish Market, Poultry Waste etc in the central core of the windrow and is not allowed to scatter around or on the outer surface of the windrow lest it may attract stray dogs, pigs, birds, vultures to the area. The windrows should be properly covered with waste coming from the 3rd screening, which generally contains lot of recoverable organic matter. This covering will help

- **To improve the look aesthetically**
- **To drive away flies, birds etc**

- To suppress emission of foul odour
- To improve overall recovery percentage.

Moisture level

Since microbes carry out the biological process, availability of moisture is essential. If the moisture level is very low microbes may not survive and delay the composting process. Hence moisture level may be monitored continuously for speedy decomposition and better output and quality of the end product. Ideal level of moisture will be around 40%. By taking a handful of degradable waste from the windrows, one could feel the level of moisture through wetness. If wetness is not felt, spray water to increase moisture. On pressing, if water oozes out, the material has excessive moisture. In such case, water spraying should be stopped.

During summer, daily spraying may be needed. Hence, it is advisable to have a permanent system consisting of storage tank, water pump, and pipeline with tapings at the windrow area. Using a flexible hose, water could be sprayed. Movable sprinklers also can be used. However, excessive spraying should not be practised, as it would create environmental problems.

Leachate formation

During the initial days of decomposition, inherent moisture in the organic components especially fruits, vegetables and animal waste starts oozing out in the form of leachate. Although the leachate contains nutrients, its overflow will create environmental pollution. Hence, it should be collected and used in the windrows so that on one side environmental nuisance is reduced and on the other side valuable nutrients are preserved.

How to collect

Leachate may be collected by spreading a bed of absorbent medium around the windrow, after it is formed. Initially saw dust can be used for this purpose. Once the screening operation starts, the rejects coming from 3rd screening operation can be used as an absorbent medium for collection of leachate provided they contain fiberous organic fraction in sufficient proportion. This carpet of medium around the windrow will absorb the leachate coming out. If leachate formation is more, thickness of the bed may be increased and the wet absorbent may be put back over the windrow. Depending upon the climatic conditions the quantity of leachate may vary. One should observe the status of leachate formation and efficacy of absorbent bed daily. If the bed is fully soaked with leachate, it may be scrapped and spread over the windrow and a fresh bed may be laid all around the windrow again.

Benefits

If the leachate formation is controlled, overall status of the yard will get hygienically improved. Problems of bad odour and nuisance of flies will be reduced substantially. By using the rejects from 2nd and 3rd screening operations for absorbing the leachate, further decomposition of organic fractions present in the rejects also takes place, thus, improving overall recovery percentage of the process.

Tips

- If leachate formation is excessive due to wetness of garbage during monsoon, reduce the quantity of water being used for preparing slurry.
- During rains, the windrow may be covered with tarpaulins/plastic sheets.
- If feasible, erect a temporary monsoon shed in such a way that turning vehicles are not obstructed, during operation.
- Run off during monsoon may be contaminated with leachate. Hence it may be treated and discharged through a proper drainage system.

Temperature

Due to the biological activity of aerobic bacteria, part of the organic carbon gets converted to carbon dioxide. This chemical activity is exothermic and hence lot of heat is generated. The heat thus generated has to be preserved inside the heap. Destruction of pathogens and weed seeds are very important to get an acceptable quality of the end product. This could be possible only by maintaining the temperature inside the heap for a long time. Hence, measurement and management of temperature should also be given utmost importance in the windrow management operation.

The temperature has to be maintained between 65-70^{0}C. Temperature of every heap should be measured every day at different locations. The temperature starts to rise from 2nd day of windrow formation and on 4th day it should reach around 60^{o}C. If this is not happening it could be due to following reasons:-

- **Inadequate dosage of culture**
- **Improper mixing**
- **Inadequate moisture level**

Depending upon the cause, corrective action may be taken immediately. In successive windrows after 1st, 2nd and 3rd turning, temperature should rise and get stabilised at 65-70^{0}C on the 3rd day of turning. Corrective action should be taken in case of temperature does not rise to this level.

Dial type temperature meter with a probe long enough to reach deep into the windrow (5meters), should be used. As the probe may not be strong enough to pierce and penetrate the heap to the desired depth, a hole may be made into the windrow where the temperature is to be measured with the help of a pointed pipe, and the probe be inserted.

Turning of windrows

Aerobic bacteria need oxygen regularly. Regular turning of the windrow is required to ensure availability of oxygen. Hence turning of windrows at fixed intervals should be strictly followed. Besides providing aeration, turning also helps in lateral movement of the garbage towards the drying area of platform at the center from where matured and decomposed garbage is taken up for mechanical screening.

Planning of the windrows is done in such a way that any backlog in turning will restrict area for acceptance of fresh garbage. Hence, turning should not be stopped at any cost. In case of breakdown of the turning machine, turning should be done by hiring a similar machine from the market. This is the only way by which availability of oxygen can be ensured for the aerobic microbes to survive and multiply to make the aerobic composting process fast and perfect.

Since turning is a costly operation because of the diesel consumption of the machines, there could be a natural tendency to reduce turning operation to gain economy. The improper turning will result in poor quality of end product and lesser recovery and push up unit cost of production. Improvement in quality and increase in recovery percentage offset cost of turning operation.

