TECHNICAL GUIDANCE
ON THE OPERATION OF
ORGANIC WASTE TREATMENT PLANTS

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1 Foreword

Biological treatment of solid waste can be a complex set of operations, processes and activities of degradation and rearrangement of biodegradable organic compounds of different nature and origin which, exploiting the activity of micro-organisms, allow the mineralization of the putrescible fractions (a process also known as "stabilization"), the transformation of the remaining organic fraction into humic compounds and ultimately into a highly valuable organic fertilizer. Possible effects of biological processes are the generation of significant amounts of heat in the case of aerobic digestion which sanitises organic waste and the production of biogas in the case of anaerobic digestion. Aerobic and anaerobic processes can be differently combined depending on the type of waste and the local conditions, with the ultimate aim of properly recycling source-separated organic waste and reducing the environmental impact of residual waste (RW). Since no specific indications are provided on anaerobic digestion (AD) by the PGIRS (the Master Plan for Municipal Waste Management in Sao Paulo for the period 2014-2033) of the Municipality of Sao Paulo in Brazil, this document intends to regard AD as a part of an integrated system, combined with aerobic processes applying to digestate from AD, thus allowing the combined production of biogas and compost in the case of organic waste from separate collection or dry bio-stabilised organic fraction in the case of RW treatment through MBT. This document will consider AD as an alternative of the intensive bio-oxidation step of a composting process or an MBT process, as indicated in Chapters 5 and 7.

The document is aimed at providing technical guidelines to local authorities, plant suppliers and plant managers in order to help them manage the organic waste fraction in a proper way both from a processing as well as from an environmental protection point of view. Information will be given on how to make proper choices on waste acceptance and treatment in such a way that it leads to an optimized transformation and the derivation of a product suitable for being utilized as an organic fertilizer in the case of organic waste from separate collection or a safe residue for final disposal with possible recovery of materials (in t case of RW). For each type of plant, indications will be given on possible layouts, mass balances and building and managing approaches aimed at minimizing environmental impacts on the surroundings of the installation and the health of workers.

Indications and recommendations will be mainly addressed to throughput capacities indicated by the PGIRS, which can be summarized below:

- Small-scale, low-tech composting plants with a capacity up to 50 t/d (from a few hundred t/y up to some thousand t/y);
- Medium-to-large composting plants with a capacity ranging from 50 to 600 t/d (approximately 15.000 to 185.000 t/y);
- Large MBT plants with a capacity of 1.250-2.500 t/d (387.000 – 775.000 t/y)

Due to the technical nature of this documents, the basic biological concept of composting, AD and MBT is not described thus it is assumed that readers have such basic knowledge. Nevertheless, since the guidelines on issues related to plants' construction and management will be based on their processes and environmental impact, a basic understanding of the biochemical processes that occur during the controlled decomposition of organic source materials is an indispensable pre-requisite for proper, quality-orientated process management.

Home-composting with an aerobic bin or by means of vermicomposting is not covered by this document. When dealing with organic waste at an industrial scale, vermicomposting is usually not practiced on fresh organic waste but rather on the compost produced, in order to increase its quality; for this reason, vermicomposting is not covered by this document.

A particular category of organic waste is animal by-products, which is usually ruled in countries with a developed sector for biological treatment of waste by a separate regulation. Since the main scope of this document is related to municipal solid waste, animal by-products will not be mentioned here.

2 Abbreviations and glossary

ABP	Animal by-product
ABPR	Animal by-product regulation
ACT	Active Composting Time or intensive bio-oxidation, rotting phase, or thermophilic phase
AD	Anaerobic digestion
AT4	Atmungsaktivität after 4 days (a respiration index)
BWC	Organic Waste Compost
CETESB	Companhia Ambiental do Estado de São Paulo (Environmental Company of the State of Sao Paulo)
CONAMA	Conselho Nacional do Meio Ambiente (National Environmental Council)
d.m.	dry matter
DRI	Dynamic Respiration Index
f.m.	fresh matter
GWC	Green Waste Compost
HRT	Hydraulic Retention Time
LHV	Lower Heating Value
MSW	Municipal Solid Waste
OLR	Organic Loading Rate
OFMSW	Organic Fraction from Separate Collection of Municipal Solid Waste
RW	Residual Waste
MAPA	Ministerio da Agricultura, Pecuária e Abastecimento (Ministry of Agriculture, Livestock and Supply)
IN	Instrução Normativa (Normative Instruction)
PGIRS	Plano de Gestão Integrada de Resíduos Sólidos (Master Plan of Integrated Solid Waste Management)
% (w/w)	weight related percentage
% (v/v)	volume related percentage
ABP	Animal By-Products
°C	Celsius/centigrade

ha	hectare
OC	Organic Carbon
OM	Organic Matter
Rpm	Round per Minute
SC	Separate Collection
SP	Sao Paulo
t	tonne (metric 1000 kg) / ton (imperial)
VFA	Volatile Fatty Acids
VOA	Volatile Organic Acids
VOC	Volatile Organic Compounds
VS	Volatile Solids
WWTP	Waste Water Treatment Plant

Aerated static pile: a heap of compostable materials formed to promote the aerobic decomposition of the organic matter. Ventilation is either provided by passive or forced aeration rather than through frequent turning.

Anaerobic digestion: a process of controlled decomposition of biodegradable materials under managed conditions where free oxygen is absent, at temperatures suitable for naturally occurring mesophilic or thermophilic anaerobic phase and facultative bacteria species, that convert degradable organic matter into biogas and digestate.

Biodegradable materials: materials capable of undergoing biological decomposition.

Biogas: Combustible energy rich gaseous mixture of methane and carbon dioxide and other trace gases like hydrogen sulphide, ammonia and steam, produced in anaerobic digestion process

Bio-stabilization: biological process occurring in the organic material aimed at degrading the putrescible fraction by means of aerobic or anaerobic pathways. At the end of the process the condition of bio-stability is achieved.

Organic waste: biodegradable waste from gardens and parks, food and kitchen waste from households, restaurants, caterers, hotels and retail premises and similar waste from food processing plants.

