Municipal Solid Waste Treatment Concept
for West-Zone Bangalore, India

by order of

Mr. Kiron Shah, Chairman
Electronics City Industrial Township Authority (ELCITA)
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prepared by

wasteconsult INTERNATIONAL

associated partners

Hannover, February 2016

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<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BBMP</td>
<td>Bruhat Bengaluru Mahanagara Palike</td>
</tr>
<tr>
<td>D2D</td>
<td>Door-to-Door</td>
</tr>
<tr>
<td>FE</td>
<td>Ferrous Material</td>
</tr>
<tr>
<td>GCV</td>
<td>Gross Calorific Value</td>
</tr>
<tr>
<td>HD</td>
<td>High Density (Areas)</td>
</tr>
<tr>
<td>HDPE</td>
<td>High Density Polyethylene</td>
</tr>
<tr>
<td>INR</td>
<td>Indian Rupee</td>
</tr>
<tr>
<td>ISAH</td>
<td>Institute for Sanitary Engineering and Waste Management, Hannover</td>
</tr>
<tr>
<td>LD</td>
<td>Low Density (Areas)</td>
</tr>
<tr>
<td>LS</td>
<td>Litter Spots</td>
</tr>
<tr>
<td>MBS</td>
<td>Mechanical Biological Stabilisation</td>
</tr>
<tr>
<td>MBT</td>
<td>Mechanical Biological Treatment</td>
</tr>
<tr>
<td>MD</td>
<td>Medium Density (Areas)</td>
</tr>
<tr>
<td>mDM</td>
<td>Mineral Dry Matter</td>
</tr>
<tr>
<td>MPS</td>
<td>Mechanical Physical Stabilisation</td>
</tr>
<tr>
<td>MSW</td>
<td>Municipal Solid Waste</td>
</tr>
<tr>
<td>NCV</td>
<td>Net Calorific Value</td>
</tr>
<tr>
<td>NF</td>
<td>Non-ferrous Material</td>
</tr>
<tr>
<td>oDM</td>
<td>Organic Dry Matter</td>
</tr>
<tr>
<td>PVC</td>
<td>Polyvinyl chloride</td>
</tr>
<tr>
<td>RDF</td>
<td>Refuse Derived Fuel</td>
</tr>
<tr>
<td>RTO</td>
<td>Regenerative thermal oxidation</td>
</tr>
<tr>
<td>SRF</td>
<td>Specified Recovered Fuel</td>
</tr>
<tr>
<td>SS</td>
<td>Street Sweeping</td>
</tr>
<tr>
<td>TFF</td>
<td>The Forward Foundation</td>
</tr>
<tr>
<td>TOC</td>
<td>Total Organic Carbon</td>
</tr>
<tr>
<td>VOC</td>
<td>Volatile Organic Compound</td>
</tr>
</tbody>
</table>
1 Project description

Bangalore city in India has a population of around 10 million. The city is under the jurisdiction of Bruhat Bengaluru Mahanagara Palike (BBMP) which is the municipal body. The administrative area is divided into 8 zones and 198 wards (BBMP, 2015).

A detailed waste characterization study was conducted for the west zone of Bangalore by The Forward Foundation (TFF), Bangalore in collaboration with Electronic City Industrial Township Authority (ELCITA), Bangalore and BBMP under the guidance of Institute for Sanitary Engineering and Waste Management (ISAH), Leibniz Universität Hannover, Germany. The study area comprised of 44 wards with a total area of approximately 46.70 km\(^2\) with a population of about 1.66 million.

Based on the results from this study, Wasteconsult International based out of Langenhagen (near Hanover), Germany has been engaged to develop an appropriate waste treatment solution for the study area. Following the study, several meetings and discussions were conducted in Bangalore from Aug 10-13, 2015 with all stakeholders, where the status of waste characterization study was assessed and further steps in the project for collection, transfer and treatment were discussed in brief. During the meetings, it was communicated that the concept must have a high level of health and safety standards to avoid direct contact of the workers with dirty and unsegregated waste. A balance between high level of automation in the treatment process and maximum possible labour intensity needs to be achieved.

The aim of this project is to develop a reliable, approved and successful waste processing facility. This requires the availability of a reliable process, machinery and personnel with appropriate skills, education and working morale.

The main objectives of this feasibility report are:

1. Concept development:
   - Evaluation and selection of different process technology for waste treatment
   - Plant sizing, Material flow balance, Preliminary plant layout, Material receipt, handling and storage
   - Comparison of different concepts and Budget estimates
   - Process specifications and utility requirements
   - By-product specifications for recycling market and downstream treatment suggestions
   - Automation level required (e.g. minimising manual handling), Plant Safety – Health and Environment

2. Treatment design
   - Process design of the selected waste treatment solution
   - Plant sizing and material flow balances, process specification and utility requirement
   - Formulating the criteria for different end products and downstream treatment
   - Formulating appropriate standards for automation, health & safety
   - Setting standards for emission and design of appropriate treatment systems
   - Cost estimates for the treatment solution

Remark: This is a concept study. Before building the plant, detailed engineering and verification of process parameters is necessary.
2 Input waste quantity and characteristics

2.1 Methodology

For conception and dimensioning of a waste treatment plant, sound data about waste composition and also about chemical and biological properties and physical data like density is required.

Values for the quantity and composition of the waste are taken or adopted on the basis of the waste characterization study performed by ISAH, TFF, ELCITA and BBMP (Weichgrebe et al., 2015).

The area of west zone was stratified based on population density into high, medium and low density areas. The average per capita waste generation was found to be 0.431 kg/d, however variations were observed among different strata.

2.2 Waste composition

Physical waste compositions were analysed based on the MSW sample collected from all waste streams and strata in West Zone of Bangalore city. Figure 1 graphically depicts the primary categories of waste and overall physical composition.

The overall size fraction distribution of the waste is as mentioned below:

- <14mm - 13%
- 14–55mm - 37%
- 55–77mm - 17%
- >77mm - 33%
The detailed waste composition is as mentioned in Table 1.

Table 1: Primary waste categories by weight– overall composition (Weichgrebe et al., 2015)

<table>
<thead>
<tr>
<th>Primary Categories</th>
<th>Est. Percentage [%]</th>
<th>Cum. Percentage [%]</th>
<th>Est. Sample [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic</td>
<td>62.63</td>
<td>62.63</td>
<td>11347.69</td>
</tr>
<tr>
<td>Plastics</td>
<td>9.92</td>
<td>72.55</td>
<td>1798.02</td>
</tr>
<tr>
<td>Paper and Cardboard</td>
<td>8.76</td>
<td>81.31</td>
<td>1587.27</td>
</tr>
<tr>
<td>Textiles</td>
<td>4.60</td>
<td>85.92</td>
<td>834.06</td>
</tr>
<tr>
<td>Fines</td>
<td>4.18</td>
<td>90.09</td>
<td>756.58</td>
</tr>
<tr>
<td>Composites (Al, plastic, paper)</td>
<td>3.30</td>
<td>93.39</td>
<td>597.65</td>
</tr>
<tr>
<td>Biomedical Waste (mostly napkins)</td>
<td>2.03</td>
<td>95.42</td>
<td>367.90</td>
</tr>
<tr>
<td>Inert</td>
<td>1.61</td>
<td>97.03</td>
<td>292.30</td>
</tr>
<tr>
<td>Glass</td>
<td>1.45</td>
<td>98.48</td>
<td>261.86</td>
</tr>
<tr>
<td>Liquids</td>
<td>0.42</td>
<td>98.90</td>
<td>76.12</td>
</tr>
<tr>
<td>Wood</td>
<td>0.35</td>
<td>99.24</td>
<td>62.57</td>
</tr>
<tr>
<td>Hazardous Household Waste</td>
<td>0.34</td>
<td>99.58</td>
<td>60.92</td>
</tr>
<tr>
<td>Metals</td>
<td>0.30</td>
<td>99.88</td>
<td>53.87</td>
</tr>
<tr>
<td>Mixed Waste of Electrical and</td>
<td>0.12</td>
<td>100.00</td>
<td>22.07</td>
</tr>
<tr>
<td>Electronic Equipment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100</strong></td>
<td><strong>100</strong></td>
<td><strong>18118.89</strong></td>
</tr>
</tbody>
</table>

The waste characterization involved size separation by screening and also sorting. This was conducted for all the waste streams – Door-to-Door (D2D) collection, litter spots (LS) and street sweeping (SS). The fine fraction (<14mm) was mostly organic waste; however it could not be physically characterized.
<table>
<thead>
<tr>
<th>Primary Waste Categories</th>
<th>&gt;77 mm</th>
<th>55–77 mm</th>
<th>14–55 mm</th>
<th>All together</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic</td>
<td>11.75</td>
<td>12.68</td>
<td>36.31</td>
<td>60.74</td>
</tr>
<tr>
<td>Plastics</td>
<td>6.67</td>
<td>2.30</td>
<td>0.86</td>
<td>9.84</td>
</tr>
<tr>
<td>Paper</td>
<td>5.82</td>
<td>2.03</td>
<td>0.71</td>
<td>8.56</td>
</tr>
<tr>
<td>Textiles</td>
<td>3.31</td>
<td>0.57</td>
<td>0.22</td>
<td>4.10</td>
</tr>
<tr>
<td>Composites</td>
<td>2.15</td>
<td>0.47</td>
<td>0.25</td>
<td>2.87</td>
</tr>
<tr>
<td>Biomedical</td>
<td>1.74</td>
<td>0.41</td>
<td>0.09</td>
<td>2.25</td>
</tr>
<tr>
<td>Glass</td>
<td>0.96</td>
<td>0.22</td>
<td>0.10</td>
<td>1.27</td>
</tr>
<tr>
<td>Inerts</td>
<td>0.24</td>
<td>0.14</td>
<td>0.15</td>
<td>0.53</td>
</tr>
<tr>
<td>Hazardous</td>
<td>0.18</td>
<td>0.12</td>
<td>0.13</td>
<td>0.43</td>
</tr>
<tr>
<td>Metals</td>
<td>0.17</td>
<td>0.06</td>
<td>0.07</td>
<td>0.30</td>
</tr>
<tr>
<td>Wood</td>
<td>0.08</td>
<td>0.03</td>
<td>0.06</td>
<td>0.16</td>
</tr>
<tr>
<td>Mixed WEEE</td>
<td>0.05</td>
<td>0.04</td>
<td>0.04</td>
<td>0.14</td>
</tr>
<tr>
<td>Fines</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.42</td>
</tr>
<tr>
<td>Liquids</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>8.39</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>33.11</strong></td>
<td><strong>19.08</strong></td>
<td><strong>39.00</strong></td>
<td><strong>100.00</strong></td>
</tr>
</tbody>
</table>

2.3 Detailed chemical composition

Table 3 shows detailed chemical data of the various screening fractions and waste components. Based on experience, the moisture contents are too low for this type of waste. This is probably caused by the fact that moisture partly evaporated during the sorting and screening process. This has to be considered while using moisture contents and net calorific values for the dimensioning of the waste treatment plant.
Table 3: Detailed chemical composition (data from Weichgrebe et al., 2015)

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>D2D Waste Stream</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;77 mm</td>
<td>7.48</td>
<td>32.45</td>
<td>59.70</td>
<td>7.85</td>
<td>55.60</td>
<td>0.09</td>
<td>11.15</td>
<td>9.50</td>
<td>13.55</td>
<td>244.80</td>
<td>167.0</td>
<td>25.40</td>
<td>14.31</td>
</tr>
<tr>
<td>55-77 mm</td>
<td>9.36</td>
<td>34.20</td>
<td>61.21</td>
<td>4.59</td>
<td>37.20</td>
<td>&lt;0.02</td>
<td>6.23</td>
<td>14.03</td>
<td>1.73</td>
<td>107.43</td>
<td>36.30</td>
<td>24.38</td>
<td>14.11</td>
</tr>
<tr>
<td>14-55 mm</td>
<td>6.99</td>
<td>43.50</td>
<td>47.11</td>
<td>9.39</td>
<td>26.17</td>
<td>0.03</td>
<td>6.60</td>
<td>10.90</td>
<td>4.40</td>
<td>34.00</td>
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<td>14.36</td>
<td>0.14</td>
<td>5.24</td>
<td>17.77</td>
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<td>44.07</td>
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<td>4.89</td>
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<td>16.8</td>
<td>32.15</td>
<td>38.35</td>
<td>10.50</td>
<td>1.63</td>
<td></td>
</tr>
</tbody>
</table>

2.4 Comparison of Carbon, oDM and TOC contents (for D2D)

From door-to-door collection there are values for organic dry matter (oDM), total organic carbon (TOC) and carbon available:

Table 4: Comparison of carbon contents with oDM and TOC for D2D, Weichgrebe et al. (2015)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Fraction group (door-to-door collection)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&gt;77 mm</td>
</tr>
<tr>
<td>Carbon [%]</td>
<td>49.4</td>
</tr>
<tr>
<td>oDM [%]</td>
<td>59.7</td>
</tr>
<tr>
<td>TOC (ppm)</td>
<td>1700</td>
</tr>
</tbody>
</table>
2.5 Respiration Activity (RA4 / AT4)

Compared to literature values of raw waste the given results are low. This could be a result of the rather long storage period of the waste samples, which means the actual values could assumed to be higher. Moreover, this test is not yet standa

Table 5: Respiration activity RA4 (AT4), Weichgrebe et al. (2015)

<table>
<thead>
<tr>
<th>Sample Waste streams</th>
<th>Oxygen uptake (mg O\textsubscript{2}/ g DM)</th>
<th>Limit Value for Waste Deposit on Landfill\textsuperscript{1}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Moisture content [%]\textsuperscript{1}</td>
<td>&gt; 77 mm</td>
</tr>
<tr>
<td>Door-to-Door</td>
<td>50</td>
<td>15.0</td>
</tr>
<tr>
<td>Litter Spots</td>
<td>50</td>
<td>22.4</td>
</tr>
<tr>
<td>Street Sweepings</td>
<td>50</td>
<td>24.3\textsuperscript{2}</td>
</tr>
</tbody>
</table>

\textsuperscript{1} As per German Landfill Ordinance, \\
\textsuperscript{2} Only for Organic Fraction

2.6 Gross calorific value

For the identification of appropriate waste treatment and recovery techniques, the knowledge of the calorific value of the waste is important, especially for thermal energy recovery processes. Table 6 shows the calorific values according to waste streams and size fractions. Additionally, two different mixtures of waste streams were calculated depending on the individual share of each waste stream for different waste sources and collection characteristics. By this, varying waste generation and collection characteristics can be projected for a downstream waste treatment.