Backhoe front-end loader is a suitable machine for turning. The machine may be stationed between the windrow to be turned and the area where the turned material is to be formed into a windrow. By keeping the machine on jacks the backhoe may be used to dig the heap and drop the material to the new area.It may be dropped from maximum height so that interlocking is removed and the material is properly aerated. Top and outer portion of the old windrow may be dry and slow in decomposition process. This material should go to the core of the new windrow to have speedy decomposition. If the moisture is less, water may be sprayed during turning so that moisture level is maintained uniformly. Supplementary dosage of innoculum should also be done during turning to ensure uniform mixing.

Monthly timetable should be prepared wherein the turning programme is clearly spelt out for each windrow. By looking at the chart, one should be able to find out the heaps to be turned on a particular day. After turning, the windrow should properly be dressed up with or without the rejects from the 3rd screening to present an aesthetic look.

In the outer cells of windrows, which contain less than one-week-old garbage, chances of improper composting and anaerobic conditions cannot be ruled out. This will naturally lead to generation of foul smelling gases like Methane and Hydrogen Sulphide. So while turning any heap from the outermost periphery, Methane and Hydrogen Sulphide may get released. It is advisable to puncture these windrows before hand, so that foul smelling gas like Methane and Hydrogen Sulphide get slowly released. This will reduce the intensity of foul smelling gases at the time of first turning.

Turning schedule

Following schedule is recommended during normal conditions.

1st turning	-	**6th day of windrow formation**
II nd turning	-	**6th day after 1st turning**
IIIrd turning	-	**6th day after IInd turning**
Spreading	-	**6th day after IIIrd turning**
Screening	-	**Next day after spreading and drying**

Maturity

The end product has to be fully matured and biologically stabilised to give better results in the filed. Hence maturity of the fermented material should be checked by adopting starch Iodine test, which is described in the quality control manual.

Maturity of the decomposing garbage will have to be ensured before taking up for mechanical screening. The main indication of maturity is Carbon Nitrogen Ratio (CNR). If CNR is brought down to the range of 20-25, it could be fairly assumed that the material is biologically stabilized and matured. If immature garbage is taken up for screening, recovery will be reduced and quality of end product will be poor. Besides, end product after packing will keep on generating heat due to continuation of biological process, due to imperfect bio-stabilization, at yard or intermediate storage.

Intermediate storage

A provision has been kept in the layout to store semi-finished product after two initial screenings (upto-14/16mm). It has following advantages.

Biological activity still continues to reach perfection in maturity.

Initial screening machines may accommodate higher levels of moisture (20-25%). Optimum level of moisture for final screening is below 10%. Storage in intermediate allows excess moisture to evaporate due to heat generated. Proper ventilation with exhaust fans can speed up drying process.

- Recovery of end product is improved.
- Quality of end product is improved.
- Breakdowns in upstream/downstream machines do not paralyze total screening operations.
- Interruption due to rains could be surpassed fairly.
- Storing of semi-finished product for not less than 30days improve recovery percentage and product quality substantially. While taking for final screening and packing FIRST IN FIRST OUT (FIFO) procedure should be adopted to ensure uniform maturation time for all lots.

House keeping

Since the project aims at reducing environmental pollution, operation should be streamlined in so well that it does not create pollutionary effect on the surroundings. Hence, one should maintain good house keeping practices. Attention to following areas will help in better house keeping

Control of bad odour

Bad odour is due to green-house gas emissions. It not only pollutes the atmosphere but also discredit the whole effort at the project site. Foul smelling gases emit when anaerobic pockets are created in the windrows. Proper treatment with adequate dosage of innoculum, regular turning of the windrows for proper aeration, maintenance of optimal moisture level and control of leachate formation can avoid spread of unbearable and offensive odours.

If the bad odour is beyond limits, the defective windrows should be broken and treated with supplementary dosage and after proper aeration, it should be reformed into a windrow. The walkway between the windrows is always kept clean by sweeping/scrapping.

Nuisance of flies and birds

Presence of flies and birds also present a bad look for the site. Improper windrow management especially with reference to the windrow formation invites flies. Slaughter house waste, rotten organic waste, presence of leachate and contaminated stagnant water will also promote presence of flies. Once flies are observed abnormally, immediate action should be taken to improve the sanitary level of the site. The cause should be studied and corrective action taken to remove the cause.Herbal insectcides should be sprayed twice a day to drive away flies.

Overall cleanliness

The premises shall be maintained clean and neat.

Littering of plastics

Plastic packets getting sorted in the first and second screening should not be scattered all over the area. Even if it may not fetch remunerative prices, all plastic should be sorted out and kept aside in proper bundles.

Dusting

Another disturbing element is dust. Abnormal dust production indicates defective site operation. Dusting should be controlled wherever possible, by plugging leakages. The premises, especially the shop floor should be cleaned daily by sweeping.