Organic waste compost (BWC): compost produced from organic waste.

Compost: humified solid particulate material that is the result of composting, which has been sanitised and stabilised, and which confers beneficial effects when it is added to soil, used as growing media constituent, or used in another way in conjunction with plants. *Note: post-composted digestate materials are defined as compost*

Composting: an aerobic exothermic process of biological decomposition of organic substance which occurs under controlled conditions and allows to obtain a biologically stable product characterized by a highly mature organic matter content.

Compost batch: a separately stocked pile of rotting material or ready-made compost manufactured in a uniform process.

Contaminant: element, compound, substance, organism, or form of energy which through its presence or concentration causes an adverse effect on the natural environment or impairs human use of the environment.

Digestate: product of anaerobic digestion of biodegradable materials, including organic waste, agricultural residues and animal by-products. It can be presented in whole or separated in a liquid and solid digestate. Digestate can be post composted or dried and further upgraded to pellets or granulates.

Dry digestion: anaerobic digestion with dry matter content over 20 % in the digester.

Food waste (OFMSW): in this document used as synonym to organic kitchen waste or catering waste from domestic origin and restaurants.

Green waste compost (GWC): Compost produced from green waste.

Hydraulic retention time (HRT): average time that material stays in the digester vessel, determined by the loading rate and operational digester capacity. *Note: The hydraulic retention time can be calculated by dividing the digester working volume by the rate of flow of input materials into the digester: HRT [days] = digester volume [m^3] / influent flow rate [m^3 per day].*

Impurities: any matter over 2 mm in dimension that results from human intervention and has organic or inorganic components such as metal, glass, synthetic polymers (for example plastic and rubber) and that may be present in the compost but excluding mineral soil, woody material and pieces of rock.

Ingestate: organic waste introduced in the first anaerobic digester after all the mechanical pre-treatment operations.

In-vessel composting: diverse group of composting methods in which composting materials are contained in a reactor vessel; the purpose is to maintain optimal conditions for composting.

Liquid digestate: Digestate from wet digestion or the liquid fraction of material by separating the whole digestate. *Note: Less than 15 % of its mass should be dry matter in order that the sample is suitable for laboratory tests as a liquid material. It should contain sufficient moisture to be pumpable.*

Mature compost: term used to designate a compost that, when used as an organic soil conditioner, does not have phytotoxic effects arising from, for example, nitrogen immobilization or anaerobiosis.

Organic loading rate: a specific amount of organic matter which can be daily fed to an anaerobic digester, generally expressed as kg VS/m^3 digester * day.

Shovellable: suitable to be transported with a wheel loader, characterised by a solid content usually over 20%.

Pathogens: organisms, including some bacteria, viruses, fungi and parasites that are capable of producing an infection or disease in a susceptible human, animal or plant host.

Pumpable: semi liquid, suitable to be pumped in a pipeline, characterised by a solid content usually lower than 20%.

Residual Waste: waste collected from households, commerce and industry which has not been separated at source.

Sanitisation: reduction of human, animal and plant pathogens to acceptable levels as a result of the hygienisation process.

Semi-dry digestion: anaerobic digestion with dry matter content between 10% and 20% in the digester.

Sharp impurities: any foreign matter over a 2 mm dimension that may cause damage or injury to humans and animals during or resulting from its intended use. Sharp foreign matter may consist of, but is not limited to, the following: metallic objects or pieces of metallic objects, for example utensils, fixtures, electrical wiring, pins, needles, staples, nails and bottle caps; glass and porcelain or pieces of glass and porcelain, for example, mirrors, containers, dishes, glass panes and electric light bulbs and tubes.

Solid digestate: digestate from a dry digestion or the solid or fibrous fraction of material by separating the coarse fibres from whole digestate. *Note: At least 15 % of its mass should be dry matter in order that the sample is suitable for laboratory tests as a solid material.*

Stability: Stability is the level of biological activity. Unstable compost or residual waste containing organic fraction consumes nitrogen and oxygen in significant quantities to support biological activity and generates heat, water vapour and carbon dioxide. A stable material consumes little nitrogen, oxygen and generates little heat and carbon dioxide. If stored improperly, unstable material scan become anaerobic giving rise to methane, nitrous oxides and ammonia which creates an odour nuisance.

Maturity: Maturity can be defined as the point at which the end product is stable and the process of rapid degradation is finished, or, a biodegraded product which can be used in horticultural situations without any adverse effects. Maturity is a measure of the compost's readiness for use.

Thermophilic phase (also known as Active Composting Time, ACT): biological phase in the composting process characterized by the presence of micro-organisms which grow optimally in a temperature range of 45°C to 75°C.

Vermicomposting: also called "worm-composting", is the breakdown of organic matter using earthworms. It produces a heterogeneous mixture of decomposing food waste, bedding materials and worm humus (or otherwise termed worm manure) that is rich in nutrient as a fertilizer.

Volatile solids (VS): solids in water or other liquids that are lost on ignition of dry solids, generally above 500°C.

Wet digestion: anaerobic digestion with dry matter content ≤ 10 % in the digester.

Windrow: elongated piles of triangular or trapezoidal cross-section that are turned in order to aerate and blend the material.

Yard waste: also called green waste, is a vegetative matter resulting from gardening, horticulture, landscaping, or land clearing operations and includes materials such as tree and shrub trimmings, plant remains, grass clippings and chipped trees.

3 Legal framework on waste treatment facilities, output quality and application and their environmental impacts

3.1 National regulations

Both composting facilities and their outputs must be registered to MAPA (applying to the "*Registro do Estabelecimento e Registro do Produto"*). MAPA is in charge of monitoring the quality of compost.