Table 6: Gross Calorific value of the waste in West Bangalore, Weichgrebe et al. (2015)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>&gt;77 mm</td>
<td>55–77 mm</td>
<td>14–55 mm</td>
<td>&lt;14 mm</td>
</tr>
<tr>
<td>D2D GCV</td>
<td></td>
<td>14.31</td>
<td>14.11</td>
<td>7.25</td>
<td>8.61</td>
</tr>
<tr>
<td>% share</td>
<td></td>
<td>34 %</td>
<td>19 %</td>
<td>38 %</td>
<td>9 %</td>
</tr>
<tr>
<td>LS GCV</td>
<td></td>
<td>12.30</td>
<td>3.86</td>
<td>1.68</td>
<td>1.78</td>
</tr>
<tr>
<td>% share</td>
<td></td>
<td>35 %</td>
<td>17 %</td>
<td>36 %</td>
<td>12 %</td>
</tr>
<tr>
<td>SS GCV</td>
<td></td>
<td></td>
<td>0.65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% share</td>
<td></td>
<td>26 %</td>
<td>15 %</td>
<td>36 %</td>
<td>24 %</td>
</tr>
</tbody>
</table>

Overall GCV [MJ/kg]

8.10

8.78
3 Selection of general waste treatment type

3.1 Overview

There are two proven and more sustainable ways of treating municipal solid waste (MSW) to avoid the direct landfilling of solid waste:

- Mass burn (incineration) includes flue gas treatment and slag handling.
- Mechanical–biological treatment processes are usually operated with reuse of the output (i.e. RDF) and/or with landfilling of the stabilized low-volume process outputs.

3.2 Waste incineration

Incineration, also often called “waste to energy”, can be useful when the waste is comparatively dry and has enough components with a high calorific value to enable an auto-thermal process with a high generation of usable energy. For a sustainable recovery of energy, not only electricity but also the generated heat should be used. As a reference, the EU Waste Framework Directive (Annex II, R13) requires a minimum energy efficiency of 65% which can only be achieve with heat recovery.

Incineration requires a fixed, constant amount of appropriate fuel with constant average properties. In case of changing waste amounts or qualities, severe economic and technical problems can be expected.

The mixed solid waste investigated in Bangalore consists mainly (63%) of (moist) organic materials (Figure 1) and the calorific value is low (less than 9 MJ/kg gross calorific value, see Table 6). This will lead to low energy production in the incinerator. In combination with the high construction costs of incinerators, incineration as a solely solution would not be appropriate in this project. Drying the waste with abundant heat could increase the heat caloric value but this is not in-line with the Indian waste hierarchy of the MSW Rules 2000 or even does not lead to a sustainable or economic solution under the local conditions.

However, if Waste Incineration Plants are installed in places where there is a demand of heat and or power and the calorific value of the waste is higher (e.g. in central Europe), they can play an important role in holistic waste management concepts.

3.3 Mechanical–biological treatment (MBT)

Mechanical–biological waste treatment (MBT technology) is a material–specific process. Mixed (residual) waste is separated into various fractions, each of which is treated and, if possible, recycled in a way that is customised to its properties, as shown in Figure 2. The core elements of MBT are mechanical or physical separation technologies and the biological treatment of biodegradable waste components unless they are diverted to recycling (e.g. paper). Most MBT plants divide their input into a fine fraction for biological treatment and a coarse high-calorific fraction that undergoes extended mechanical treatment. Mechanical–biological stabilisation plants (MBS) deviate from this concept as their entire input (or in a few places only the mechanically separated, high-calorific fraction) undergoes biological drying. High calorific fractions from MBT and MBS are mostly used as refuse derived fuel (RDF), but can be also separated in various materials for recycling. The latter requires a market / destination for the separated materials.
The objectives of mechanical-biological waste treatment vary depending on the location, waste flow, legal and economic situation, and they can thus be weighted differently as follows:

- minimising climate-relevant methane emissions from landfills
- decreasing landfill leachate contamination
- reducing landfill void consumption
- filling existing landfill volume capacities
- minimising thermal waste treatment
- separating recyclable materials
- producing a high-calorific secondary fuel (RDF / SRF)

Mechanical biological treatment processes with subsequent energy recovery from the high calorific fraction are appropriate for the project tasks. They are comparatively flexible and can be better adapted to changing waste quantities and qualities than mass burn incineration. However, MBT plants are only successful if they are tailor-made according to the output usage. The subsequent utilization is inseparable part of the MBT and should be prepared for as early as possible. Figure 3 shows the high calorific fraction converted into a process product.
3.4 Bioreactor landfill

Sometimes, bioreactor landfills are seen as an alternative to waste treatment. Bioreactor landfills are sealed landfills with forced leachate recirculation and water infiltration. They require proper sealing with landfill membranes and a leachate treatment system. They produce biogas (methane) which is collected by gas wells in the landfill, but can also be operated with forced aeration as an aerobic system. The landfill gas of anaerobic systems is used to produce electrical energy in gas motors. It is important, that the gas capture rate is limited and a part of the methane, that is a strong greenhouse gas, is lost to the atmosphere. After the stabilisation of the organic matter in the landfill by the infiltration process and the biological degradation processes in the landfill (takes usually decades), there is still a landfill full of waste left.

Bioreactor landfills are not a significant step forward in waste management; they are just slightly better landfills. Mechanical-biological treatment hat lots of advantages over bioreactor landfills:
Benefits of MBT over bioreactor landfill:

- Full control and prevention of gaseous emissions in enclosed systems
- Industrial process in which the total waste is involved. No dry (not affected) zones such as in a landfill
- Leaves more stabilized material in the landfill (Aerobic degradation is more effective on poorly biodegradable substances than the anaerobic processes in the landfill)
- Higher gas yield and capture (intensive treatment and no loss of open installation areas or leaks in a landfill)
- Valuable resources (metals, wood, plastics, paper, etc.) are recycled and not lost in the landfill
- Producing a high calorific solid fuel
- Less land consumption and avoidance of burden for future generations

3.5 Conclusion

Considering the waste properties and the target of a long term sustainable and sanitary solution, mechanical-biological techniques are the most appropriate processes. Hence, MBT is chosen as the appropriate system for this project. It has to be pointed out, that the utilisation of the MBT output products, especially the high calorific secondary solid fuel is required for a meaningful operation of a MBT. Concepts and markets for that should be prepared as early as possible. There are lots of different MBT technologies. The next chapters describe the main groups of MBT processes and do a pre-section amongst them.
4 Description of Mechanical–Biological waste Treatment processes (MBT)

4.1 Types of mechanical–biological waste treatment

Mechanical–biological waste treatment plants are grouped into the following types based upon the main technology used in the biological stage:

- MBT with a major landfill or compost fraction
  - Aerobic processing
  - MBT with 'dry' anaerobic treatment
  - MBT with 'wet' anaerobic treatment
- MBT (MBS) for solid recovered fuel (SRF/RDF) production
  - Short aerobic drying process (BD) and efficient material separation after drying for combustion and recycling
- Mechanical–physical drying plant (MPS). Similar to MBS, but drying with fossil energy and no biological step

Anaerobic technologies yield both solid output streams and biogas (methane) that can be used as a source of energy. Anaerobic stages are always followed by an aerobic treatment phase. Installations with digestion stages can operate as full-stream or partial-stream fermenters (in relation to the input to biological treatment).

The choice of MBT machinery is based upon the following factors:

- the treatment objective
- the type and composition of waste
- the requirements for subsequent biological treatment
- the requirements for energy recovery

Basic elements of most MBT plants:

- Input control /selection, input buffering / bunker (reception hall)
- Extraction of material with high energy content (high calorific value) by sieving (diameter >60-150 mm / ~3-6´´) or other technologies
- Metal separation
  - Magnetic separator for ferrous metals (always available)
  - Eddy current separator for non-ferrous met. (many plants)
- Biological treatment of fine fraction (e.g. < 60 mm)
- Intermediate storage facility
- If necessary, further mechanical treatment of biologically treated fraction for the withdrawal calorific constituents by sieving or air classification
- If necessary, further processing of the calorific fraction

In biological drying plants, usually the entire input is shredded and fed to the biological drying process. Separation can be done better after the drying. Figure 4 to Figure 9 visualizes a selection of important
Figure 4: Reception, intermediate storage and feeding the shredder
Source: Wasteconsult International

Figure 5: Inside a trommel screen
Source: Wasteconsult International
Figure 6: Outside encapsulated trommel screen
Source: Wasteconsult International

Figure 7: Metal separation (Doedens 1998)
Figure 8: Tunnel hall with tunnel doors on the left side  
Source: Wasteconsult International

Figure 9: Optical sorting from two suppliers  
Source: Wasteconsult International

Figure 10 and Figure 11 show simplified process charts of the various MBT processes. They are meant to show the main differences. For better clarity, the exhaust air path is not included.
Figure 10: Simplified process chart of MBTs with a major landfill (or compost like) fraction
4.2 Main material flows

4.2.1 Input materials

Input material of MBT plants usually consists mainly of the mixed residual fraction left over after source-separated waste collections or mixed household and household like commercial waste. Besides household waste and commercial waste with similar properties, these facilities sometimes also process a smaller amount of commercial waste, bulky waste, sorting residues, sewage sludge and grit chamber residues.

4.2.2 MBT output

Table 7 is an example for the average breakup of solid material flows at German MBT plants handling residual waste. A distinction is made between MBT (upstream of a landfill) and MBS (primary objective: producing alternative fuels, biological drying) technology.
Table 7: Solid output streams by fraction (wt.%) in terms of overall output (excluding rotting and drying losses) for different types of plants, showing the average and range of German installations (Kühle-Weidemeier, M. et. al. 2007)

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Percentage by weight</th>
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<tbody>
<tr>
<td></td>
<td>MBS/MPS</td>
</tr>
<tr>
<td>FE metals</td>
<td>4.2 (2.6-7.0) 3 (0.3-4.8)</td>
</tr>
<tr>
<td>NF metals</td>
<td>0.4 (0-0.9) 0.1 (0-0.7)</td>
</tr>
<tr>
<td>Impurities</td>
<td>1.3 (0-8.7) 2 (0-12)</td>
</tr>
<tr>
<td>Other</td>
<td>6.4 (0-33) 5 (0-22)</td>
</tr>
<tr>
<td>Landfill fraction (compost-like output)</td>
<td>12 (0-26) 41 (19-64)</td>
</tr>
<tr>
<td>Other low-calorific material</td>
<td>8.9 (0-39) 3 (0-21)</td>
</tr>
<tr>
<td>High-calorific fraction</td>
<td>67 (28-97) 46 (29-77)</td>
</tr>
</tbody>
</table>

Note: A few MBT plants have now been retrofitted to add NF separators, which were not installed at the time when these measurements were taken. The NF material stream would have increased currently.

Figure 12 shows the cumulated mass flow of all German MBT plants. The values represent the annual average. Of course, depending on technology and treatment targets the mass flow in individual plants will be different.

Figure 12: Mass flow of the total of Germany’s MBT plants (various technologies in 2007), (Kühle-Weidemeier, 2007)
The output fractions coming out of different technologies in Germany is mentioned in Figure 13. It has to be noted that the MPS data is based on only 3 plants and the high content of RDF output might have been influenced by input composition.