Greenification

A green belt of 20meters should be developed and managed to improve the hygiene standard of the site. While selecting trees for plantation, preference should be given to fast growing trees with broad leaves and large hoods. Flowering trees should also be included to improve appearance of the site. All open area should be converted to gardens and lawns. Bushes, creepers, and climbers of fragrant flowers could be very useful. Well maintained garden and green belt improves the environmental image of the site, substantially. .

DO's

- Implement and maintain SOP faithfully
- Monitor yard operation diligently
- Survey the raw material catchment area periodically
- Select MSW rich in organic matter
- Keep a regular watch on the quality of MSW
- Always use fresh slurry
- Test the water sample for pH and salinity regularly.
- Always follow saftey measures
- Enforce traffic rules strictly for incoming vehicles
- Keep dumpyard area neat and clean
- Develop & maintain good rapport with Municipal Corporation at all levels
- Keep records for all observations in prescribed formats.
- Collect and use Leachate with garden mix
- Take corrective actions without delay.
- Develop and maintain greenbelt and garden
- Dispose process rejects scientifically
- Harness maximum resource recovery
- Apply innoculum in correct dosage
- Turn the windrows as per schedule.
- Reject outrightly, hospital/industrial/hazardous waste
- Always mask slaughter house/fish/chicken waste with regular garbage

DON'Ts

- Do not create conditions for pathogens to develop
- Do not allow pigs and birds in dumpyard.
- Do not allow ragpickers inside the premises
- Do not allow Heaps/windrows to become compact
- Do not Work in dumpyard without mask,handgloves,gumboot and cap
- Do not touch electric fittings with wet hand
- Do not allow smoking in the dump-yard
- Do not use saline/hard water for spraying
- Do not use old slurry in treatment
- Do not spray excess water on the heap
- Do not keep dead animal / slaughter house /fish/chicken waste in open
- Do not Accept industrial / hospital / hazardous waste with garbage.
- Do not allow leachate to flow out of windrows.
- Do not litter plastics within the premises.

Annexure-'A"

COMPOSITION OF MSW

S. No : ____ Date : ______
Collection Point : ____ Vehicle No : ______

	Sample Weight	Weight[Kg]
1	Garbage with container	
2	Weight of container	
3	Weight of garbage (1-2)	
	Composition of the Garbage	
	Content	Weight [%]
1.	Easily degradable organic components*	
2	Straw, bagasse, Banana leaves	
3	Wooden materials **	
4	Plastic bags / sachets / bottles	
5	Stones / pebbles	
6	Clothes / rags	
7	Metals	
8	Rubber / Leather	
9	Glass / Ceramics	
10	Sand	
11	Silt	
12	Others (specify)	

Remark If 1 + 2 > 70% = very good = 1
If 1 + 2 > 50 – 70% = average = 2
If 1 + 2 < 50% = poor = 3

Yard Supervisor | Site In-charge

* Vegetable / fruit / food / slaughter house / fish /chicken / leaves
** Mat / Basket / Tree pruning / twigs

Annexure-'B'

RECEIPT OF GARBAGE

Date ______

Vehicle No	Drivers Name	Collection Point	Time		Vol.	Wt.	Quality	Unloaded at
			in	out				

Yard Supervisor

Site In-charge

Annexure 'C'

MONTHLY CALENDER OF TURNING

Month______

Date	Fresh windrow	Turning				Spreading	Screening
		1st	2nd	3rd			

Yard Supervisor Site In-charge

Annexure-'D'

DATA SHEET OF WINDROW

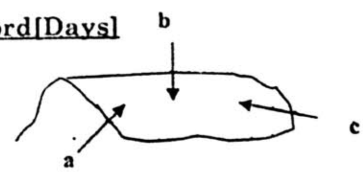
Formation Date : _______ Windrow Reference No.: _______
Quantity received: _______ General quality : _______
Culture used : _______ Water used : _______

<u>Dimensions of windrow</u>

Length : _______ Base width : _______ Height : _______

<u>Temperature record[Days]</u>

Location	2nd	3rd	4th
a			
b			
c			



<u>General observations before First turning</u>

Moisture: dry ☐ wet ☐ too wet ☐
Odour: negligible ☐ bearable ☐ unbearable ☐
Leachate: less ☐ normal ☐ excessive ☐
Colour change : _______
Any abnormality : _______
Corrective action to be taken : _______

Schedule date : _______ Actual date : _______
Reason for delay : _______ New location : _______
Culture added : _______ Water used : _______

Dimensions of windrow

Length : ________ Base width : ________ Height : ________

Temperature record[Days]

Location	2nd	3rd	4th	5th	6th
a					
b					
c					

General observations before Second turning

Moisture:	dry	☐	wet	☐	too wet	☐
Odour:	negligible	☐	bearable	☐	unbearable	☐
Leachate:	less	☐	normal	☐	excessive	☐

Colour change : ____________

Any abnormality : ____________

Corrective action to be taken : ____

____

Schedule date : ______________ Actual date : ________

Reason for delay : ______________ New location : ________

Culture added : ______________ Water used : ________

Dimensions of windrow

Length : ________ Base width : ________ Height : ________

Temperature record[Days]