Relevant national regulations are the following:

1) DECRETO Nº 4.954, DE 14 DE JANEIRO DE 2004 Aprova o Regulamento da Lei nº 6.894, de 16 de dezembro de 1980, que dispõe sobre a inspeção e fiscalização da produção e do comércio de fertilizantes, corretivos, inoculantes ou biofertilizantes destinados à agricultura, e dá outras providências[1]

2) DECRETO Nº 8.059, DE 26 DE JULHO DE 2013 Altera o Anexo ao Decreto nº 4.954, de 14 de janeiro de 2004, que aprova o Regulamento da Lei nº 6.894, de 16 de dezembro de 1980, que dispõe sobre a inspeção e fiscalização da produção e do comércio de fertilizantes, corretivos, inoculantes ou biofertilizantes destinados à agricultura[2]

3) IN 23 de 31/08/2005 – Revisada e Substituída pela IN 25 de 27/07/2009 Aprova as definições e normas sobre as especificações e as garantias, as tolerâncias, o registro, a embalagem e a rotulagem dos fertilizantes orgânicos simples, mistos, compostos, organominerais e biofertilizantes destinados à agricultura[3]

4) IN 27 de 05/06/2006 - Dispõe sobre fertilizantes, corretivos, inoculantes e biofertilizantes, para serem produzidos, importados ou comercializados, deverão atender aos limites estabelecidos no Anexos I, II, III, IV e V desta Instrução Normativa no que se refere às concentrações máximas admitidas para agentes fitotóxicos, patogênicos ao homem, animais e plantas, metais pesados tóxicos, pragas e ervas daninhas[4]

5) Resolução Conama nº 375 de 29/08/2006 Define critérios e procedimentos para o uso agrícola de lodos de esgoto gerados em estações de tratamento de esgoto sanitário e seus produtos derivados, e dá outras providências[5]

3.2 Sao Paulo state-level regulation

Permit for the construction and operation of composting facilities is released by CETESB. A list of the documents required for permit application can be found at the following web link (last access 24/02/2016)

http://licenciamentoambiental.cetesb.sp.gov.br/atividades-e-empreendimentos-sujeitos-ao-licenciamento-ambiental/roteiros/usina-de-compostagem/

[1] http://www.planalto.gov.br/ccivil_03/_ato2004-2006/2004/decreto/d4954.htm
[2] http://www.planalto.gov.br/ccivil_03/_Ato2011-2014/2013/Decreto/D8059.htm
[3] http://www.inmetro.gov.br/barreirastecnicas/pontofocal/..%5Cpontofocal%5Ctextos%5Cregulamentos%5CBRA_194_add_1.htm
[4] http://www.agricultura.pr.gov.br/arquivos/File/PDF/in_27_2006.pdf
[5] http://www.siam.mg.gov.br/sla/download.pdf?idNorma=5956

4 The type of plants addressed

This technical guidance is primarily intended to cover all types of plants treating organic waste of municipal origin, either from separate collection or mixed with residual solid waste.

Due to the differences in the purpose and processes of different types of waste treated, the document will refer to three types of plants:

1) Medium/high-tech facilities (composting and AD) for food waste recycling

2) Small-scale low-tech facilities for green waste composting and food waste composting

3) MBT for RW pre-treatment prior to final disposal

medium/high-tech recycling facilities	small-scale, low-tech recycling facilities	MBT pre-treatment facilities
Composting	**Composting**	Aerobic digestion
Anaerobic digestion	n/a	**Anaerobic digestion**
Capacity: above 50 tons/day	**Capacity**: from a few tons/day up to 50 tons/day	Capacity: from 50 tons/day up to 1.000 tons/day
Inputs: Green waste and food waste from separate collection	**Inputs:** Green waste and food waste from separate collection	**Inputs**: organic waste from mechanical sorting of RW
Main outputs: Compost Biogas	Main outputs: Compost	Main outputs: Biostabilised organics (ev.) biogas

For each type of facility the following key aspects will be evaluated and described:

Input waste	•Type of innput waste •Acceptance criteria and characterization
Standards	• Requirements for plant equipment •Technical requirements on the design and operation •Foot print of the plant
Output	•Outputs quality, characterization and applications •Mass balance

5 Medium/high-tech facilities for recycling organic waste

In this chapter, composting and anaerobic digestion of food waste in appropriate mixture with other types of organic waste is considered. According to the PGIRS, plants considered here are those whose capacity range **from medium (50 t/day) to high treatment capacity (600 t/y)**. Due to the type of waste treated and the throughput, these facilities require a higher level of environmental protection than those dealt with in the Chapter 6 and are generally considered here to be managed on sealed ground, within enclosed buildings provided with adequate ventilation and exhaust air depuration.

5.1 Acceptable input waste

Besides food waste, composting facilities can accept a number of different types of shovellable organic waste that, according to the necessities of a composting plant, can be divided in the following two categories:

Table 1: Acceptable organic input waste at medium/high-tech organic waste facilities

Putrescible organic waste (high nitrogen concentration, high moisture content, low permeability to air)	Lignin/cellulose based organic waste (high carbon concentration, low moisture content, high permeability to air)
Food waste (OFMSW)	Yard waste (e.g. grass, tree and shrub pruning, flowers)
Vegetable waste from food industries (e.g. fruit and vegetable residues, cereals, tea and coffee brew, vegetable catering waste)	Waste from private gardens or from public areas such as parks and playgrounds[2]
Waste from markets (e.g. vegetable and fruit rejects)	Wood (solid or chippings)
Solid manure	Saw dust/shavings (untreated wood only)
Food industry sludge and sewage sludge[1]	Paper, cardboard and other compostable packaging (e.g. wood fibre, cotton fibre, jute)
Solid fraction of digestate from AD	

[1] sewage sludge utilization is subject to the conditions contained of the CONAMA Res. N. 375/2006

[2] mowing from green strips of highly frequented roads shall be excluded

In case of presence of an AD section, other liquid or semi-liquid organic waste can be accepted, such as slurry, expired beverages, exhaust vegetable oils.