Figure 13: Share of the various fraction of the total solid output of the total of German MBTs from different technologies (Kühle-Weidemeier, 2007)

The huge amount of the high calorific fraction in the MPS output is likely caused by local/plant and waste specific reasons (only 3 MPS plants). All data shown about mass flows are meant as an illustrating example. However waste composition differs in other countries and may be much different from waste composition in Germany which will lead to different output composition.
5 Evaluation / pros and cons of the process types

5.1 Aerobic MBT prior to landfill for the production of compost like output

+ Lowest investment costs of all modern MBT types
+ Smaller units are also feasible
+ Simple and the most reliable MBT process
+ 50% or more landfill diversion
- No biogas production
- Pure energy consumer due to required aeration (negative energy balance if the recovered energy from produced secondary fuel is not taken into account)
- Comparably long biological treatment time (4-12 weeks depending on treatment targets)

5.2 MBTs with anaerobic digestion

+ Biogas production that can exceed the energy demand of the MBT by far
- Higher investment costs due to more sophisticated process
- MBTs with anaerobic stages are more complex than aerobic MBTs
- The anaerobic process is more sensitive than the aerobic
- Operation requires higher skills of the operational personnel

5.3 Aerobic MBT (or MBS) with biological drying (BD)

+ Reliable aerobic process
+ Tunnel / box system with good emission control
+ Dried material allows enhanced sorting and material recovery
+ 65-90 % landfill diversion
- Increased risk of fires
- No biogas production (but huge amount of refuse derived fuel RDF with high calorific value)
- Energy consumption through aeration

5.4 Mechanical–physical stabilization (MPS)

MPS is excluded due to high fossil energy consumption in general, especially due to the comparatively high moisture content of Bangalore’s waste to that of Germany.

5.5 Pre–decision

A main objective of the project is to establish a reliable, approved and successful waste processing facility. This requires the availability of a reliable process, reliable machinery and personnel with appropriate skills, education and working morale.

Under the current situation, a simple and robust process will offer the best precondition to fulfil the project targets described in the previous paragraph. MBTs with anaerobic process steps are sophisticated units that require skilled personnel with an in-depth understanding of the chemical and biological
processes in the reactor, the influence of feedstock variations and how to react to a wide variety of possible complications in the biological process. While for the given conditions (treatment of mixed solid waste) an aerobic process is comparatively easy to handle and tolerant to unfavourable process conditions, anaerobic digestion processes are easy to "kill", difficult to handle and time consuming to recover. Depending on the technology, MBTs need a wastewater management, especially (e.g. 0.5-0.7 m$^3$/t in wet anaerobic MBTs that requires treatment.

Due to the sensitivity and complexity of the process, anaerobic processes are excluded from the process selection based on the premises of this project. Hence, an aerobic plant with composting step, an aerobic biological drying plant or a combination of both will be subject of closer investigations in this project. However, the process will have a negative energy balance which can be recovered by the reuse of the products. Also, the skilled personnel have to understand and maintain the process with proper air and water management to avoid self-ignition.
6 General description of process steps and machinery in aerobic MBT / MBS plants

6.1 Manual sorting and removal of impurities

Improperly sorted items and large impurities are first removed by hand or using grippers before mechanical treatment truly begins. This step prevents damage to technological systems and avoids introducing hazardous substances or items that might stop the technology from working properly. According to the waste characterisation, currently not much contraries have to be expected, but this may change following the economic growth.

6.2 Mechanical treatment

6.2.1 Functions of mechanical treatment

Mechanical processing prepares waste for subsequent treatment. The degree of processing is determined mainly by the application for high-calorific coarse fraction and biological treatment process for the fine fraction.

Mechanical treatment has the following functions:

- Removal and/or processing (e.g. shredding) impurities
- Screening out fine fraction with a high level of degradable organic components for biological treatment (not at MBS plants)
- Sorting, shredding or customising high-calorific waste fractions for energy recovery (in the MBT plant’s main stream before or after biological treatment)
- Ejecting heavy fractions
- Separating groups of materials for recycling (e.g. metals)
- Breaking down and homogenising waste components for biological treatment
- Customising high-calorific output material

6.2.2 Shredding and homogenisation

In the first stage of mechanical processing, waste is prepared for subsequent treatment, pre-shredded to the necessary maximum size and thereby also homogenised for the first time. The shredding process also opens containers and bags etc., and increases the surface area of the waste components, improving the breakdown of degradable organic elements for biological treatment.

The decision of pre-shredding the material depends upon the waste’s properties. The machinery used in this phase varies in terms of its shredding effect and depends on the type of waste to be treated. Most often, the plants use breaking (e.g. single or multi-shaft breakers), cutting (rotary shear or cutting mill) or shearing (screw mill) machinery. One alternative is high-pressure compactors, which combine shredding and sorting of fractions that will undergo biological treatment. Depending on the waste properties, pre-shredding can be avoided for some waste streams and replaced by just a bag opener.
6.2.3 Separation of coarse and fine fractions

The separation of high-calorific coarse waste fractions and the fine fraction destined for biological treatment is largely performed using screening (drum, vibrating and star screens). As a result of the waste characterization of West Zone, Bangalore (Weichgrebe et al., 2015), the screen cuts are chosen to be 10 mm and 60 mm. Air-classifiers are used occasionally and a few plants also utilise ballistic separators.

High-pressure compactors are used in some plants with anaerobic digestion to separate the wet organic fraction from the dry fractions.

6.2.4 Separating FE and NF metals

Magnets remove ferrous metals; non-ferrous (NF) metals are extracted using eddy current separation systems.

6.2.5 Processing the high-calorific fraction

The resulting high-calorific fraction can undergo additional processing prior to energy recovery, if necessary. This depends on the customer's specifications. Apart from additional shredding, other steps include further removal of metals and other impurities, such as rocks or other inert, non-combustible materials.

6.2.6 Ejection of impurities and recyclables using sensors

Some plants also utilise sensor-based sorting technologies (optical NIR sensors) in order to remove PVC, for example, from the high-calorific value fraction. The PVC's high chlorine level lowers the fuel quality. Sensor-based sorting can also be used remove recyclables like paper, wood or selected plastic material from coarse and sometimes even from the fine fraction.

6.3 Biological treatment (aerobic)

6.3.1 Intensive decomposition (degradation)

The stages of biodegradation follow first-order kinetics, corresponding to a curve that first falls steeply before showing an asymptotic motion. Most decomposition by mass occurs when the degradation curve is steep during a period that typically lasts two to three weeks. This phase is known as intensive decomposition because of the significant break-down of material (which is simultaneously accompanied by the most intense phase of emission activity).

Aerobic degradation releases carbon dioxide, water, ammonia and heat as the main (gaseous) products of metabolism. The temperature typically is around 50-60°C in the intensive decomposition phase, and is even higher in MBS plants. The temperature has a sanitising effect on the waste. The water content, aeration and temperature are the key process and control parameters in composting.

Enclosing or encapsulating the intensive decomposition stage is a core element of efforts to minimise emissions and optimise process efficiency. After around 3-5 weeks starts the maturation phase with much lower emissions. This phase is more feasible for not completely enclosed processing, but due to
higher process efficiency and better emission control often the complete biological treatment is done encapsulated.

At MBS plants, the overall biological degradation process is restricted to a hot (intensive) decomposition (drying) phase lasting 7 to 14 days, during which moisture is expelled from waste through the exhaust air and is not replaced.

6.3.2 Maturation

Substances that are tough to decompose or unusable decomposition and transformation products release humic substances during the maturation phase. Maturation takes ca. 4 to 8 weeks depending on the process and feedstock and stabilization requirements.

6.3.3 Shape and encapsulation of composting windrows

6.3.3.1 Box, container and tunnel windrows

In this method, waste rots in actively aerated concrete tunnels or containers that can be closed securely and allows a high level of emission control. This enclosed system permits comparatively accurate control of the composting process by measuring and regulating temperature and oxygen levels in the exhaust air. Process conditions can be tailored exactly to the stage of decomposition as each tunnel contains material of the exact same age. The material is turned upon input and removal. The rotting time is short (2 to 4 weeks) as the parameters can be easily controlled. However, to produce mature compost (as against raw compost) it could be subjected to odour emissions.

6.3.3.2 Linear windrows

This technique composts material in fortified open-air composting lines (which may also be covered by a roof or enclosed) that are actively aerated on an individual basis. Special turning machinery turns the windrows line by line.

6.3.3.3 Table windrows

Table windrows are over-sized windrows that are typically set up throughout almost entire halls and equipped with automatic turning machinery (bucket wheel or screw system). A ventilation floor provides active aeration. The aeration floor is divided into segments, allowing aeration intensity to be adjusted based upon how well the material is decomposing.

6.3.3.4 Triangular windrows

Triangular windrows are laid out in elongated lines in a hall or in a space covered by a roof structure. Material is stacked by a closed cabin wheel loader, for instance, and turned by a closed cabin wheel loader or a windrow turner. Triangular windrows mostly employ passive aeration and are mainly used for maturation when the demand for oxygen is no longer quite as high.
6.3.3.5 Composting and homogenisation drums

A few installations begin biological treatment in a steel drum that rotates very slowly. The turning motion slightly shreds and homogenises the material, improving bioavailability and also helping to aerate the mixture. Integrated nozzles can inject moisture, if needed. The residence time is one to seven days. Material then undergoes conventional rotting. Composting drums are rarely used because of their high cost of operation.

6.4 Wastewater treatment

Unless a plant is wastewater-free, wastewater that is not re-circulated is treated prior to discharge. This step typically takes place in landfill leachate treatment units or the wastewater is sent to the local sewage sludge treatment plant (depending on the NH₄, COD load, heavy metals, etc.) through the sewer network, depending on availability and permission. Wastewater treatment is thus not typically part of the mechanical-biological treatment plant itself (except the MBT with full wet anaerobic fermentation). Requirements for discharge before mixing may necessitate pre-treatment before wastewater is discharged into the sewer network.

The following techniques or often combinations thereof are essentially suitable for treatment: biological treatment with ultra filtration, reverse osmosis and/or activated carbon adsorption.

6.5 Waste gas (exhaust air) treatment

6.5.1 Machinery

A combination of gas scrubber (not required for wet anaerobic digestion plants) and at least one downstream process are generally used to treat waste gas generated by MBT plants. The downstream process is usually a biofilter and in Germany, it is a regenerative thermal oxidation (RTO). RTO achieves the highest level of exhaust gas purification but has a high energy consumption, especially in aerobic MBT plants.

6.5.2 Wet and acidic scrubber

The scrubbing process captures dust and humidifies dry waste gas from mechanical treatment before it enters the biofilter. It also washes out some nitrogen compounds.

The main function of an acidic scrubber is to remove nitrogen compounds that would lead to the release of nitrogen oxide (NOₓ) and nitrous oxide (N₂O), caused by processes in the biofilter, from waste gas. Any ammonium nitrogen in the waste gas stream is transferred into the scrubbing liquid (generally diluted sulphuric acid), which usually achieves the required fertilizer quality.

6.5.3 Biofilter

In a biofilter, the waste gas flows extensively through a bundle of organic material (often root wood) whose surface is teeming with microorganisms.

Conditions must be put in place to facilitate microorganism growth in order to achieve the necessary degradation efficiency of odour and volatile organic carbons (excluding methane). In particular, these conditions include having consistent and suitable temperature and moisture conditions, a suitable pH.
level and adequate surface area contamination for degradation, i.e. not too large (degradable material per m² and hour). Figure 14 shows the surface of a biofilter in Germany.

![Biofilter](Image)

**Figure 14: Biofilter**
Source: Wasteconsult International

6.5.4 Regenerative thermal oxidisers

Regenerative thermal oxidisation (RTO) is a flameless oxidation technique that involves a heated bed of ceramic material. The function of an RTO is to reduce greenhouse gas emissions (e.g. methane), odour and to dispose of other organic substances that have an impact on the environment and human health.

Non-catalytic regenerative thermal oxidisers can essentially be broken down into the following systems:

- RTO systems with a combustion chamber (largely three chamber systems)
- RTO systems without a combustion chamber (largely one chamber systems)

RTO systems consist of an oxidation zone and heat exchange system before and after the oxidation zone. Crude gas is preheated to the oxidation temperature of ca. 800°C to 1,000°C in the upstream heat exchange element (Stockinger, 2004).

The RTO can source some of its operating energy and temperature from the oxidation of organic waste gas components, except in the start-up phase. For the rest, a supply of biogas or fossil gas is required.
RTO is an appropriate solution for MBTs with a high load of volatile organic carbon in the exhaust gas. When this exceeds about 1500ppm, RTO can be run auto thermal and needs no or very few external energy / heating except for the start procedure. These conditions can be found in some anaerobic MBTs. Aerobic MBTs usually have much lower VOC loads in the exhaust gas, however, higher levels VOC can be expected in India due to experiences on ground. This causes enormous costs for feeding fossil gas to heat the RTO and in some cases the operation of the RTO causes more greenhouse emissions than it avoids. Hence, RTO is often a good solution for anaerobic MBT but less for aerobic MBT. Although VOC is expected to be high in India, increased aeration leads to a reduction of VOC levels and thereby waives the need for RTO.