Location	2nd	3rd	4th	5th	6th	7th
a						
b						
c						

General observations before Third turning

Moisture:	dry	☐	wet	☐	too wet	☐
Odour:	negligible	☐	bearable	☐	unbearable	☐
Leachate:	less	☐	normal	☐	excessive	☐

Colour change : ____________

Any abnormality : ____________

Corrective action to be taken : ____

____

COMPOST PROCESS CHART

Input Output chart

Compose

Raw Material Inward 100 kg

RDF

Debri

Cost centers	P & D Compost					P & D RDF			
	Pre Sorting 100 MM	Windrow (1 to 4)	Pre Sorting 35 MM	Pre Sorting 16 MM	Pre Sorting 4 MM	Pre Sorting 50 MM	Destoning	Shedder process	Briqutte Machine- Briqutte RDF
Compose	70	35	29.75	24.25	17.95	nil	nil	8.4	7
RDF	28								
Debri	2								
Normal Loss	0	35	5.25	5.25	6.30			19.6	1.4

actual

Raw Material Inward **1261.64 MT**

Cost centers	P & D Compose					P & D RDF			
	Pre Sorting 100 MM	Windrow (1 to 4)	Pre Sorting 35 MM	Pre Sorting 16 MM	Pre Sorting 4 MM	Pre Sorting 50 MM	Destoning	Shedder process	Briqutte Machine- Briqutte RDF
Compose	883.15	441.57	375.34	309.10	228.74	0	0	105.98	88.31
RDF	353.26								
Debri	25.23								
Normal Loss	-	441.57	66.24	66.24	80.37			247.28	17.66

Appendix C: A2Z Informational Pamphlet

Specifications

Particulars	Properties
Colour	Dark Brown to black
Texture	Free flowing coarse powder
pH	6.5-7.5
Odour	Absence of smell
Maturity Test	Positive (Digested)
Viable seeds	Absence
Moisture	20-25 %
Total Organic Carbon	14-18%
Carbon: Nitrogen ratio	<20
Nitrogen	1.0-1.5%

Particulars	Properties
Phosphorus	0.5-1.0%
Potassium	1.0-1.5%
Bulk Density	0.7-0.9%
TBC	10^4-10^6
Fungi	10^4-10^6
Actinomycetes	10^4-10^6
Azotobacter	10^4-10^6
PSB	10^4-10^6

कार्बनिक खाद की मात्रा हेतु निर्देश

फसलों के प्रकार	खाद की मात्रा	खाद डालने का तरीका
अद्धवार्षिक फसलें गेंहू, धान, ज्वार, बाजरा, रागी, मूँगफली, सूर्योमुखी, सरसों तिल, मटर, चना मूंग एंव उड़द	300-500 किलोग्राम प्रति एकड़	बुवाई से पहले खेत तैयार करते समय आखिरी जुताई पर खाद को हाथों द्वारा एक समान खेत में छिड़के एंव तदुपरान्त 4-6 सेंटी मीटर गहरा टीलर चलाकर पटेला लगा दें।
वार्षिक फसलें कपास, मिर्च, सभी प्रकार की सब्जियां सभी प्रकार के फूल, आलू, हल्दी, अदरक, लहसून एंव प्याज	800-1000 किलोग्राम प्रति एकड़	उपर दिये गये निर्देशों की तरह एंव निराई गुडाई के समय भी खाद को लगाया जा सकता है।
बहुवार्षिक फसलें गन्ना, चाप, कॉफी काली मिर्च, रबर केला, पपीता, अनानास सभी बागवानी फसलें जैसे आम, अंगूर, अमरूद, चीकू, केला, निम्बू, नारियल और सजावटी वृक्ष	600-800 किलोग्राम प्रति एकड़	उपर दिये गये निर्देशों की तरह
पिट बनाने एंव पौधे लगाते समय	5 किलोग्राम-10 किलोग्राम	पौधें की जडों के चारों ओर खाद को अच्छी तरह से मिट्टी में मिलायें
गमलें में खाद लगाते समय	½ किलोग्राम-1 किलोग्राम प्रति गमला	गमलें में उपर से छिड़काकर उपर वाली 10 सेंटी मीटर मिट्टी की परत में मिलायें एंव गमलों को भरते समय 1/2 मिट्टीः 1/2 खाद मिलायें

यह एक मात्र जैविक खाद है जिसमें कीट तथा बीमारी प्रतिरोधक जीवाणु उपलब्ध कराये गये है जिनकी उपयोगिता निम्नलिखित है।

• एजेटोबैक्टर (नाइट्रोजन स्थापक) • ट्राइकोडर्मा (फफूंदी नाशक) • बैवेरिया बैसियाना (कीट तथा दीमक नाशक) • फास्फेट सॉलू बलाइजर (फास्फेट घुलनशील बैक्टेरिया) • सूडोमोनेस (फफूंदी व बैक्टीरिया नाशक) • वर्टीसीलियम (चूसक कीट रोधक)