Additives and auxiliary agents can be used in limited quantities (up to 15% by weight) to biological decomposition and humification process and to minimize odour emissions. An example is given in the

Table 2:

Table 2: Additives and auxiliary agents to optimise the biological treatment

Additive	Remarks	Properties	Function
Matured compost	addition: 5 – 15%	Inoculation of mixture with humifying microorganisms	Enhancement of humus formation Sorption of water and odour compounds
Saw dust	addition: < 20% needs liming and nitrogen addition to be well decomposed	Carbon source	C/N equilibration
Straw	Carbon source needs liming and nitrogen source to be well decomposed	Carbon source	C/N equilibration
Ash from biomass incineration	addition: < 5%;	phosphorus and potassium provider	Increase in nutrients
Egg shells	From catering services and food processing industries	liming effect	Composting process enhancement
Animal hairs / wool / feathers	no furs	reducing the C/N ratio slowly available N source	C/N equilibration
Guano, poultry manure	n.a.	Nitrogen and phosphor source	C/N equilibration Increase in nutrients

5.2 Acceptance criteria and characterization

In principle, the use of the acceptable input waste listed in the previous paragraph should allow the production of a high quality final product. Source separated organic feedstock is not required of quality check at acceptance but it is recommended to do quality check from time to time. The main contaminants of concern are sharp impurities or physical contaminants such as plastics, glass and metals present in organic waste separately collected due to incorrect sorting by the waste producers. As a reference, the following quality classes of food waste are identified according to the classification set by the Italian Composting Association (CIC):

Table 3: Classification of organic waste according to the amount of non-compostable materials

Class	Amount of Non Compostable Materials	Description
A	≤2,5%	Excellent quality
B	2,5%<MNC≤5%	Good quality
C	5%<NCM≤10%	Sufficient quality
D	10%<NCM≤15%	Poor quality
E	NCM>15%	Bad quality

The mechanical refining steps taken during a composting process can remove most physical contaminants, however the poorer the quality of input waste, the more expensive the process, as it requires more sorting operations and a higher amount of rejects to be managed and disposed.

Regular and effective waste information and public communication work by municipalities, coupled with a control system to monitor the sorting behaviour of citizens (through periodical composition analyses on source segregated food waste) should help improve the purity of input waste. Eventually the goal is to receive mostly "class A" organic waste, to discourage "class B" and "C", and to codify an agreement with waste collection service to reject organic waste of "class D".

As far as sewage sludge is concerned, characterization must comply with CONAMA Res. N. 375/2006 which contains parameters and frequency of monitoring with particular regard to the following issues:

- Art. 10 tab. 1 (frequency of monitoring)
- Art. 11 tab. 2 (heavy metals)
- Art. 11 tab. 2 (pathogens)
- Annex I – criteria for quality monitoring
- Annex VI – sampling criteria
- Annex V – potentially toxic organic pollutants to be monitored

5.3 Objectives for composting and anaerobic digestion

The main objective for **composting** is that of turning source-segregated organic waste of municipal origin into a valuable solid organic fertilizer complying to the most commonly accepted standards of compost by an aerobic process that develops through a double step (respectively called "ACT" and "curing" step) biological process.

Anaerobic digestion is a process of controlled decomposition of biodegradable materials under controlled anaerobic conditions where free oxygen is absent, at temperatures suitable for naturally occurring mesophilic or thermophilic anaerobic phase and facultative bacteria species that convert degradable organic matter into biogas and digestate. Anaerobic digestion is here meant as a substitute of the ACT step of composting, whose main objectives are:

- The recovery of a high LHV gas called "biogas" suitable for being further exploited for energy, heat or biofuel production
- The reduction of the environmental impacts of the organic waste processing activity, especially due to the encapsulation of putrescible waste in sealed reactors that allow anaerobic processes to take place
- The reduction of the overall plant footprint, due to the more compact solutions for treating organic waste anaerobically.

Anaerobic digestion is here meant to be followed by a curing phase which ends with the generation of a solid output, i.e. compost (from digestate) complying with the same standards of the compost produced by an entirely aerobic process.

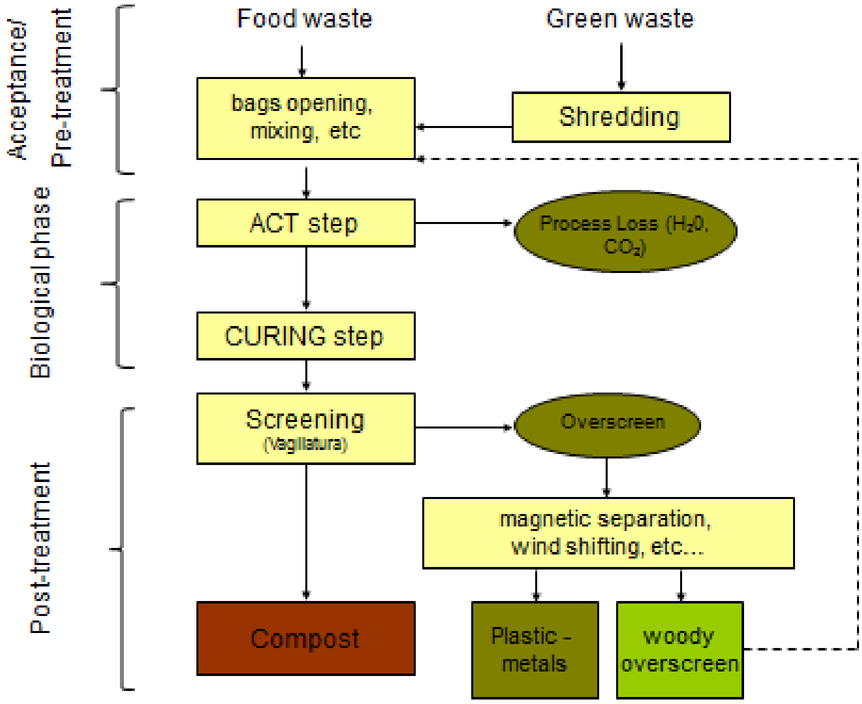
5.4 Composting: minimum standards for plant equipment, process criteria and key issues

With reference to the typical layout shown in Figure 1, the composting process can be described in the following steps, each associated to standard equipment and key issues:

- Waste acceptance
- Mechanical pre-treatment
- Biological phase
- Mechanical post-treatment (refining)
- Final product (compost) storage

The definitions of pre- and post-treatment are related to the core of the composting process: the biological phase.