![Image of RTO and acid scrubber](image)

**Figure 15:** RTO and acid scrubber (black in the image centre)

Source: Wasteconsult International

### 6.5.5 Waste gas combustion

Three of the German plants do not treat waste gas in an RTO, but send it to an incineration plant as waste or secondary fuel where it is used as supply air. These plants have a backup RTO that is used when the incinerators are under maintenance. Feeding the exhaust gas to the incinerator requires special corrosion protection measures in the incinerator. This way of treatment is interesting, when a biofilter is not appropriate for exhaust gas treatment and otherwise a RTO would be required.
7 Local conditions in Bangalore

7.1 Size and location

Bangalore is the capital city of Karnataka, India. It has an area of around 1300 sq. km. (BBMP restructuring, 2015) and is located at an altitude of 949 m above sea level (BBMP, 2015). It lies in 12° 58' N latitude and 77° 38' E longitude and has the following climatic conditions:

7.2 Climate

- Mean annual temperature – 24.1 °C
- Average temperature in hottest month(April) – 28 °C
- Average temperature in the coolest month(December) – 21.1 °C
- Annual Precipitation – 905 mm
- Annual average relative humidity – 62.5% (Bangalore Climate Maps, 2015)
- Annual average wind speed – 2.82 m/s
- Annual average solar radiation – 5.26 kwh/m2/d (Synergy Enviro Engineers, 2015)
- Low effect of monsoon, comparatively even distribution of rainfall

The actual location of the proposed treatment plant has not been identified yet and hence the above climate data is assumed for the calculations in this feasibility study.

7.3 Geology, sub soil

No information is available for the plant location about the earthquake, inundation or risks due to any other natural disaster. Therefore, this study doesn’t take into account any special requirements related to them. These risks must be evaluated during further planning of the project.

No information about the sub soil at the plant location is available either. This study assumes that the sub soil has normal load-bearing properties that don’t require any special foundation work. This should be further reviewed during the further planning once the project location is chosen.

7.4 Infrastructure and transport

As the site had not been determined at the time of this study, information also cannot be provided regarding the local situation with regards to:

- Transport connections (road and rail)
- Connection to utilities and waste management infrastructure (electricity, gas, drinking water, wastewater, telephone, data etc.)
- Distance to the landfill and the planned incinerator for the high-calorific fraction
- Distance to the next development, especially housing and any protected areas
- Size and layout of the building plot.

This study estimates the area required for the MBT plant and develops a rough surface layout. It does not take account of any special requirements or limitations relating to the aforementioned points. Infrastructural interfaces for which no specific local rules exist are located at the boundaries of the building plot.
This study assumes that trucks or compactors / trucks with press containers will be used to transport the solid output streams.

7.5 Technical standards for the project

Discharge limit values set by the local Pollution control board are considered for the discharge of contaminated wastewater. This study assumes that the wastewater is generated relatively consistently and, if necessary, discharged without restriction after treatment according to the limit values. On the other hand, surface water will not be generated all the time because of the nature of precipitation. A rainwater collection basin is planned to even out discharge volumes. It can also be used as a fire extinguishing water reservoir.

There are no specific requirements for discharging exhaust air from the MBT plant into the environment in India. This study assumes that dust and odour emissions are to be limited in accordance with the state of the art and achieve the air pollution limit values set by the local Pollution control Board and protect the health of workers and population.

This study presumes that solid waste generated by the MBT plant should be adequately stabilised and thus meet requirements in the range of EU criteria regarding e.g. gas formation potential and respiration activity. This study considers water content and loss on ignition to be the indicative parameters. The study also ensures that the landfill fraction meets any standards set by MSW Rules 2000, India.

Any other legislations or statutory requirements for this project must be considered during further planning and implementation of the project.
8 Process selection and dimensioning of the waste treatment plant

8.1 Chosen concept

In chapter 3 mechanical biological waste treatment processes (MBT) were identified as the most feasible waste treatment option for waste from West Zone, Bangalore. Later in chapter 5.5 the pre-decision was made that only aerobic MBT processes will be considered for the waste treatment plant.

Currently it is little known about the local market for output fractions from the MBT plant. Even less is known about the future development of these markets and about the change of waste properties. To be able to react to changing markets and waste properties, a very flexible concept of the MBT plant is the best option.

This flexibility is achieved by choosing a plant design that allows the classic production of compost like output and secondary solid fuels as well as doing biological drying and converting nearly all of the waste in a secondary fuel. The required machinery is very similar and the plant is designed in a way that it can be easily switched between both operation modes or even a combination of both.

The main difference lies in the operation mode of the biological treatment and a partly different sequence of the mechanical treatment aggregates. The following chapters describe the two operation modes separately as if there were two different MBT pants.

8.2 Waste Collection Development and Impact on the modular development of the MBT

Currently there is mixed waste collection in Bangalore. With the future implementation of a new waste collection system, increasing waste segregation is expected. This segregation affects the plant operation when it is run in compost production mode. In composting mode, the separately collected fractions are discharged on different heaps in the reception hall (flat bunker).

Hazardous waste will be directly discharged in an appropriate container.

Segregated wet (organic) waste will be accumulated daily as long (max. 1 day) as storage capacity is available. Then the plant is fed with the wet fraction only until the wet waste input heap is cleared. The fine output (<60mm) of the segregated wet waste mechanical processing will be put in a composting tunnel, that is only fed with segregated wet (organic waste). These tunnels have to be clearly marked to avoid mixing of compost from (comparatively clean) segregated wet waste and compost like material from mixed waste. The coarse fraction of this process (>60mm) will be put to the coarse fraction of the processing of the rest.

The rest is mechanically processed in the time before and after the mechanical processing of segregated wet waste is done. This fraction can be either processed for and by biological drying or composting and separation of a coarse fraction.

When the plant runs in full bio-drying operation (total waste input goes to bio-drying for solid fuel production), the segregated wet fraction can be mixed with the dry / mixed fraction, and segregation would not be required in this case.
8.3 Level of Automation

There are four main reasons for automation of major parts of the process:

- Workers health: Minimising contact between waste and workers
- Public health: Automation facilitates emission control
- Process efficiency: Increasing throughput (minimising retention time)
- Reliable output quality: Automated process control especially in biological treatment and sorting of output fractions

The waste will be fed in the process by a material handler. Moving the waste in the plant will be done by wheel loaders (biological treatment and reception hall) and conveyors (mechanical processing). All material separation steps are done mechanically (screen, wind sifters, magnetic metals separators, eddy current metal separators, optional sensor based optical sorting (NIR). Manual picking of waste components may only be done optionally for quality control and enhancement of output fractions. Moisture, temperature and aeration control of the biological treatment is computerised.

8.4 Bio-drying Process

The main objective of this process is to obtain a high quality secondary fuel such as RDF that can substitute primary fuels in industrial boilers, cement kilns, co-incineration plants, etc. Apart from RDF production, recyclables such as ferrous and non-ferrous metals, high quality plastics and contraries such as car batteries are separated during the operation. The treatment line is designed such that it is easy to switch to the composting operation if required. The overview of this process is shown in Figure 16.

The waste delivered waste is transferred to the bunkers by the waste collection and transfer trucks. There it can be selectively discharged (on heaps) depending on the type of waste. The first step involves removal of large contraries such as large batteries (not common in the current waste) by spreading the waste using a wheel loader or a grab so that larger hazardous components and pollutants are removed before further processing. These contraries need to be sent to appropriate recycling or disposal facilities. The waste is then loaded to shredders which reduce the particle size to about 150 mm. Shredding is also important to cut the ropes and other similar materials which can entangle the machinery in the MBT. A separate bag opener might not be required since shredding will open up the bags. The shredded output is then passed through an over belt magnetic separator to remove ferrous metals. The recovered metals are stored in separate containers and can be directly sent to recycling.

The waste is then fed into closed drying tunnels using wheel loaders where the waste is dried using exothermal heat from the intensive rotting of waste. The process typically takes about two weeks and the tunnels are operated to such that both composting and bio-drying processes can be accommodated. During this process, the organics are partially degraded. To remove fine mineral parts / inerts, etc. the output from bio-drying is passed through a (vibrating) screen of 20 mm screen diameter (in case of a one line plant this will be a graded 20 mm / 60 mm trommel screen like in compost operation).

The fine fraction after biological drying can be further processed through composting or directly used for various purposes in landfill construction depending on its characteristics and on demand for the material. The particles greater than 20mm are passed through another magnetic ferrous metal separator and afterwards through an eddy current separator which will extract the non-ferrous metals. The metals can be stored separately and directly sent for recycling.
The remaining fraction is then passed through a three fraction separating wind sifter that will separate the light, medium and heavy particles. The heavy particles will mostly be minerals and can be sent for landfill or for reuse as construction material. The light and medium fractions (potentially secondary fuel) can optionally be separately processed through optical sorting for removal of high quality plastics (for recycling), wood and unwanted components like PVC.

The optical sorting along with an additional quality control unit where negative sorting can be performed manually in an isolated cabin is optional and depends on many factors such as quality requirement by the RDF buyers, pollutant levels in this waste stream, cost of implementation, etc. Alternately, the recovered materials from the optical sorting process such as high quality plastics can be sent for recycling directly.
Figure 16: Process diagram for Bio-drying operation
8.5 Composting (rotting) process

The main objective of this alternative is to separate the (fine) organic fraction of the waste from the remaining coarse fraction and produce compost and a secondary fuel. The quality of the compost should be applicable for agricultural purposes or at least for land reclamation purposes. The secondary fuel can substitute primary fuels in industrial boilers, cement kilns, co-incineration plants, etc. Apart from these main products, recyclables such as ferrous and non-ferrous metals, high quality plastics and contraries are separated during the process. The treatment line is designed such that it is easy to switch to the Bio-drying operation if required. The overview of this process is shown in Figure 17.

The delivered waste is transferred to the bunkers by the waste collection and transfer trucks. There it can be selectively discharged (on heaps) depending on the type of waste. The first step involves removal of large contraries such as large batteries (not common in the current waste) by spreading the waste using a wheel loader or a grab so that larger hazardous components and pollutants are removed before further processing. These contraries need to be sent to appropriate recycling or disposal facilities. The waste is then loaded to a shredder that reduces the particle size to about 150 mm. This homogenises the waste, creates fresh surfaces for the biological process and opens bags. Shredding is also important to cut the ropes and other similar materials which can entangle the machinery in the MBT. The latter is the main reason for installing a shredder in this case. Alternately, after the removal of contraries, waste can be processed through a bag opener instead of shredding. In further progress of the plant design it should be evaluated, whether the high amount of ropes (remains from garlands, a special property of Indian waste) requires shredding / such fine shredding or if shredding can be avoided and replaced by a cheaper bag opener.

The output from the either of the above process is then passed through an over belt magnetic separator to remove ferrous metals. The recovered metals are stored in separate containers and can be directly sent to recycling. The waste is then processed through a screen of 60 mm size and the undersize and oversize particles are transferred to separate conveyors.

The <60 mm fraction is loaded into tunnels using wheel loaders where the waste is composted for about 4-6 weeks and the tunnels are built to such that both composting and bio-drying processes can be accommodated. During this process, the organics are degraded.

The composting output is transported under a magnetic separator and then an eddy current separator (currently optional, decision made after detailed calculation of the mass balance) to remove ferrous and non-ferrous metals that can be separated for recycling. This fraction is then passed through a 3 fraction separating wind sifter that will separate the light, medium and heavy particles.
Figure 17: Process diagram for Composting operation
The heavy particles will mostly be minerals and can be sent for landfill or for reuse as construction material (e.g. for roads on landfills). The middle fraction will be further screened to produce fine compost (<4 mm), medium compost (4-20 mm) and coarse compost (20-60 mm). The decision for a 4 mm fraction is only based on Indian regulations. Such a fine fraction is not common in other countries and will cause problems in practical screen operation (closing of screen holes). Deviation from this screening diameter should be discussed with the authorities due to other purification measures in the concept (wind sifter). The different grades of compost can be used for different purposes such as in agriculture, forestry, land reclamation, etc. based on the quality and legislative requirements for its use. It can also be upgraded with additives for reaching the fertilizer quality. The light fraction from the wind sifter can be handed to the secondary fuel stream and optionally processed through an optical sorter or manual quality control as described in the bio-drying section.

The waste fraction greater than 60 mm is transported through a magnetic separator and then an eddy current separator to remove ferrous and non-ferrous metals that can be separated for recycling. This fraction is then passed through a three fraction separating wind sifter that will separate the light, medium and heavy particles.

These fractions can be then be separately processed through optical sorting for removal of high quality plastics (for recycling), wood and unwanted components like PVC. The optical sorting along with and additional quality control unit where negative sorting can be performed manually in an isolated cabin is optional and depends on many factors such as quality requirement by the RDF buyers, pollutant levels in this waste stream, cost of implementation, etc. Alternately, the recovered materials from the optical sorting process such as high quality plastics can be sent for recycling directly. The heavy fraction from the wind sifter can be sent to landfill if it's mainly inert materials or minerals.

8.6 Construction of the aerobic biological treatment

8.6.1 Process options

To reach best process efficiency and minimise emission, aerobic biological treatment will be done in closed tunnels / boxes. This can be either done in concrete tunnels or membrane covered tunnel-like construction. The system decision will be done after cost calculation.