A2Z Infrastructure Ltd. & its subsidaries

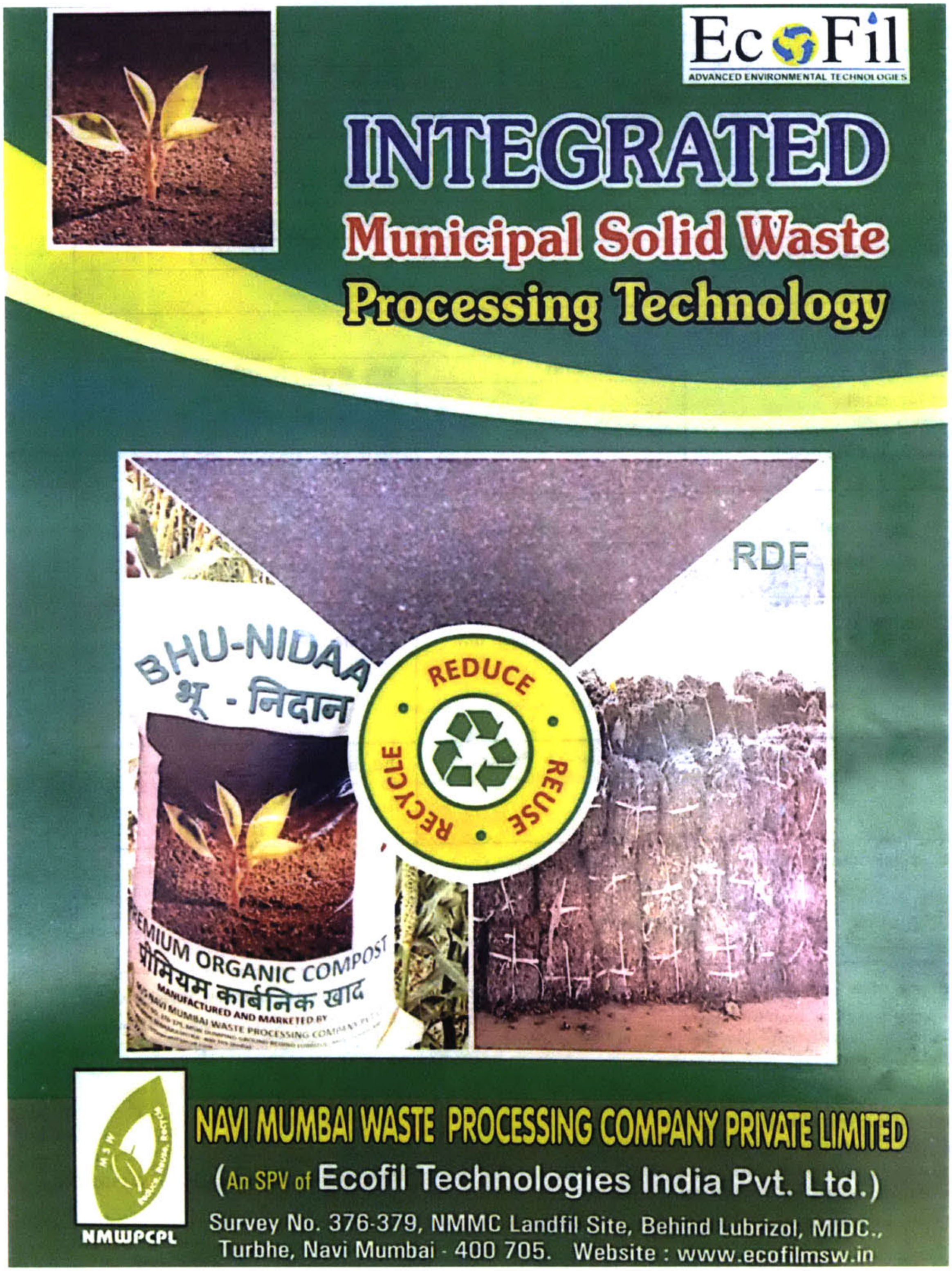
Kanpur : NH-2, Bhausingh Nagar, P.O. Panki-208020, Distt-Kanpur (UP), Ph: 7860025805

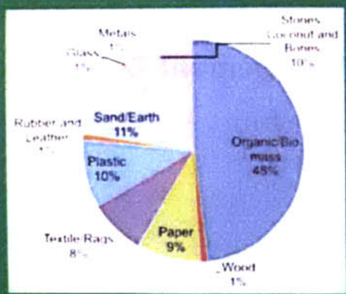
Muzaffarnagar : Khad Factory, Near Macchi Talab, Near UPJAL Nigam Sewage Treatment Plant, Kidwai Nagar, Ph: 8439004000

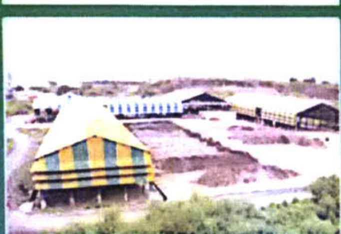
Aligrah : 21 MIG Duplex kaveri Enclave Phase- 1, ADA Colony , Avantika, Ph: 8449718115

Indore : DH- 53, Scheme No. 74/C, Vijay Nagar, Ph: 7354881203

Appendix D: EcoFil Informational Pamphlet (for proposed, not current system)