Figure 1: Material flow of a standard composting process



5.4.1 Mechanical pre-treatments

Pre-treatments are mainly aimed at:

- "condition" the physical nature of waste to be biologically processed:
    - Shredding/de-fibering lignin based woody organic waste to a maximum length of 20-25cm
    - Opening bags containing the putrescible organic waste fraction
    - Mixing/homogenizing different types of organic waste
    - Drying/moistening the input mixture
- Remove non compostable materials:
    - Screening by size (removal of large-size fractions, rich in plastics)
    - Removing metals through magnetic belts

5.4.1.1 *Specific requirements for pre-treatment*

In order to minimize the quantity and environmental impact of rejects, it is recommended to remove non-compostable materials after the biological phase, unless differently required by the specific technology chosen.

For organic waste quick degradation, input materials must be a mixture (called "starting mixture") of easily degradable wet organic substances and structure-improving organic matter. Bulking materials, commonly woody garden waste, are needed to create structure with adequate porosity for air flow and a high number of pores in the pile when air conductivity is low.

Feedstock properties can affect both the rate, hence the efficiency of degradation, as well as emissions. The principal factors are the following:

- Moisture content: The water content of composting feedstock may vary considerably, and is partly dependent upon the structure and water holding capacity of the materials. A balance needs to be found between ensuring sufficient pore structure in the composting mass to allow air to permeate, and ensuring that particles in the mass are covered with a film of water, which is the habitat of microorganisms. The optimum moisture content is 50 – 60% (w:w) for well-structured materials.

- Bulking agents: The addition of *bulking agents* is often required in order to create the necessary water-free pore space and enable gas exchange to take place in the compost pile. The optimum proportion depends on the active decomposition system (mechanical agitation, forced aeration, diameter of heaps, etc.), the bulking properties of the material and the water content of the mix. It is recommended that a mixture is made by 35-50% (w:w) of bulking material.

- Mixture density: a starting mixture density not exceeding 0,65 t/m^3 is recommended. This value is an indirect and empirical benchmark of adequate moisture content and free air space within the mixture.

- PH-value: In general, decomposition works best when the pH is neither too acidic nor alkaline. However in many instances this may be out of the control of the site manager. For example, a high proportion of fresh kitchen and vegetable waste may result in a low pH-value (between 4 to <6) due to the release of short-chain fatty acids. This causes a major slow-down of the organic carbon decomposition during the initial 3 to 7 days (*lag-phase*). On the other hand, sludge treated with quick lime may have a pH-value > 12 which also hinders decomposition if not mixed with appropriate feedstock amendments.

- C/N-ratio: Organic carbon and nitrogen sources need to be offered in a balanced and accessible proportion to the evolving microbial communities within the composting mass. A surplus of easily available nitrogen (C/N approximately < 15 - 20:1) can lead to high N losses in the form of Ammonia (NH_3) and Nitrous oxide (N_2O). However, materials with high carbon to nitrogen ratios may compost slowly, as nitrogen will be limiting. A target value of <u>25 to 35 part carbon to 1 part nitrogen</u> is desirable for optimum composting. In practice, acceptable C/N ratios are obtained by mixing putrescible waste and lignin base organic waste in appropriate rates (50-65% putrescible; 35-50% garden waste). Table 4 gives examples of C/N ratio of the most important feedstock.

5.4.1.2 *Main equipment used for pre-treatment of organic waste*

The basic equipment required for pre-treatment of organic waste are the following machineries:

- Shredding; three main categories of shredder can be identified:
  - <u>Hammer mills</u>: the most commonly used in the composting sector, have shredding unit made of one or more horizontal fast-rotating shafts (1.000-2.000 rpm), provided with swinging hammers or clubs

(the number and shape depending on the model). These machines are particularly suitable for green waste shredding, since they are able to de-fibre wood instead of cutting it, thus increasing the contact surface between C-rich and N-rich materials. On the other hand, hammers and clubs are subject to frequent maintenance and replacement due to the high wear.

- Blade shredders: install a slow rotation shaft provided with fixed blades. Compared to hammer mills, waste is less de-fibered but with a more homogeneous size thanks to the presence of filtering grid with the desired mesh size.

- Screw shredders: install a shredding unit made by screw shafts (generally 3 horizontal ones) put side by side or overlapping. They are particularly suitable for large size or very moist materials thanks to the slow rotation (<100 rpm), and they can generally reverse their rotation direction in case of clogging.

➢ Mixing; installed in all medium and large-size composting facilities treating putrescible organic waste. Mixing units are made of a wide hopper feeding 2-4 flanked horizontal screw shafts, or other rotating units provided with differently shaped blames. Among the qualifying features of these machines, the important factor is to be able to mix the materials as long as needed in order to obtain a proper starting mixture.

Table 4: Examples of C/N ratio for different types of organic waste

Feedstock / material	C/N ratio	Feedstock / material	C/N ratio
Manure		**Green waste**	
Liquid manure (urine)	2-3	Grass clippings	12-25
Poultry manure without bedding material	10	Mixed fine garden waste	20-60
Poultry manure + straw	13-18	Bulky bush cuttings, shredded	23-31
Cattle manure (with little straw)	20	Mixed leaves	30-60
Organic waste		Straw (oat)	60
Vegetable waste	10-20	Bark	100-130
Food waste (restaurants)	12-20	Pure ligneous tree cuttings	100-150
waste from fruit processing	15-25	**Others**	
Mixed kitchen waste	20-23	Saw dust	100-500
Flowers and mixed plant tissue	20-60	Paper and cardboard	200-500
Kitchen waste	23		
Fruits	35		
Paper waste	120-170		

Source: Amlinger et al. (2005)

5.4.2 Biological phases

The biological phase of the composting process can be described and split into two main steps:

➢ Active Composting Time ("ACT", also known as intensive bio-oxidation, rotting phase, or thermophilic phase) where the fast degradation of the putrescible organic substances takes place. During this phase a great amount of O_2 is consumed by micro-organisms and high temperatures are reached, thus making it necessary to "drain" the excess of heat generated and to supply the system with the oxygen needed for the microbial to work.