8.6.2 Tunnel processing

This enclosed system permits comparatively accurate control of the biological process by measuring key parameters like temperature, humidity and oxygen levels in the exhaust air. Process conditions can be tailored exactly to the stage of decomposition as each tunnel contains material of the exact same age. The material is turned upon input and removal. The rotting time is short as the parameters can be easily controlled. Figure 18 shows a tunnel processing unit.
8.6.3 Membrane covered processing

Semi-permeable membrane covers (for example GOREtex®) are a hybrid form of tunnel or in-vessel composting on the one hand, and covered windrow composting on the other. The semi-permeable membrane cover, which is water-resistant but also permeable to gas and steam, prevents water logging. The cover and the active aeration it provides should create process conditions under which odours, VOCs and other emissions are largely contained.
Investigations published by *BGK* (2010) demonstrated that the level of emissions from membrane covered composting plants is equal or often lower than emissions from conventional biofilters.

The BGK documented emissions based upon the installation's degree of encapsulation, as shown in Table 8.

**Table 8: Grouping into types of processes in BGK 2010**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Type of process variations</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1</td>
<td>Enclosed composting</td>
</tr>
<tr>
<td>V2</td>
<td>Partially enclosed composting</td>
</tr>
<tr>
<td>V3</td>
<td>Composting under a semi-permeable membrane</td>
</tr>
<tr>
<td>V4</td>
<td>Open-air composting of organic waste (biowaste bin) together with green waste</td>
</tr>
<tr>
<td>V5</td>
<td>Open-air composting of green waste</td>
</tr>
</tbody>
</table>

It is apparent that the variations within a single process are greater than the variations from one process to the next (*BGK*, 2010). The varying emission outputs are plotted in Figure 21 to Figure 26.
Figure 21: Average emission factors for ammonia (NH$_3$) in g/t input material from composting
Note: Processes as shown in Table 8 (BGK, 2010)

Figure 22: Average emission factors for nitrous oxide (N$_2$O) in g/t input material from composting
Note: Processes as shown in Table 8 (BGK, 2010)
Figure 23: Average emission factors for total carbon (TOC) in g/t input material from composting
Note: Processes as shown in Table 8 (BGK, 2010)

Figure 24: Average emission factors for non-methane volatile organic compounds (NMVOC) in g/t input material from composting
Note: Processes as shown in Table 8 (BGK, 2010)
As MBT (mixed waste) and organic waste composting processes are very similar, it can be assumed that membrane covers also provide good conditions for the process and emission control of MBT processes. In fact, membrane covers are applied in several MBT plants (MBT prior to landfill) in Germany and other European countries. They are successfully applied also in a German MBT plant with biological drying.
However, the higher moisture content of Indian waste and the partly lower difference of the ambient temperature and the temperature in the windrow are more challenging to the membrane process (the temperature difference is required for water diffusion through the membrane). Currently, two large MSW biodrying plants (2,000 t/d) are operating in the Mediterranean area (Turkey and southern Italy), where temperatures are higher than in Germany.

The main advantages and disadvantages of the membrane covered windrows are

+ No (bio) filter required for exhaust air
+ Less waste water
+ Potentially lower costs for operation and construction
- Less durable (e.g. replacement of membranes)
- Longer treatment time due to lower air flow
- Higher demand of area due to longer treatment
- Higher risk of leakages

Table 9 compares membrane covered windrows to tunnels.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Membrane technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area demand</td>
<td>higher</td>
</tr>
<tr>
<td>Duration of treatment</td>
<td>longer</td>
</tr>
<tr>
<td>Amount of wastewater</td>
<td>less</td>
</tr>
<tr>
<td>Other material streams</td>
<td>no change</td>
</tr>
<tr>
<td>Process stability</td>
<td>less control, more dependent of weather conditions</td>
</tr>
<tr>
<td>Staff requirements</td>
<td>Equal or more</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>no change or less</td>
</tr>
<tr>
<td>Other operating resources</td>
<td>Higher (replacement of membranes)</td>
</tr>
<tr>
<td>maintenance</td>
<td>no change or less</td>
</tr>
<tr>
<td>Investment and capital costs</td>
<td>potentially less, but higher area demand</td>
</tr>
<tr>
<td>Treatment costs, total costs MBT</td>
<td>potentially less</td>
</tr>
</tbody>
</table>

8.7 Exhaust gas treatment

The facility will be enclosed to minimise odour emissions by capturing and purifying exhaust air. Exhaust air (technically exhaust gas) will be treated by a wet scrubber if required, and afterwards a biofilter. As much as possible air from the mechanical treatment will be used to aerate the biological treatment tunnels. In case of using the membrane technology, the exhaust gas from the biological treatment requires no treatment. The part of the exhaust gas from mechanical treatment, that is not used to feed
the biological treatment, requires dust removal, but a smaller biofilter to avoid odour emissions from waste discharge, bunkers and mechanical treatment would be still recommended.

8.8 Waste water treatment, water balance

Waste water from the process will be used to moistenise the waste in the biological processing. In general, the aerobic process requires water and loses water on the exhaust air path. Due to the high moisture content of the waste, a comparatively high air throughput will be applied. For intermediate storage, a process water buffer tank is considered.

8.9 Plant dimensions

The West Zone of Bangalore produces 267,000 t of waste annually. This could either be treated in a large two line facility, or in 2–3 smaller, decentralised units. The decentralised option will be more expensive in construction and operation, but may reduce costs and effort for collection (transfer) and transport. In this project, a 91,000 t/a unit is recommended for initial evaluations. That means that the total amount of money spent initially will be less. More important, it allows verifying assumptions and obtaining locally full scale operational experience, before spending money for the treatment of the total amount of waste. In contrast to a larger plant, setting up two process lines would be too expensive as there is machinery available that can cover this amount with just one line. The mode of the Plant (machine sequence and operation mode of the biological treatment) can be switched between rotting (composting) and biological drying. The MBT plant will separate the biological and mechanical processes in different halls, in order to optimize the aeration management, to maintain fire and safety standards and to keep the plant design flexible to changing framework conditions.

8.10 Mass balance and properties of the output fractions

8.10.1 Operation mode

The MBT plant’s design is based upon the following framework data:

- Delivery volume: 91,000 t/a of municipal solid waste (Door-to-Door (D2D) collection, litter spots (LS) and street sweeping (SS), 50%:30%:20%)
- Daily throughput: 249 t/d
- Delivery time: 365 d/a, 16 h/d
- Time of operation: 365 d/a, 14 h/d (2 shifts per day)
- Maintenance during operation (if possible) or at night shift / end of day shift.

8.10.2 Moisture in Bangalore waste

The study is based upon a waste composition of Door-to-Door (D2D) collection, litter spots (LS) and street sweeping (SS) of 50%:30%:20%. The moisture contents shown in Table 3 would lead to an overall moisture content of round about 43 mass-% related to the wet matter. This low moisture content might be explained due to moisture loss (drying at warm air temperature) during the waste sorting process in the waste characterisation study. Based on our experience, the overall moisture content of that kind of waste will be between 50 and 55% or even more. Hence, we did not use the moisture values from the waste characterisation study and set (increased) the expected moisture content to 50 %.
The study estimates an average loss on ignition (oDM) of 37 % in relation to fresh mass. The level of inert material (mDM) averages 13 % (Figure 27).

The relative high water content (compared to central European waste) requires a customised treatment concept for the MBT facility. The study takes this factor into account both from a technical and design standpoint.

![Pie chart showing moisture, organic dry matter (oDM), and mineral dry matter (mDM) in Bangalore waste](image)

Figure 27: Moisture, Organic dry matter (oDM) and mineral dry matter (mDM) in Bangalore waste

### 8.10.3 Calorific value in Bangalore waste

The waste analyses reveal a gross calorific value averaging 8.1 MJ/kg for waste composition of Door-to-Door (D2D) collection, litter spots (LS) and street sweeping (SS) of 50%:30%:20% (see chapter 2.6).

Based on this the following estimations presume a lower calorific value of the input waste averaging 7.0 to 7.5 MJ/kg.

### 8.10.4 Size distribution of Bangalore waste

For the size distribution of the waste input to the MBT-plant see chapter 2.2.

According to the process concept after removal of contraries pre-shredding of the delivered waste is presupposed. By this, the size distribution is shifted to a higher portion of small particles. As consequence the fraction < 60 mm from the first screening step (while composting operation) will be significantly higher than estimated based on the size distribution of the non-shredded waste.

The data for the non-shredded waste lead to a portion < 60 mm of approx. 55 %. For the shredded waste a higher level of 65 to 70 % is assumed for mass balancing.
8.10.5 Mass balance and output qualities

Material streams and mass balances were calculated for the two MBT operation concepts based on the waste composition (Figure 28 and Table 10):

### Figure 28: Calculated mass balances of MBT

### Table 10: Mass balance of MBT (output)

<table>
<thead>
<tr>
<th>Output t/y</th>
<th>Composting operation</th>
<th>Bio-drying operation</th>
<th>Use/discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contraries</td>
<td>400</td>
<td>400</td>
<td>Waste incineration</td>
</tr>
<tr>
<td>metals (ferrous and non-ferrous)</td>
<td>300</td>
<td>300</td>
<td>recycling</td>
</tr>
<tr>
<td>RDF middle</td>
<td>22,300</td>
<td>19,700</td>
<td>Thermal utilization</td>
</tr>
<tr>
<td>RDF light</td>
<td>9,800</td>
<td>5,500</td>
<td>Thermal utilization</td>
</tr>
<tr>
<td>Compost &lt; 4 mm</td>
<td>4,600</td>
<td>-</td>
<td>Agricultural utilization</td>
</tr>
<tr>
<td>Compost 4–20 mm</td>
<td>11,000</td>
<td>-</td>
<td>Agricultural utilization</td>
</tr>
<tr>
<td>Compost 20–60 mm</td>
<td>2,800</td>
<td>-</td>
<td>Agricultural utilization</td>
</tr>
<tr>
<td>Fine fraction (dry) for composting</td>
<td>-</td>
<td>18,300</td>
<td>Composting (agricultural utilization) or landfill</td>
</tr>
<tr>
<td>Solid residues (heavy fraction)</td>
<td>5,300</td>
<td>2,200</td>
<td>landfill</td>
</tr>
<tr>
<td>Mass and water loss</td>
<td>34,500</td>
<td>44,600</td>
<td>Exhaust air treatment, atmosphere</td>
</tr>
<tr>
<td>Total</td>
<td>91,000</td>
<td>91,000</td>
<td></td>
</tr>
</tbody>
</table>
In the Bio-drying mode nearly 100 % of incoming waste passes through the drying process (2-3 weeks in tunnels) with a target water content of 20 % (average) after drying. In the Composting mode the treatment time is estimated to 4 weeks in tunnels (intensive rotting) and subsequent 4 weeks post-rotting (maturation). Ca. 68 % of incoming waste (fine fraction < 60 mm) pass through the biological part of the composting process. The water content in the output of post-rotting averages ca. 30 %.

It is assumed that generation of wastewater has to be avoided during regular plant operation. To fulfil this requirement, comparatively high amounts of air are needed in the biological process.

When looking at the mass balance, special attention should be paid to how the high amounts of water in waste are handled. For this purpose mass flow according to the concepts for plant operation is estimated and examined in more details (Figure 29 and Figure 30):
Figure 29: Calculated mass flow for composting operation
The authors' own models for biological degradation, including air, water and heat balances, were drawn on to calculate the expected average breakdown of water content, loss on ignition (oDM) and inert materials (mDM) from incoming waste into the resulting material streams for the evaluated MBT techniques. Due to remaining uncertainties in waste composition and normal seasonal variations of waste characteristics estimated values are given as ranges (Table 11):
Table 11: Characterization of MBT-output

<table>
<thead>
<tr>
<th>Input/output streams</th>
<th>Dry matter content [% of OM]</th>
<th>Organic dry matter content [% of DM]</th>
<th>Lower calorific value [MJ/t]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste input</td>
<td>50,0</td>
<td>74,7</td>
<td>7,000-7,500</td>
</tr>
<tr>
<td>Both operation concepts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contraries</td>
<td>55-65</td>
<td>70-80</td>
<td>10,000-13,000</td>
</tr>
<tr>
<td>metals (ferrous and non-ferrous, incl. impurities)</td>
<td>90-100</td>
<td>0-20</td>
<td>0-4,000</td>
</tr>
<tr>
<td>Composting operation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RDF middle</td>
<td>50-60</td>
<td>75-85</td>
<td>9,000-13,000</td>
</tr>
<tr>
<td>RDF light</td>
<td>60-70</td>
<td>80-90</td>
<td>11,000-14,000</td>
</tr>
<tr>
<td>Compost &lt; 4 mm</td>
<td>65-75</td>
<td>40-50</td>
<td>4,500-6,500</td>
</tr>
<tr>
<td>Compost 4-20 mm</td>
<td>60-70</td>
<td>60-70</td>
<td>5,500-7,500</td>
</tr>
<tr>
<td>Compost 20-60 mm</td>
<td>70-80</td>
<td>60-70</td>
<td>7,500-9,500</td>
</tr>
<tr>
<td>Solid residues (heavy fraction)</td>
<td>65-75</td>
<td>30-40</td>
<td>3,500-5,000</td>
</tr>
<tr>
<td>Bio-drying operation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RDF middle</td>
<td>75-85</td>
<td>75-85</td>
<td>13,000-17,000</td>
</tr>
<tr>
<td>RDF light</td>
<td>80-90</td>
<td>80-90</td>
<td>16,000-20,000</td>
</tr>
<tr>
<td>Fine fraction (dry) for composting</td>
<td>70-80</td>
<td>50-60</td>
<td>6,000-8,000</td>
</tr>
<tr>
<td>Solid residues (heavy fraction)</td>
<td>80-90</td>
<td>35-45</td>
<td>4,500-6,000</td>
</tr>
</tbody>
</table>

It is especially noticeable that the RDF fractions from composting operation have a higher water content compared to bio-drying operation. This results in a higher proportion of mass and a lower calorific value.