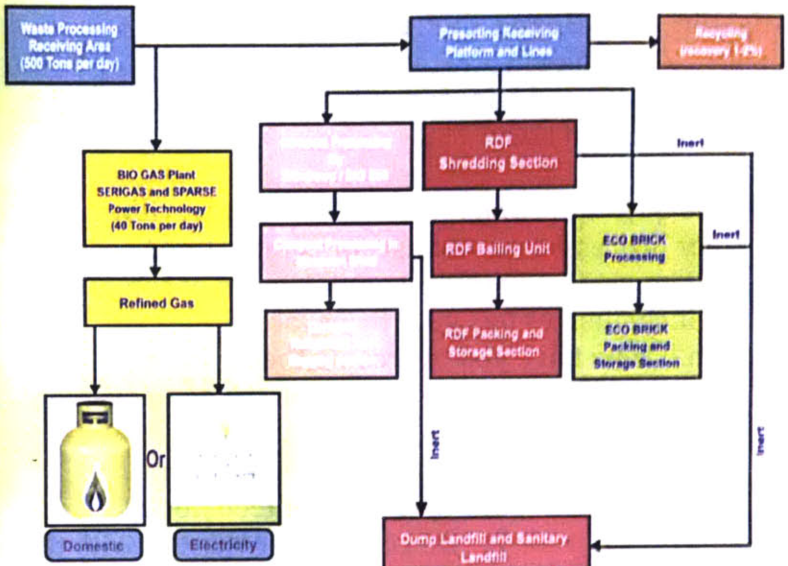






Processing Technology of MSW:

Processing Flow Diagram Turbhe



All the above processes are approved by the Pollution Control Board and are compliant to the MSW Rules 2000.

Benefits of Operating Plant

1) Requirements of land reduced through effective processing and Scientific landfill
2) Reduces health Problem
3) Reduces air Pollution
4) No Leachete formation
5) Minimum Content of Biodegradable matter in Residue Inert material reduces methane emission.

ORGANIC MANURE (COMPOST)

Manufacturing Process :

Bio Organic Fertilizer is made by accelerated bio conversion process under controlled conditions using remains of fruits, vegetables food and by products of agro process industry.

FCO Minimum Standard (FCO 1985) 3rd Amendment 2009		
Physical Appearance		
Colour	:	Black to Dark Brown
Texture	:	Free Flowing
	:	Coarse powder
Odour	:	Absence of foul odour
Moisture	:	20% to 25%
Total organic Carbon	:	12%
pH	:	6.8% to 7.8%
Carbon : Nitrogen ratio	:	10.1% to 20.1%
Nitrogen	:	0.8%
phosphorous	:	0.4%
potassium	:	0.4%

Uses : Bio Organic Fertilizer is used at the time of Transplanting as drilling or broadcast. It can be applied along with the rows or encircling around the plants. Since it is a fully digested material it can be applied at the time of crop feeding stage.

Appendix E: MSW Company Interview Questions Template

Informal interview questions for "Organic Municipal Waste Management Technology Optimization Study"

Investigator: Ellen Huang, CEE, ehuang7@mit.edu
Yeqing Liu, CEE, yeqing@mit.edu
Faculty Sponsor: David Langseth, CEE, lanseth@mit.edu
COUHES number: 1412006752

Below is the question bank for the informal interviews with composting facilities:

1. What processes do you use for composting?
2. How much do you charge per kilogram of compost?
3. What challenges has your firms faced?
    a. How have you overcome them?
    b. What are you currently still trying to overcome?
    c. More specific questions:
        i. Quality control and consistency
            1. What kind of feedstock?
            2. Do you have any issues with the inputs?
        ii. Process development
            1. Have you made any changes to your production to improve quality? (e.g. change windrow turnover rate to improve aeration)
            2. Did you have to change your composting process?
        iii. Marketing/Distribution
            1. How do you market your product?
            2. Have you had any problems changing perceptions of compost?
        iv. Growing pains (tied to efficiency levels)
4. What major breakthrough successes did you have?
    a. Overcoming growing pains?
    b. Convincing the customer?
5. Who is your main customer?
    a. Who else are your customers?
    b. Which segments are you trying to break into?
6. Are you looking to expand into other sectors?
7. Looking back, is there anything you wish you could have done?

Appendix F: Bulk Generators Analysis – Tata Seminar Simulation

Part I: INTRODUCTION

One of the key opportunities in municipal solid waste management (MSWM) is encouraging and enforcing waste segregation at source where wet and dry waste are separated. Source segregation is celebrated for its results: purer compost and higher value recyclables. The 2000 Municipal Solid Waste and Handling Rules, passed by the Indian government, encourage source segregation. Yet, numerous cities have had challenges in getting waste producers to segregate waste at the source mainly due to additional labor involved and lack of interest from waste generators.

The goal of this pilot is to evaluate how segregated waste, specifically food waste, from one bulk waste producer impacts the resulting compost processed through A2Z. This field test would explore a few aspects:

1. Is it possible to get at least one bulk producer to segregate their waste?
2. What system changes are needed to integrate segregated waste in the current process?
3. Does segregated waste change the resulting compost quality?