- Curing phase, meant to turn more stable organic compounds (mainly the lignin and cellulose based ones) under mesophilic conditions into phenolic constituents that are precursors in the formation of humic substances, the synthesis of humic substances by polymerization processes and formation of the clay-humus complex. During this phase lower draining and oxygenation operations are required compared to the intensive ACT.

5.4.3 Classification of composting technologies

In order to allow the correct development of the composting process, several approaches can be adopted in the two distinct biological phases, classified below in the context of medium-to-large composting facilities, not exclusive to each other:

- Intensive/extensive systems
- Open/enclosed systems
- Static/dynamic systems
- Forcibly ventilated/non-ventilated systems

5.4.3.1 *Intensive/extensive systems*

This refers to the degree of technological complexity (high for intensive, low for extensive systems), the duration of the process and the unitary air and energy consumption.

- Intensive systems are represented by sealed reactors (e.g. bio-cells, bio-tunnels) or housed reactors (dynamic windrows, static or dynamic basins) provided with all the technological equipment to properly oxygenate, moist and/or automatically turn the mixtures in a relatively limited space. Intensive systems are particularly suitable for ACT step of highly putrescible organic waste composting, but can even be considered for the curing step.

- Extensive systems are represented by all the technologies in which oxygenation and heat excess removal are mainly provided by mechanical turning of the mixture that, together with a longer process duration, require larger space in order to be carried out. Extensive systems can be recommended for performing the curing phase in composting plants treating up to around 20.000 t/y of composting (30.000 t/y in the case of high performance ACT step, or when ACT is substituted by an AD step).

5.4.3.2 Open/enclosed systems

Enclosed systems are those performed in closed reactors (bio-containers, bio-tunnels, bio-cells) or open reactors housed in enclosed buildings (dynamic windrows, basins). Enclosed systems allow to:

- Reduce the overall environmental impacts (dust, odour, noise and leachate production)

- Increase the efficiency of the process, thanks to the better control of the relevant parameters

Open systems are those carried out outdoor or simply under a roof. Typical open systems are represented by aerated static piles and turned windrows. This approach to composting allows to reduce the investment costs (absence of buildings and related infrastructures) and energy consumption (for the extraction and treatment of exhaust).

Unless a favourable odour dispersion modelling can be provided for a given site (settled at least 1.000m far from possible downwind sensitive receptors/ urban settlements), it is strongly recommended to adopt enclosed systems both for ACT and for curing step (even in the presence of an anaerobic digestion step) in an organic waste treatment plant with an overall throughput capacity >20-25.000 t/y, and 30-35.000 t/y in the case of a rate of bulking waste > 70% w/w. Below these capacities, open systems can be acceptable for the curing step only.

5.4.3.3 Static/dynamic systems

This classification refers to the presence of a periodical mixture turning (dynamic systems) as the main instrument to provide fresh air to the mixture or, on the contrary, the total rely on forced or passive ventilation of the piles (static systems).

Static systems are aimed at avoiding the disturbance of the microbial environment (a thermal shock is in fact associated with each turning operation) and the massive release of odours and dust in the environment associated with turning. For this reason, they are recommendable for any kind and step of composting processes.

Dynamic systems on the other hand are suitable for mass oxygenation during the curing step, or for ACT steps in which a limited availability of bulking material is available (30-35% of the overall throughput, including the over-screen woody fraction recovered from post-treatments).

5.4.3.4 Forcibly ventilated/non-ventilated systems

Forced ventilation is an important instrument for process optimization, particularly during the ACT step in composting plants treating putrescible organic waste. Forced ventilation can be provided through air blowing from a grid pavement fed by a ventilation system, or through air suction when air flows down to the grid pavement after having passed through the mixture and directly driven to the exhaust air treatment devices.

Whenever ventilated systems are provided, fans must be properly dimensioned in order to provide up to 15 Nm3/h per ton of fresh waste according to two commonly known approaches:

- On-off systems: fans are switched on and off according to a precise timing, irrespective of the state of the mixture. In this case, due to the quick O_2 consumption in the mixture, it is recommended to keep a maximum off time of 30 minutes during ACT step.

- Continuous ventilation modulated on the basis of actual demand of oxygen and fresh air by the mixture, generally measured by monitoring the temperature and/or O_2 concentration in exhaust air.