8.10.6 Energy balance

The annual calorific load is calculated at ca. 185,000 MWh/a assuming an average lower calorific value of ca. 7,300 MJ/t for incoming MSW. The following image shows how this breaks down into material streams for the MBT operation modes evaluated here (Figure 31):
The estimated combinations of mass breakdown and energy content in the output streams lead to nearly identical energy breakdowns for Composting and Bio-Drying operations. The main difference between the operation modes is, that output fractions from bio-drying are drier compared to composting. Hence, total mass of RDF from bio-drying is significantly lower and calorific values are higher.

8.10.7 Biological treatment and wastewater

The balance for bio-drying and for the first composting step ("intensive rotting") is based upon an enclosed and completely encapsulated tunnel process with air recirculation. Any exhaust air from the process is collected by pipes and treated by air scrubbers and biofilters and then discharged to the atmosphere.

Exhaust air from the process will be largely water-saturated and most of the water will leave the process as steam with the exhaust air. Transporting and treating exhaust air effects cooling of the air. However, cooling of exhaust air might generate some condensate, depending on weather conditions, amount of process air and water content of waste input. This condensate has to be collected in the process water system. Assuming high amounts of process air, during regular operation the collected
water can be completely fed to the tunnel process again and no excess of process water has to be discharged or treated as wastewater.

In addition, other techniques for bio-drying or composting allow exhaust air from the process to be released into the environment without treatment by virtue of membrane cover filtration (membrane techniques). However, if odour emissions have to be considered carefully, also for membrane techniques a housing and exhaust air capture and treatment might be necessary due to emissions during windrow turning. Depending on climate, at least a roof can be required for membrane processes for protection against rain for example.

For composting operation a post-rotting process is necessary in addition to intensive rotting to produce mature compost. For post-rotting triangular windrows turned by a windrow turner (see above) are considered in a closed hall with exhaust air capture. Design of housing and air management for the post-rotting process mainly depends on local requirements concerning odour emissions. Instead of a closed hall a roofed area without exhaust air capture also can be an adequate solution. Alternatively membrane technique can be used for post rotting, too.

8.10.8 Exhaust air

Fresh air is basically used to provide a healthy environment for the workers and to conduct heat and moisture out of the waste. In order to fulfil those functions, big amounts of air will be required. Therefore we calculate approx. 60,000 m³/h for reception, mechanical treatment and tunnel hall, and another 90,000 m³/h for post-rotting.

Considering reutilization of not water saturated exhaust air from all waste treatment phases (reception, mechanical treatment and biological treatment) we expect air exchange-rates of up to 2 times per hour in reception, mechanical treatment and tunnel hall, and of 1.5 times per hour at post-rotting. Depending on operation intensity, air exchange-rates can be switched to a lower level in post-rotting and to a higher level in reception, mechanical treatment and tunnel hall. The exhaust air finally treated and released to the environment amounts to approx. 150,000 m³/h. Figure 32 pictures a basic concept of the air flow management in Bangalore.
Figure 32: Concept of exhaust air flow

- MT II 30,000 m³/h Reception + MT I
- Tunnel hall 60,000 m³/h Post-rotting
- Tunnel process 60,000 m³/h
- Biofilter I 60,000 m³/h Biofilter II 90,000 m³/h
- Atmosphere 150,000 m³/h
- Exhaust air treatment
- Acid scrubber
- Option: bypass for Bio-drying operation

- Fresh air
- Deduster
- Ventilator

- Fresh air
- Ventilator
8.11 Area and infrastructural demand

8.11.1 Area demand

The area demand for both concepts of MBT operation was estimated approximately based upon a rough design concept and key figures (Table 12).

Table 12: Estimated area demand

<table>
<thead>
<tr>
<th>Area demand in m²</th>
<th>Composting operation</th>
<th>Bio-drying operation</th>
<th>comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reception + Mechanical treatment I (MT I)</td>
<td>1,800</td>
<td>1,800</td>
<td>Closed hall</td>
</tr>
<tr>
<td>Intensive rotting or biological drying (tunnel process)</td>
<td>5,700</td>
<td>5,700</td>
<td>Closed hall</td>
</tr>
<tr>
<td>Post-rotting (triangular windrows)</td>
<td>6,000</td>
<td>-</td>
<td>Closed hall or roofed area; Post-rotting is not required for Bio-drying operation</td>
</tr>
<tr>
<td>Mechanical treatment II (MT II) (incl. loading of output)</td>
<td>3,000</td>
<td>3,000</td>
<td>Closed hall</td>
</tr>
<tr>
<td>Exhaust air treatment</td>
<td>2,500</td>
<td>2,500</td>
<td>Paved area</td>
</tr>
<tr>
<td>Auxiliary buildings</td>
<td>100 - 200</td>
<td>100 - 200</td>
<td>Control room, Repair shop, social rooms as required</td>
</tr>
<tr>
<td>Sum Buildings</td>
<td>19,200</td>
<td>13,200</td>
<td></td>
</tr>
<tr>
<td>Infrastructure, transport</td>
<td>14,500</td>
<td>12,100</td>
<td>Mainly paved area</td>
</tr>
<tr>
<td>Total MBT</td>
<td>33,700</td>
<td>25,300</td>
<td></td>
</tr>
</tbody>
</table>

The differences between the two options are essentially linked to the fact that composting operation requires additional space for post-rotting. The total area demand without post-rotting is identical, assuming that switching between both modes of operation shall be possible.

The total area demand including infrastructural installations is estimated to ca. 34,000 m² for composting operation and ca. 26,000 m² for biological drying. Hence area needed for post-rotting can be estimated to ca. 8,000 m².

For the plant layout main and auxiliary buildings are arranged in one possible configuration (optimized for process flow and area demand). Areas for technical equipment that can be located outside are also considered and necessary ways and areas for container handling, transportation and parking are included.

The configuration and footprints of buildings can be varied and presumably have to be varied during further planning steps according to local conditions and modifications in project tasks.

The proposed plant layout is shown in Figure 33 to Figure 35.
Figure 33: Overview of the proposed plant layout MBT (incl. post-rotting / maturation)
Figure 34: Layout waste reception and mechanical treatment

Abbreviations:
WS - windscreener
Fe - magnetic separator
NF - eddy current separator
BF - box feeder
PS - pre-shredder
FS - fine-shredder
OS - optical sorting
QC - quality control
C1-3 - compost fraction
Figure 35: Layout biological treatment
8.11.2 Infrastructural demand

Table 13 below summarises the main requirements for MBT in terms of external infrastructure (interfaces):

Table 13: Infrastructural demand / interfaces

<table>
<thead>
<tr>
<th>Interface</th>
<th>Composting operation</th>
<th>Bio–drying operation</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access to road, scales for trucks</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Check for hazardous waste and separation (prior to entering MBT-process)</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Power supply (MV)</td>
<td>ca. 1.5 MW</td>
<td>ca. 1.5 MW</td>
<td></td>
</tr>
<tr>
<td>Cont. access to landfill capacity</td>
<td>ca. 5,300 t/y</td>
<td>ca. 2,200 t/y</td>
<td></td>
</tr>
<tr>
<td>Cont. access to incineration capacity (RDF)</td>
<td>ca. 32,100 t/y</td>
<td>ca. 25,200 t/y</td>
<td></td>
</tr>
<tr>
<td>Incineration capacity for hazardous waste and contraries</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Cont. access to composting capacity</td>
<td>-</td>
<td>ca. 18,300 t/y</td>
<td>For fine fraction from Bio–drying (altern. landfill)</td>
</tr>
<tr>
<td>Cont. access to compost utilization</td>
<td>ca. 18,400 t/y</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Discharge of rainwater</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Discharge or treatment of wastewater</td>
<td>(-)</td>
<td>(-)</td>
<td>Excess of process water may occur at unfav. operation conditions</td>
</tr>
<tr>
<td>Diesel supply (filling station)</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Drinking water supply</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Fire water supply</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Access to public data/phone network</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Emergency power supply</td>
<td>X</td>
<td>X</td>
<td>recommended for tunnel process</td>
</tr>
</tbody>
</table>

Compared to composting the bio–drying process yields a lower mass of high–calorific material and a smaller quantity of residues to be landfilled (assuming that fine fraction from bio–drying can be placed in a composting plant).

Post–rotting as part of composting operation includes a windrow turner and a wheel loader. Active aeration of the triangular windrows is normally not necessary subsequent to 4 weeks of intensive rotting. Hence the post–rotting process is planned without process aeration. Due to this, power consumption of post–rotting can be seen as nearly negligible.

For both concepts an emergency power supply is recommended to operate crucial processes (aeration of tunnel process) in case of power breakdown.
8.12 Machine equipment

The description of the main processes is given in previous chapters. Details of the proposed process equipment are shown in Table 14.

Table 14: Main process equipment – Reception, MT I and MT II

<table>
<thead>
<tr>
<th>component</th>
<th>location</th>
<th>number</th>
<th>Throughput Composting operation</th>
<th>Throughput Bio-drying operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grab excavator</td>
<td>Reception</td>
<td>1</td>
<td>18 t/h</td>
<td>18 t/h</td>
</tr>
<tr>
<td>Wheel loader</td>
<td>Reception</td>
<td>1</td>
<td>18 t/h</td>
<td>18 t/h</td>
</tr>
<tr>
<td>Pre-shredder</td>
<td>Reception</td>
<td>1</td>
<td>18 t/h</td>
<td>18 t/h</td>
</tr>
<tr>
<td>Box-feeder</td>
<td>Reception</td>
<td>1</td>
<td>(reserve)</td>
<td>(reserve)</td>
</tr>
<tr>
<td>Magnetic separator</td>
<td>MT I</td>
<td>1</td>
<td>18 t/h</td>
<td>18 t/h</td>
</tr>
<tr>
<td>Drum screen</td>
<td>MT I</td>
<td>1</td>
<td>18 t/h</td>
<td></td>
</tr>
<tr>
<td>Vibrating screen</td>
<td>MT II</td>
<td>1</td>
<td>6 t/h</td>
<td>9 t/h</td>
</tr>
<tr>
<td>Magnetic separators</td>
<td>MT II</td>
<td>3 (2)*</td>
<td>6 t/h (each)</td>
<td>6 t/h (each)</td>
</tr>
<tr>
<td>Eddy current separators</td>
<td>MT II</td>
<td>2 (1)*</td>
<td>6 t/h (each)</td>
<td>6 t/h (each)</td>
</tr>
<tr>
<td>Wind sifter</td>
<td>MT II</td>
<td>2 (1)*</td>
<td>6 t/h (each)</td>
<td>6 t/h (each)</td>
</tr>
<tr>
<td>Compost screen</td>
<td>MT II</td>
<td>1</td>
<td>4 t/h</td>
<td></td>
</tr>
<tr>
<td>Dust filter</td>
<td>MT II</td>
<td>1</td>
<td>ca. 30,000 m³/h</td>
<td>ca. 30,000 m³/h</td>
</tr>
<tr>
<td>Ventilator (hall)</td>
<td>MT II</td>
<td>1</td>
<td>ca. 60,000 m³/h</td>
<td>ca. 60,000 m³/h</td>
</tr>
</tbody>
</table>

*for bio-drying operation the compost-line is not in use

Table 15: Main process equipment – Optional components MT II

<table>
<thead>
<tr>
<th>component</th>
<th>location</th>
<th>number</th>
<th>Throughput Composting operation</th>
<th>Throughput Bio-drying operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIR-Sorter (optical sorting)</td>
<td>MT II</td>
<td>2</td>
<td>5 t/h (each)</td>
<td>5 t/h (each)</td>
</tr>
<tr>
<td>Manual sorting boxes</td>
<td>MT II</td>
<td>2</td>
<td>3 t/h (each)</td>
<td>3 t/h (each)</td>
</tr>
<tr>
<td>Fine shredder</td>
<td>MT II</td>
<td>2</td>
<td>5 t/h (each)</td>
<td>5 t/h (each)</td>
</tr>
</tbody>
</table>
Table 16: Main process equipment – Intensive rotting/Bio-drying and post-rotting