If segregated waste improves the resulting compost quality (in terms of reduced contamination and improved nutrient content), this would argue for developing a model to collect segregated waste from bulk producers. Bulk producers include produce markets, restaurants, banquet halls, hotels, school cafeterias and other institutions that may generate a lot of food waste specifically. A future goal that would come out of this experiment would be to develop a collection route for all the bulk producers that are located in Muzaffarnagar, India and to explore how improved compost is received by the market (especially farmers in the area). Then, the cost of incorporating the additional segregated waste into the existing system will be evaluated against the improved marketability of the final compost product to determine whether this pilot has enough financial incentive to warrant scaling up to full operation..

The pilot would be evaluated on:

- Quality changes to the final compost (nutrients, presence of contaminants, stability, and maturation). This will be used to evaluate how well the system improved from the added segregated waste.
- Cost of system changes (labor, time, and materials) necessary to segregate waste and to integrate waste. This would be used to evaluate the cost versus benefit of the system (i.e., improvements in compost versus the cost in making those improvements).

Pilot location: Muzaffarnagar, India
Pilot partners:

- Shri Ram Group of Colleges -- the bulk waste generator
- Municipal government of Muzaffarnagar
- A2Z Limited, the private waste organization

Part II: STEPS FOR IMPLEMENTATION

There are two workflows for this project: one for the bulk producer (SRGC) and the other for

A2Z, the private waste organization. These are not necessarily in linear order but are all the steps required before the pilot is possible.

For Shri Ram Group of Colleges:

1. **Identify the current disposal processes at Shri Ram Group of Colleges.**

   In IAP 2015, one of our team members interviewed SRGC and found that their waste is currently burned. The disposal process would need to be confirmed and documented at the beginning of a pilot study.

2. **Evaluate the waste composition of SRGC waste.**

   The pilot depends on a steady and large source of organic waste. If SRGC does not have a large source of organic waste, another bulk generator may need to be explored.

3. **Identify a person(s) to oversee the waste segregation.**

   This person would need to ensure the quality of the segregated waste and make sure that the collection is not contaminated. They would coordinate with A2Z for the collection process.

4. **Provide a container for the segregated waste to be collected in.**

   This container or series of containers could be provided by A2Z or by the municipal government. The container should be one that is easy to dump into the A2Z trucks and is easy for Shri Ram to use for disposing their segregated waste. The container should be covered to prevent contamination.

5. **With A2Z, determine how collection with the truck would work in regards to timing and collection.**

   The coordinator would work with A2Z to set up a regular collection interval.

For A2Z Infrastructure, Ltd.:

1. **Collect the current process data.**

   Sample compost quality: Prior to the implementation of the pilot, the existing final compost quality should be measured against parameters specified in the Municipal Solid Waste (Management and Handling) Rules of 2000 and the Fertilizer Control Amendment Order in 2006. These requirements are listed in Appendix C. Multiple samples should be taken over an extended period of time to ensure natural variations in municipal solid waste (MSW) composition have been adequately characterized and represented in the data.

Determine processing rate: The current process rate should also be evaluated. This can be done by observing how long each step of the process takes for a set amount of input (e.g. preprocessing, windrows, post processing, and curing).

Validate mass balance: This can be done by measuring how much MSW feedstock is applied into the system daily and how much mass is processed in each step daily. Finally, daily compost generation will also be measured. This will confirm existing data about moisture losses, residuals for refuse derived fuel (RDF) making, and residuals for landfills.

2. **Determine the steps and tools needed to modify the existing process to account for the additional organic waste.**

With the addition of the waste collected from the bulk generators, we are assuming this will increase the percentage of organic (food) waste in the feedstock. Therefore, the existing composting process must be modified to account for the additional source of waste and the resulting altered composition of the feedstock.

Separate storage: since the additional organic waste will be of a higher uniformity and quality of the regular MSW, it will need a separate storage space when it is delivered from SRGC. This will be the holding area before it is added to the system. This storage can be as simple as a container.

Mechanized delivery system: Collected waste from the bulk generator will most likely be largely organics. Therefore, the first preprocessing step (screening through a 100mm rotary drum) can be skipped for this separate waste stream and it can be added directly to windrows. A delivery system must be designed to move this waste from the separate storage, mixed in with the existing waste and applied to windrows. One option is to utilize a backhoe to transport, mix, and form windrows. The additional labor required for this step must also be accounted for.

Space allocations in windrows: Here, space for the added volume of waste must be designed for. In addition, the material may have to be left in windrows for a slightly longer period of time to lower moisture content down to acceptable levels for post screening processes. Higher than desired moisture content will lead to clogging of the rotary drum screens which will decrease productivity and efficiency of the process.

Increased aeration: Problems that may be encountered include potential increases in microbial activity due to increased organic matter. This in turn may lead to increased demand for oxygen. Because of this, windrows may need to be turned more frequently to provide the proper aeration and to prevent the windrow piles from turning anaerobic. Another simple options may be decreasing the windrow height to give it more access to the open air. Another issue that may occur with the increased organic matter content is increased leachate generation. Organic matter is high in water content, therefore, increasing the organic matter in the feedstock will inevitably increase moisture content in the windrows. Coupled with anaerobic conditions, the windrows may begin to release leachate. Although this is not an issue at the current state of the facility, it may be a problem resulting from the additional organic waste that will need to be evaluated.