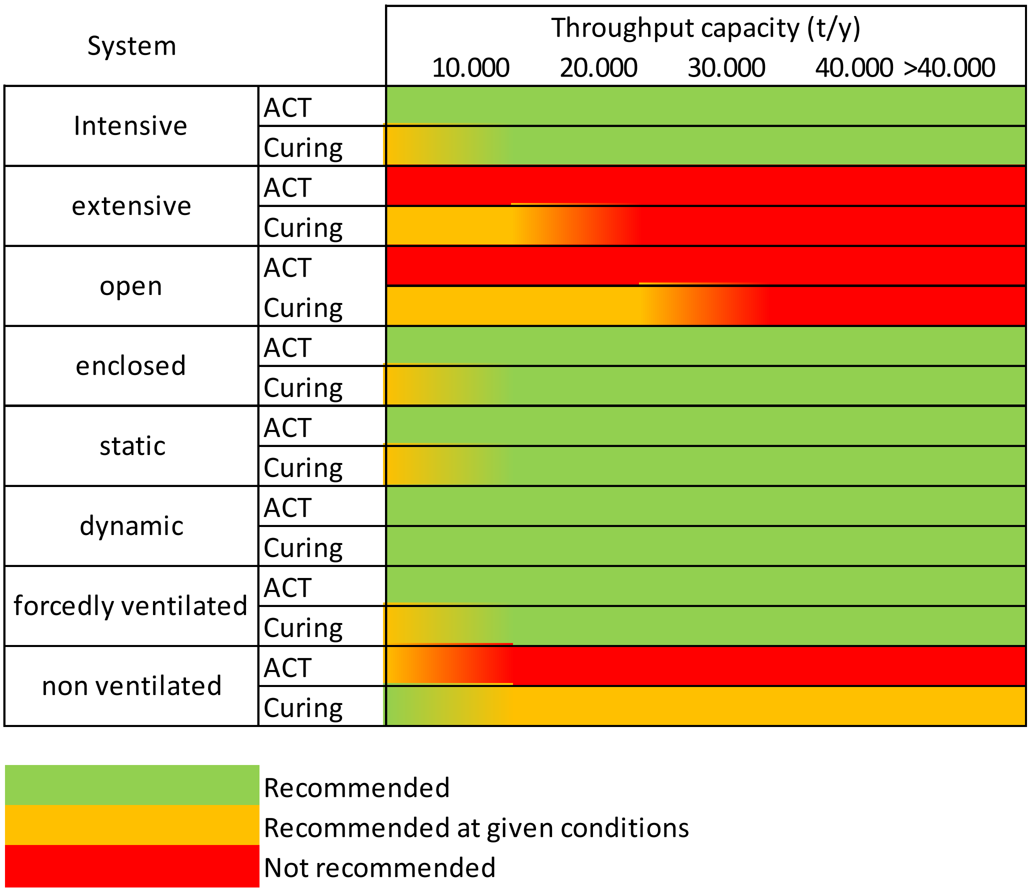
Non-ventilated systems are either associated with dynamic processes or exploit passive ventilation mechanisms, which can fit those processes in which the material is no longer or has not ever been rich in putrescible fractions (e.g. garden waste composting and curing step of any composting process after a well-performed ACT step).

For all the composting facilities with an overall throughput >15.000 t/y it is recommendable to provide ACT steps with forced ventilation, whereas curing steps can be either forcibly ventilated or periodically turned with turning frequencies depending on the effectiveness of the ACT step in reducing the putrescible organic waste component, or simply passively aerated.

A summary of recommendations with respect to the key process approaches is given in

Figure 2 below.

Figure 2: Recommendation of composting systems for different range of treatment capacities



5.4.4 Requirements for the biological phase

5.4.4.1 *Piles/windrows formation*

The following minimum requirements on mixtures shaped in piles or windrows are provided:

- Bio-reactors: Reactors shall be piled with fresh mixtures to a height not exceeding 3,0 m in the case of static systems, or 3,5m in the case of dynamic ones. The length of each reactor shall ensure that a given batch of fresh mixture is completely loaded in no more than 3-4 days

- Windrows: A variety of windrow-geometries were typically found in practice. Typical trapezoidal windrows were mostly found in enclosed facilities with forced aeration and can be equipped possibly with automated turning systems. It is recommended a height up to 2–2.5m, and a width between 4–6m

5.4.4.2 *Air supply*

In order to prevent or minimize the generation of anaerobic condition, the following indications are given:

- Forced ventilation: Forced aerated systems must be provided with fans able to supply air up to 15 Nm^3/h per ton of fresh mixtures.

  In the case of “on-off systems”, it is recommended to not exceed an off time of 30 minutes during ACT step, unless during the process evidences can be given of an adequate O_2 concentration (see below) inside the mixture despite lower ventilation frequencies.

➢ Turnings: ACT step:

- without forced aeration: 1-2 times per week during the first 21 to 28 days (windrow height < 1.5 m)
- with forced aeration: once every 15 days

Curing step (during the first 4 weeks):

- without forced aeration: at least every 2nd week
- with forced aeration: at least once

5.4.4.3 *Process optimization and monitoring*

In order to optimize the process, the following main parameters must be considered and monitored:

➢ O_2 concentration: during the composting process, concentration of O_2 in the biomass > 15% during the ACT step and > 10% during the curing step must be assured, in order to allow proper conditions for aerobic metabolism.

➢ Temperature: Temperature increases as a consequence of biogenic heat generated by putrescible organic waste degraded by micro-organisms. Its storage in the composting piles depends on the equilibrium between:

- Heat generation (related to putrescible organic waste oxidation) and,
- Heat dispersion (associated with pile size, moisture content and air removal through forced ventilation or periodical turnings).

Optimal temperature should be in the mesophilic range of 40-45°C; nevertheless, during the ACT phase temperatures typically reach or surpass 70°C. This can be useful for the sanitization of waste, which can be assured by one of the following combinations of time-temperature profiles:

Table 5: Time-temperature profiles for sanitization during high-tech composting processes

Temperature	Time	Additional requirements
≥55°C	5 days	After sanitization, appropriate measures must be taken in order to avoid any cross contamination between sanitized and fresh organic waste.
≥60°C	5 days	
≥65°C	3 days	
40°C*	5 days	At least 55°C for 4 consecutive hours.

* Sanitization requirements for sewage sludge sanitization prior to utilization in agriculture according to the Brazilian CONAMA Res. N°375/2006

Optimum temperature ranges during different steps in standard composting processes are summarised in Table 6 below.

Table 6: Temperature range for different steps in standard composting processes

Process requirement	Step	Temperature range
Sanitization	ACT	> 55°C
Decomposition rate; degradation of lignin and lignocellulose compounds / humification	ACT/Curing	45 - 55°C
Highest microbial diversity; degradation of microbial biomass; degradation of lignin and lignocellulose compounds / humification	Curing	40 - 45°C

- Moisture content: moisture content must slightly decrease from that of the starting mixture (50-60%) to that of the final product (30-40%). The aerobic process often tends to dry the mass beforehand, preventing the continuity of the microbial activity. In particular, in enclosed systems the continuous air flow and high air flow rate may result in dry stabilization. This has to be avoided by regularly watering the composting material and artificially cooling the aeration system. For this purpose, leachate collected inside the plant can be utilized for watering in the ACT only and prior to the conclusion of the sanitization step, in order to prevent waste recontamination..