<table>
<thead>
<tr>
<th>component</th>
<th>location</th>
<th>number</th>
<th>Throughput Composting operation</th>
<th>Throughput Bio-drying operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tunnel-composting, tunnels</td>
<td>Intensive rotting/bio-drying</td>
<td>18</td>
<td>Treatment time: 4 weeks; max. 450 m$^3$/h waste per tunnel</td>
<td>Treatment time: 2-3 weeks; max. 450 m$^3$/h waste per tunnel</td>
</tr>
<tr>
<td>Tunnel-ventilators</td>
<td>Intensive rotting/bio-drying</td>
<td>18</td>
<td>max. 15,000 m$^3$/h (each)</td>
<td>max. 15,000 m$^3$/h (each)</td>
</tr>
<tr>
<td>Processwater storage</td>
<td>Intensive rotting/bio-drying</td>
<td>1</td>
<td>Capacity: ca. 200 m$^3$</td>
<td>Capacity: ca. 200 m$^3$</td>
</tr>
<tr>
<td>Wheel loader</td>
<td>Intensive rotting/bio-drying</td>
<td>1</td>
<td>Input: 12 t/h; Turning: 20 t/h; Output: 7 t/h</td>
<td>Input: 18 t/h; Turning: 15 t/h; Output: 9 t/h</td>
</tr>
<tr>
<td>Box-feeder</td>
<td>Intensive rotting/bio-drying</td>
<td>1</td>
<td>7 t/h</td>
<td>9 t/h</td>
</tr>
<tr>
<td>Ventilator (hall)</td>
<td>Intensive rotting/bio-drying</td>
<td>1</td>
<td>ca. 60,000 m$^3$/h</td>
<td>ca. 60,000 m$^3$/h</td>
</tr>
<tr>
<td>Dust filter</td>
<td>Intensive rotting/bio-drying</td>
<td>1</td>
<td>ca. 60,000 m$^3$/h</td>
<td>ca. 60,000 m$^3$/h</td>
</tr>
<tr>
<td>Post-rotting (8 triangular windrows)</td>
<td>Post-rotting</td>
<td>1</td>
<td>Treatment time: 4 weeks; max. 550 m$^3$/h waste per windrow</td>
<td>-</td>
</tr>
<tr>
<td>Windrow turner</td>
<td>Post-rotting</td>
<td>1</td>
<td>(max.) 4,000 m$^3$/h</td>
<td>-</td>
</tr>
<tr>
<td>Wheel loader</td>
<td>Post-rotting</td>
<td>1</td>
<td>40 t/h (input + output)</td>
<td>-</td>
</tr>
<tr>
<td>Box-feeder</td>
<td>Post-rotting</td>
<td>1</td>
<td>6 t/h</td>
<td>-</td>
</tr>
<tr>
<td>Ventilator (hall)</td>
<td>Post-rotting</td>
<td>1</td>
<td>ca. 80,000 m$^3$/h</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 17: Main process equipment – Exhaust air treatment

<table>
<thead>
<tr>
<th>component</th>
<th>location</th>
<th>number</th>
<th>Throughput Composting operation</th>
<th>Throughput Bio-drying operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid scrubber</td>
<td>Exhaust air treatment</td>
<td>2</td>
<td>ca. 75,000 m$^3$/h (each)</td>
<td>ca. 75,000 m$^3$/h (each)</td>
</tr>
<tr>
<td>Ventilator</td>
<td>Exhaust air treatment</td>
<td>2</td>
<td>ca. 75,000 m$^3$/h (each)</td>
<td>ca. 75,000 m$^3$/h (each)</td>
</tr>
<tr>
<td>Biofilter</td>
<td>Exhaust air treatment</td>
<td>2</td>
<td>ca. 75,000 m$^3$/h (each)</td>
<td>ca. 75,000 m$^3$/h (each)</td>
</tr>
</tbody>
</table>

Compared to bio-drying, composting operation needs some more equipment especially for post-rotting and for screening (MT I and II).

8.13 Costs

8.13.1 Estimation of investment costs

The estimated costs are net costs as EURO (€) without tax, including design, construction, commissioning, instruction, test operation, regular documentation and common warranties.

Following costs are not included:

- Costs for area
- Costs for land development outside of the plant area
- Costs for special foundation measures (due to abnormal ground quality or seismic risks)
- Costs for waste incineration

Remark to cost estimation

The cost estimations are based on:

- Executed projects of equivalent plants in Central Europe
- Costs investigated in studies of central-European waste treatment plants
- Reference facility information of suppliers
- Costs for hall constructions approaching to Indian prices (2,000 Rs. per square feet or 287 €/m$^2$ respectively)

With regard to the available information we increased the confidence of the estimated costs. However because of ongoing development of market and maybe regional differences there is still a significant uncertainty. Rising of material prices, increasing demand and limitation of suppliers capacities might cause exceptional rising of prices.

8.13.2 Investment costs

Preliminary estimation of investment costs includes buildings, machine technology, electrical equipment (power supply and automatic control system), vehicles for internal transport, outside facilities, costs for planning and commissioning by a general contractor (Table 18). Ancillary construction costs and costs of financing are not considered.

The investment costs are calculated including a post-rotting step for composting operation and considering the option to switch between composting and bio-drying operation with very low effort. All technical equipment for both operation modes is included. Also included are the costs for the required building area for optional components in mechanical treatment (optical sorting, fine shredding, quality control).

The additional machine and electrical equipment for the optional components is considered separately (see last line of Table 18).
Table 18: Investment costs MBT in Euro (composting operation)

<table>
<thead>
<tr>
<th>Investment costs [€]</th>
<th>Machine equipment (normal strain)</th>
<th>Machine equipment (high strain)</th>
<th>Electrical equipment</th>
<th>Buildings</th>
<th>Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reception/Mechanical treatment</td>
<td>2,738,000</td>
<td>347,000</td>
<td>463,000</td>
<td>1,541,000</td>
<td>576,000</td>
</tr>
<tr>
<td>Tunnel process (intensive rotting or biological drying)</td>
<td>1,708,000</td>
<td>-</td>
<td>275,000</td>
<td>4,641,000</td>
<td>157,000</td>
</tr>
<tr>
<td>Post-rotting (only for Composting)</td>
<td>386,000</td>
<td>-</td>
<td>39,000</td>
<td>1,260,000</td>
<td>473,000</td>
</tr>
<tr>
<td>Exhaust air treatment</td>
<td>1,478,000</td>
<td>-</td>
<td>148,000</td>
<td>504,000</td>
<td>-</td>
</tr>
<tr>
<td>Outside facilities</td>
<td></td>
<td></td>
<td></td>
<td>1,087,000</td>
<td></td>
</tr>
<tr>
<td>Planning and commissioning (General contractor)</td>
<td>664,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total MBT</td>
<td></td>
<td></td>
<td></td>
<td>18,485,000</td>
<td></td>
</tr>
<tr>
<td>thereof Post-rotting</td>
<td></td>
<td></td>
<td></td>
<td>2,158,000</td>
<td></td>
</tr>
<tr>
<td>Additional investment costs for optional components</td>
<td>1,839,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The total investment costs (w/o optional components) result in specific investment costs of ca. 203 €/t. This is at the lower end of comparable plants in Central Europe, mainly due to hall construction costs, which we have calculated approaching to Indian prices. Regarding machine technology, quality equipment is considered based on Central European price level.

In principle it has to be stated, that delivery time and time of plant operation (7 days per week, 2 shifts) are comparatively long in relation to amount of incoming waste. Hence low treatment capacities and throughputs of machine equipment are needed in the present case. This leads to higher investment costs specific to throughput, because specific investment costs of machine equipment are higher for equipment with low throughput. Regarding total costs, a shorter time of plant operation combined with higher throughputs of machine equipment might save costs.

8.13.3 Investment costs of membrane technique

For Bio-drying operation, instead of 2–3 weeks biological treatment in tunnels, 4 weeks treatment with membrane technique can be an alternative. Due to expected odour emissions during windrow turning, housing is calculated for the required area for a concept with membrane technique (approx. 8,000 m², rough estimation based on supplier data). Combined with investment costs for process technology, Bio-drying by membrane technique might save 10 to 15 % of investment costs of total MBT in the present case.

For Composting operation 9 weeks treatment with membrane technique and a required area of approx. 12,000 m² were specified by the supplier. Taking into consideration additional costs for housing total MBT investment might be up to 20 % lower compared to the conventional concept described above (4 weeks of intensive rotting in tunnels + 4 weeks post-rotting using triangular windrows). It has to be mentioned, that membranes have to be replaced after a few years of operation.

However confidence in the estimated costs of membrane technique is not as high as for conventional techniques, due to lack of own data from realized membrane projects.
8.13.4 Staff and operation resources

Required staff

For operation and maintenance of the MBT-plant several efforts have to be considered. Due to operation time (see above) for estimation of the required staff operation with 2 shifts at 7 days a week has to be taken into account. Normal working time in India is set to 5 days per week and 9 h/d.

Replacement for holidays and illness is not considered in the following estimation. For MBT-plants in Central Europe replacement is calculated as additional 15 to 30 % of required staff.

Table 19: Staff requirement

<table>
<thead>
<tr>
<th>Function</th>
<th>Composting operation</th>
<th>Bio-drying operation</th>
<th>comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant manager</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Shift manager</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Operators (mechanic, electrician)</td>
<td>8</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Drivers</td>
<td>13</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Helpers</td>
<td>6</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>30</td>
<td>27</td>
<td>w/o replacement, w/o options</td>
</tr>
<tr>
<td>Optional: Helpers for manual sorting/quality control</td>
<td>6</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

Operation resources and maintenance

Electrical power and Diesel are the most important operation resources for the described MBT concept. Diesel and tap water consumption are significantly lower for bio-drying operation compared to composting operation.

Table 20: operation resources (consumption)

<table>
<thead>
<tr>
<th>Resource (specific values per t of waste input)</th>
<th>Composting operation</th>
<th>Bio-drying operation</th>
<th>comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power (electricity)</td>
<td>ca. 45 kWh/t</td>
<td>ca. 43 kWh/t</td>
<td></td>
</tr>
<tr>
<td>Diesel</td>
<td>ca. 2.0 l/t</td>
<td>ca. 1.3 l/t</td>
<td>vehicles</td>
</tr>
<tr>
<td>Tap water (maybe rain water, if available)</td>
<td>ca. 0.1 m³/t</td>
<td>ca. 0.03 m³/t</td>
<td>biological process</td>
</tr>
<tr>
<td>Sulfuric acid</td>
<td>ca. 0.003 m³/t</td>
<td>ca. 0.003 m³/t</td>
<td>exhaust air treatment</td>
</tr>
<tr>
<td>Oil, grease etc.</td>
<td>0,02 kg/t</td>
<td>0,02 kg/t</td>
<td></td>
</tr>
<tr>
<td>miscellaneous</td>
<td>-</td>
<td>-</td>
<td>Add. 10 % of costs for operation resources</td>
</tr>
</tbody>
</table>

In German MBT-plants exhaust air treatment often includes RTO-technology (regenerative thermal oxidation) to reduce emissions according to legislation. In this case significant amounts of natural gas or biogas are needed as additional resource. For the present exhaust air treatment concept just using biofilters gas supply is not necessary.

Costs for maintenance can be defined by specific values for installation. The factors depend on the kind of equipment, operation time and intensity of wear and tear:
Table 21: specific values for maintenance (% p. a. of investment costs)

<table>
<thead>
<tr>
<th>equipment</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical equipment normal strain</td>
<td>4–5 % p. a.</td>
</tr>
<tr>
<td>Mechanical equipment high strain</td>
<td>8–10 % p. a.</td>
</tr>
<tr>
<td>Electrical equipment</td>
<td>2.5–4 % p. a.</td>
</tr>
<tr>
<td>Vehicles</td>
<td>10–15 % p. a.</td>
</tr>
<tr>
<td>Buildings</td>
<td>1–1.5 % p. a.</td>
</tr>
<tr>
<td>Outside facilities, infrastructure</td>
<td>0.5 % p. a.</td>
</tr>
</tbody>
</table>
9 Health and safety

9.1 Introduction

This chapter describes the health and safety requirements of the MBT system for the city of Bangalore and its equipment. It does not intent to be a full risk assessment; therefore that document has to be prepared separately during the project execution.

These sections refer mostly to technical aspects that help in fulfilling the health and safety requirements. It also contains structural and technical specifications derived from the equipment's safety requirements.

Organizational aspects and safety obligations are mentioned if relevant. The operation manual should contain a complete description of them.

The health and safety concept assumes that only qualified employees will be part of the operation. This concept follows international standards while accounting for Indian regulations.

9.2 Risk Assessment

Treatment of solid waste using MBT processes and the handling of different kind of residues including biological waste represents a potential risk to the health and safety of employees.