3. **Identify a person(s) to oversee the pilot project from A2Z's side.**

   A2Z facility operators or managers will be best suited to this job as they will have the most knowledge about the existing process and be sensitive to any changes and modifications needed to accommodate the pilot project. Saifi Ahsan is the local facility operator for composting, sorting and other operational activities at the A2Z composting plant in Muzaffarnagar.

4. **Develop a collection schedule with SRGC.**

   All organic waste must be processed as soon as possible to avoid putrefaction and anaerobic activity which will lead to odor issues and loss of important nutrients such as nitrogen. However, more frequent collection will also increase cost of transportation. Therefore, the collection schedule must be developed balancing both these factors. We estimate collection will occur on a bi-weekly basis depending on the amount of space for waste storage at SRGC, any odor issues or complaints, and the amount of funds and labor available for collection and transportation.

5. **Collect the relevant data.**

   Below is a list of important information to be collected during the duration of the pilot:

   Measure amount of additional waste added: This can be measured by weighing this incoming stream before it deposited in its separate storage space.

   Sample final compost quality: All the same parameters will be tested for as with the former process compost. This data will be important compare how the addition of the organic waste affects the quality of the compost generated. Does the compost quality improve or contain more nutrients and less contaminants?

   Determine processing rate: Evaluating how long each process takes after adding the waste stream from SRGC. Does it improve and become more efficient?

   Determine mass balance: This will be important in evaluating how the mass balance changes from the former operation process. Does the process have less rejects going to landfill from this process? Is a higher percentage of compost being produced from the waste?

   Monitor parameters in windrows: The windrows should be tested periodically to check the carbon to nitrogen (C:N) ratio and ensure it is within the optimal range (26:1 to 30:1). This will ensure healthy microbial activity is occurring. pH should also be tested regularly to observe whether or not the windrow piles are becoming too acidic. Low pH levels may be an indicator of anaerobic activity and phytotoxicity. Temperature should also be regularly tested to understand whether windrow piles are getting too heated that microbial activity slows and the piles become too sterile. If leachate is generated, this may also be a sign that anaerobic activity is occurring.

Part III: ADDITIONAL CONSIDERATIONS

Timing:
To verify the results, this pilot would need to run over the span of at least one month to test multiple weeks of compost results and account for any day to day variations in feedstock composition.

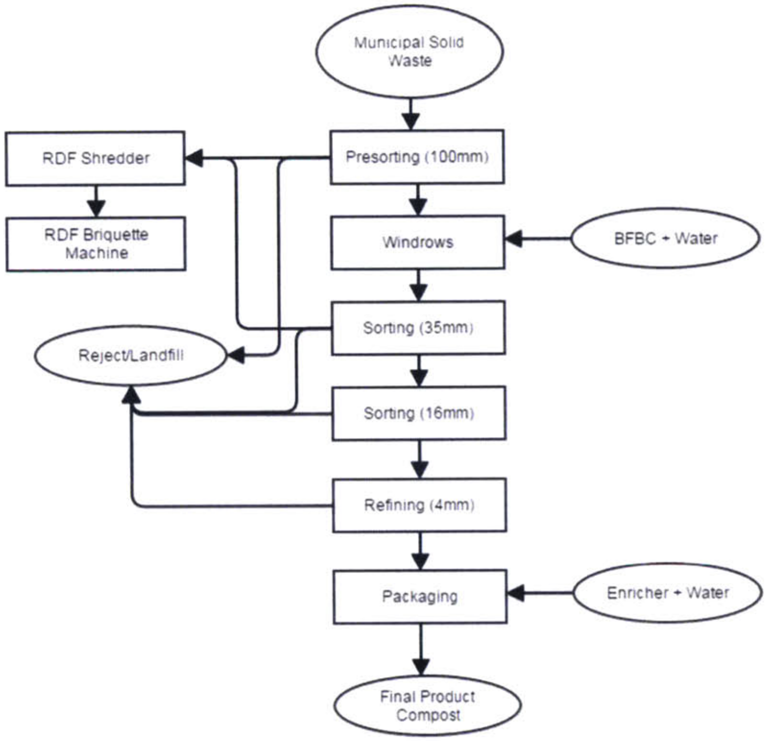
Costs:

- Fuel for the A2Z truck
- Container for storage at Shri Ram Group of Colleges and for A2Z
- Time allotted for A2Z employee (~7000 INR) and/or Shri Ram Group of Colleges employee (~7000 INR)
- Any truck modifications that may be needed
- Test equipment for compost quality testing
- Equipment usage and labor cost associated with adding the waste from SRGC

Questions:

- Will SRGC be in session and generating a similar amount of waste from day in day out?
- Are A2Z's trucks actually able to collect from SRGC (able to get into the gates and to the waste storage site)?
- Are all steps and tools required for pilot feasible or available?

Flow Diagram for A2Z Composting Facility Process



Above: Flow Diagram for current process. Circles indicate materials and squares indicate processes.
Below: Flow Diagram for pilot incorporating bulk generator segregated waste. Green arrows indicate expected increases and red arrows indicate expected decreases (in mass).