The most important risks related to the operations are:

- Health risks due to the potential exposure to airborne dust and bio-aerosols. During standard operations, the exposure is low; however during maintenance and cleaning it increases. This kind of exposure can arise mostly during reception of waste.
- Health risk due to handling of hazardous waste and materials.
- Risk of injuries in manual sorting or quality control cabins, due to the presence of sharp objects in waste
- Exposure to electromagnetic fields
- Accidents related to heavy doors and gates, uncovered mobile equipment parts and conveyors
- Explosion risk due to the presence of dust
- Pollution risk due to the use of water polluting substances e.g. Diesel
- Accidents caused by traffic within the facilities

9.3 Prevention measures

9.3.1 Measures in the facilities

9.3.1.1 General

The facility should be built in a way that, risks are prevented and controlled as much as possible. The proper design and operation of the process minimizes the issues related to health and safety. For reducing and avoiding the risks mentioned in the previous section, the following actions are planned:
9.3.1.2 Reception and storage

In the reception gate, a radioactive radiation detector should be placed to reduce the risk of radioactive materials entering the facility / process and the final products.

The bunkers have to operate under the principle of First in- First Out, in order to prevent the occurrence of anaerobic processes in the waste on stock.

For the unloading process of waste into the bunkers, a full guideline has to be prepared. This guideline should contain a description of the safe procedures and proper conduct.

9.3.1.3 Ventilation and exhaust air system

In all the buildings, a ventilation system should be installed. Depending on the conditions of each stage, the air exchange rate is defined. Table 22 shows common exchange rates in different sections of MBT plants:

Table 22: Common air exchange rates for the ventilation system

<table>
<thead>
<tr>
<th>Location/Hall</th>
<th>Air exchange rate per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reception</td>
<td>1.5 - 2</td>
</tr>
<tr>
<td>Bunker Hall</td>
<td>1.5 - 2,5</td>
</tr>
<tr>
<td>Sorting cabins</td>
<td>10</td>
</tr>
<tr>
<td>Mechanical separation and sorting</td>
<td>1.5 - 3</td>
</tr>
<tr>
<td>Stabilization, composting and loading hall</td>
<td>15</td>
</tr>
<tr>
<td>Storage for secondary fuel</td>
<td>1.5 - 3</td>
</tr>
</tbody>
</table>

Depending on detailed engineering, final construction and machinery details, these rates may vary in the final MBT plant. For the locations with a higher potential of air pollution e.g. Shredder or screens, a separated extraction unit is installed. The exhaust air coming from the equipment is not part of the exchange rates. A forced ventilation system working with fresh air should be installed in manual sorting cabins. This prevents the contact between employees and harmful substances. Both extraction and ventilation systems need to be constantly monitored; flowmeters and manometers are appropriate control instruments. In case of a failure, visual and acoustic indications should appear. An air treatment system should be installed for cleaning the polluted air coming from the extraction and ventilation unit in the facilities. This system can consist of a wet scrubber and a biofilter. In this section, emergency showers and eyewash station are mandatory due to the presence of corrosive / acidic substances. These stations have to be in accordance with the Indian standard IS 10592.

9.3.1.4 Changing rooms

In order to isolate the elements that have been in contact with the waste and potential polluted environment, a special room should be provided. The design should follow the concept of black-white system.

The room should allow the employees to keep their street clothes separated from their work ones; these two sections must be connected through a lavatory. The lavatory should be equipped with showers, soap and hand disinfectant dispensers.

Rooms with other purposes e.g. break or meeting rooms should be located before the changing room.
9.3.1.5 Equipment and machinery

All the installed machines must have an identification number according to the regulation, as well as a quality certificate issued by the manufacturer.

In addition all the installed machines should have an emergency stop switch. Once the switch is activated, the correspondent conveyors upstream are stopped along with the machine. Depending on the case, a specific emergency stop sequence should be activated. Especially for those machines with moving parts or elements which cannot be completely covered, the emergency stop switch must be located in easily accessible places.

9.3.1.6 General measures

Adequate and frequent lighting at all the work stations and paths should be guaranteed.

All the platforms for both standard operation and maintenance activities must be designed and built such that they provide the safest possible environment. They should contain non-slip areas on their surface to prevent accidents. In order to access those, ladders and stairways must be planned accordingly. The design of platforms and working surfaces should follow the subpart D of the OSHA 1910 standard.

Pits and all equipment underground should have enough protection and warning signs to avoid accidents. A vaccination scheme against tetanus and hepatitis A and B is highly recommended. Additionally, a good hygiene practices manual should be generated. Cleanliness is an important factor for health and safety in waste treatment facilities. Dust and dirt removal from machinery, stairs, ladders and floor is a daily task.

9.3.2 Personal Protective Equipment (PPE)

9.3.2.1 General

The use of PPE is crucial for reducing the risks within the facilities; however it is a secondary measure that complements the design considerations and safety precautions. PPE is used as protection against risks that cannot be minimized by other means. Employee must be trained to use PPE.

The PPE should fit perfectly to each employee. Otherwise it may be as risky as not wearing anything at all.

9.3.2.2 Standard Operation Condition

A standard PPE contains feet, ears eye, head, hands, and body protection. Safety boots with a steel toe cap are the appropriate footwear. Feet protection has to be worn at all time. For hearing protection, ear plugs or ear muff should be provided. They have to assure the noise levels permitted by the regulation (Standard OSHA 1926.52 and OSHA 3074 guideline). Frequent cleaning and change is suggested. This kind of PPE is highly recommended when working near to the shredder, conveyors, screens, wind sifters, composting halls etc.

Goggles are the best option for eye protection. They should have enough impact resistance and can be adapted to prescription glasses. Eye protection has to be worn at all time. For protecting the head, an impact resistant helmet is advised.
In the case of hand protection, needle resistant gloves are mandatory especially in the manual sorting cabin, aiming to protect the employees from possible injuries caused by sharp objects. This kind of gloves is also suggested whenever waste is handled. In laboratory work and during sampling, nitrile gloves are appropriate.

For body protection, as mentioned in the section 9.3.1, only work clothes are necessary. Extreme weather conditions (high temperatures) have to be taken onto account when selecting the clothes. High visibility clothes are recommended especially at night shifts and for traffic areas. The OSHA 3151-12R guideline contains all the information regarding to selection of PPE according to the existing standards.

9.3.2.3 Additional PPE, special situations

In case of special conditions in the facilities, an additional set of PPE should be available for the employees. As mentioned above, the main risk in the plant is under the presence of polluted air, therefore during cleaning and maintenance face masks are mandatory to worn. For emergencies and special situations, respiratory protection is needed. Simple filtering respirators are a good option. The air is filtered during inhalation thus the exposure to the pollutants is minimized. Depending on the device and the hazardous substances, the filters can be interchangeable and have to be replaced within a certain period. The OSHA 3079 guideline contains all the information related to selection of respiratory protection according to the existing standards.

9.3.3 Information, instruction and training

All the relevant health and safety information should be provided to the employees, so that they can comply with all the established procedures and measures. The associated documents have to be available every time for consultation. Safety signs have to be displayed in the locations where there is a risk for the employees. The marked risks are the ones that could not be controlled by prevention strategies and have to be dealt with. The safety signs should be in accordance with the standard IS 9457. As a complement of all the measures mentioned above, it is crucial to establish a training program for the employees. At least one information session should be organized every year. The training should also aim to promote a positive attitude towards the safety, and therefore safer work environment.

A comprehensive list of topics has to be compiled taking into account the regulation and legal requirements. The appendix E of the OSHA 1910.120 standard gives a complete overview of a site-specific training.

9.3.4 Protection against external risks

Around the facilities, adequate fencing should be built and it should have continuous surveillance. The establishment of a buffer zone in accordance to the correspondent regulations of the Indian Ministry of Environment and Forest must be considered. Additionally, a minimum distance to housing areas of 500m should be kept. In addition to the vehicles that belong to the company, only vehicles for charging and discharging of material should be allowed within the facilities.
9.4 Safety in the facility

9.4.1 Instrumentation and control (I&C) protection measures

To avoid the occurrence of dangerous operation states due to the failure of the regular I&C devices, a safety I&C system has to be implemented for the most risky equipment. The safety I&C system has to be highly reliable and safe. Two different strategies can be used for the implementation of the safety I&C; either a redundant wiring network or separated control system can be used. In case of an energy outage, the safety I&C system must go to safe operation states or must be connected to the emergency power supply. In case of a failure of any of the instruments, they should turn off and an alarm should be triggered. Frequent maintenance and verification is compulsory for all I&C devices; specialized personal has to conduct those actions.

9.4.2 Emergency stop system

An emergency system for the facilities should be planned. The main tasks of this system are to switch off all the necessary machines and turn on all the relevant alarms. The system should be initiated manually using emergency stop switches. These switches have to be placed in easily accessible locations e.g. emergency exits and exit routes. After initiation of the system, the responsible person has to be informed about the type and extent of the situation and at the same time, he/she has to establish a contingency plan and take measures to safeguard the employees. An emergency action plan should be generated in accordance with the requirements established in the OSHA 1910.38 standard.

9.4.3 Emergency power supply

In case of a power outage, the machines that must continue operation have to be connected to an auxiliary power source. The machines that are automatically able to go into a safe condition after an outage do not need to be connected to the auxiliary source. The auxiliary system consists of a UPS (Uninterruptible Power Supply), which is responsible for the energy supply of the control system and the small machinery. In addition to this, a standby generator e.g. Diesel generator must be available within the facilities. This system must allow a safe stop/shut down of the plant as well the alarm and safety systems to come into operation. In addition to that the signals for the exit routes, they should have illumination signs powered by batteries. When an outage occurs, an indication (visual or acoustic) must be given along with a notification of the incident.

9.4.4 Other measures

Due to the risk of ejection of particles from the shredder, it is not allowed to stay close to this area during operation, without a plausible reason. In case of visitors, all the pertinent safety measurements have to be presented to them before entering to the plant, additionally the appropriate PPE have to be provided (helmet and googles). During the visit, the visitors should not be allowed to go anywhere in the plant without supervision.

9.5 Explosion protection

The explosion risk due to the presence of dust is the highest in the air treatment process; especially in the dust filtration stage.
The ATEX (atmospheres explosives) directive 94/9/EC suggests the delimitation of different zones depending on the frequency and probability of occurrence of an explosion event. The directive specifies the appropriate electrical equipment that has to be installed depending on the zone. Table 23 shows the zones and their description:

Table 23: Zone classification according to the EU directive 94/9/EC

<table>
<thead>
<tr>
<th>Zone</th>
<th>Type of danger</th>
<th>Description</th>
<th>Equipment Group</th>
<th>Equipment Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>Constant</td>
<td>Permanent occurrence of dust</td>
<td>II</td>
<td>1</td>
</tr>
<tr>
<td>21</td>
<td>Potential</td>
<td>Intermittent occurrence of dust</td>
<td>II</td>
<td>2</td>
</tr>
<tr>
<td>22</td>
<td>Minor</td>
<td>Unlikely occurrence of dust or for short periods</td>
<td>II</td>
<td>3</td>
</tr>
</tbody>
</table>

The Indian PESO (Petroleum and Explosives Safety Organization) approves the ATEX scheme for the selection of equipment to be installed within hazardous areas. The input of raw gas to the filter is classified in the zone 20, the dust conveyors in the zone 21 and an area of 1 m from the dust conveyors in the zone 22. As a complementary measure, the discharge of the dust has to guarantee that all the dust remains within the delimited zone. For the construction and further design considerations, the dust explosion class St 1 applies. In all the locations where an explosion risks exists, naked light units and sparks and activities that may evade them are forbidden. Moreover sufficient signs must be placed in the entrances in order to warn about restrictions and explosion risks. Walls, doors and gates that delimit the zones with explosion risks, have to be gas and fire proof; the doors and gates should have a self-closing system.

9.6 Fire protection

The facilities have to be built in accordance with the part 4 of the national building code of India IS SP7. Surveillance with fire detecting cameras is required, especially in bunker, mechanical treatment and secondary fuel storage area. The Subpart L of the OSHA 1910 standard contains all the legal requirements related to fire suppression, detection and protection. Fire extinguishing installations and measures are not subject of this study and have to be covered in later, more detailed design steps.

9.7 Electrical grounding and lightning protection

The facilities should be electrically grounded in accordance to the Indian standard IS 3043. The facilities should have a lightning protection system in accordance to the Indian standard IS 2309

9.8 Handling of corrosive substances

As part of the air treatment system, an acid scrubber might be installed. Its operation requires the use of acid and corrosives substances. The acid substances should be stored in double shell containers. The scrubber should be surrounded by a retention dyke with no drainage; the size of the retention dyke should be enough to contain the whole amount of washing water coming from the scrubber. Both pipelines and equipment have to be made of chemical corrosion resistant material. All the pipelines that transport corrosive or acid substances should have the least possible amount of flanges. There should be a filling station adequate for the reception of acids and it has to be located outside the air treatment
hall in a separated place with a corrosion resistant floor and a pump sump. The pump sump will be used as retention dyke for possible leaks; the pumped effluent coming out of the sump should not be connected to the sewer. If necessary, the sump has to be emptied before the filling starts, thus the retention volume will be guaranteed. This area should support heavy traffic. The storage tank will be filled from a tanker using a pump that is considered as an accessory of the tanker. Other substances such as diesel and lubricants have to be stored at a distance from the corrosive substances. The storage and handling of substances have to account for the Indian code of safety and depending on the specific material appropriate guidelines has to be referred.
10 Bibliography