- Weight: proper performances of the process can also be monitored by comparing the weight of mixture batch before and after the biological phase, at the end of the ACT step and at the end of the curing step. A weight decrease should be registered as a consequence of water evaporation and putrescible organic fraction removal according to the following guiding parameters:

  - Weight after ACT: 60-70% of starting mixture
  - Weight after curing: 40-50% of starting mixture

A summary of the parameters which should be monitored along the process in order to assure optimal performances is given in Table 7. It is important that each plant keeps a database collecting the history and evolution of each parameter, monitoring in particular their constancy over time.

Table 7: Standard parameters and range for organic waste composting

	Parameter	Optimum range	Typical monitoring frequency
Waste acceptance	Bulky impurities	• check and remove bulky impurities • register a suspicious excess of impurities (plastics, glass, metals) from a given collection area	Each delivery
	Composition analysis (% of non-compostable fractions)	<2.5% (acceptable <5%)	Every year from a representative number of sources, and in the event of new types of waste/new collection areas involved
Starting mixture	Density	0,5-0,65 t/m3	Monthly
ACT	Temperature	>55°C during the stabilization step 45-55°C after the stabilization step	In the continuous presence of a process management software (recording data at least every 30 minutes); otherwise, at least daily
	O_2	>15% (acceptable >10%)	Weekly during the commissioning period; then, monthly
	pH	>7 (acceptable >6,5) at the end of this step	After each cycle during the commissioning period; then, when necessary
	Moisture content	40-50% at the end of this step	After each cycle during the commissioning period; then, when necessary
Curing	Temperature	40-45°C (acceptable 40-55°C)	Weekly
	O_2	>5% (optimal >10%)	Monthly during the commissioning period; then, every 3-4 months
Compost	See Chapter 5.6	See Chapter 5.6	Number of samples every year = 1 every 10.000 t/y treated + 1 (max 12 samples)

5.4.4.4 *Process duration*

Process duration is mainly determined by the effectiveness of technologies put in place. The length of the ACT step can vary depending on the specific technology adopted and on the chemical-physical features of the organic waste treated, generally lasting between 3 and 5 weeks. If properly performed, a decrease in temperature is observed over the last week, generally down to 40-45°C.

The length of the curing phase in turn depends on the kind of application foreseen for the final product - shorter durations for compost to be used in agriculture, longer durations for obtaining a mature compost for horticulture, gardening or domestic applications. In any case, **the curing area must be sized** in order to guarantee an overall composting duration (ACT + curing) **of at least 80 days**.

The duration can be shorter in the case of AD which allows to get to the final product (compost) after a curing phase of 4-6 weeks.

5.4.5 Mechanical post- treatments

Post- treatments are aimed at:

- Removing non compostable and sort bulky woody fractions and is done by:
    - Screening by size in order to recover large woody materials to be re-circulated in the starting mixture
    - Ballistic separation for glass/stones separation
    - Wind shifting for plastic removal
    - Magnetic separation of metals
- "Conditioning" the physical nature of the final product by:
    - Compost drying/pelletizing
- increasing the value of the final product by:
    - Vermicomposting
    - Compost blending with other ingredients in order to produce growing media

In some cases some mechanical operations such as screening can be made during the biological phase, typically between the ACT and curing steps, in order to optimize space within the plant and prevent or reduce wear and tear of machineries such as turning machines.

5.4.5.1 *Equipment used for post-treatment of organic waste*

The basic equipment required for post-treatment of organic waste are the following machineries:

- **Mechanical screening**: commonly used screens in composting plants are drum screens, made of a hopper feeding, a drum with holes of the desired size rotating around a slightly sloping axis and conveyor belts for transporting the two fractions obtained - over-screen and under-screen. The drum is continuously kept clean by means of a cylindrical counter-rotating brush.

Other types of screens used in the composting sector are:

- Vibrating screens: fine particles fall through a sloping vibrating grid
- Star screen: a number of synchronized rotating shafts provided with star shaped elements create holes through which fine particles fall. At the same time, the rotation of the shafts allows the material to move on the line until the end of the screen
- Ballistic separators: they are based on the different trajectories followed by particles pushed by a fast rotor. Light materials like compost and heavy ones such as glasses and stones fall at different distances from the launch unit and are collected in separate hoppers;

- Wind shifts: the material is fed through a conveyor belt in a chamber where ventilation units blow or suck air, thus separating light fractions like paper and plastics from heavier ones like compost and metal.

➢ **Ferrous metal separators**: these machines are generally represented by magnetic belts rotating perpendicularly to the direction of the conveyor belt carrying the organic material to be refined and placed above the conveyor belt at short distance. Ferrous metals are attracted by the magnet and then released in a box placed at the end of the magnetic belt.

5.4.5.2 *Requirements for post-treatment*

In order to ensure that the compost produced is in compliance with generally accepted standards, it is recommendable to screen the product with a mesh size of 8-10mm. The over-screen fraction must be cleaned (through screening, wind shifting, magnetic separation) before being re-circulated in fresh mixtures.

Higher mesh sizes (90-150mm) can be suitable for intermediate screening, i.e. between ACT and curing step or in the middle of the latter.

5.4.6 Storage of compost

Compost, even when sieved and matured, is still a biologically active organic material. Regular mechanical turning is necessary in order to provide the oxygen demand for the residual microbial activity. As a rule, turning once every 3 to 4 weeks would meet this requirement.

During this final stage of the entire compost production process the majority of the nitrogen is bound to humic substances (>80%). Humification proceeds at a low steady activity level, especially if adequate moisture levels are maintained. This makes it necessary, even during the final storage of screened compost, to provide aerobic conditions. If the screened material (mainly at a mesh size of 10 to 25 mm) is stocked in piles of 1,5 to several meters in height, it compacts easily resulting in the formation of reductive, anaerobic zones. The consequences are denitrification, formation of ammonia, nitrous oxide (N_2O), sulphides and consequently possible low performance in germination and growth tests.

In addition, exposing the compost to any excess of water must be avoided not only to prevent anaerobic conditions forming, but also in order to prevent plant nutrients from leaching and being drained off.

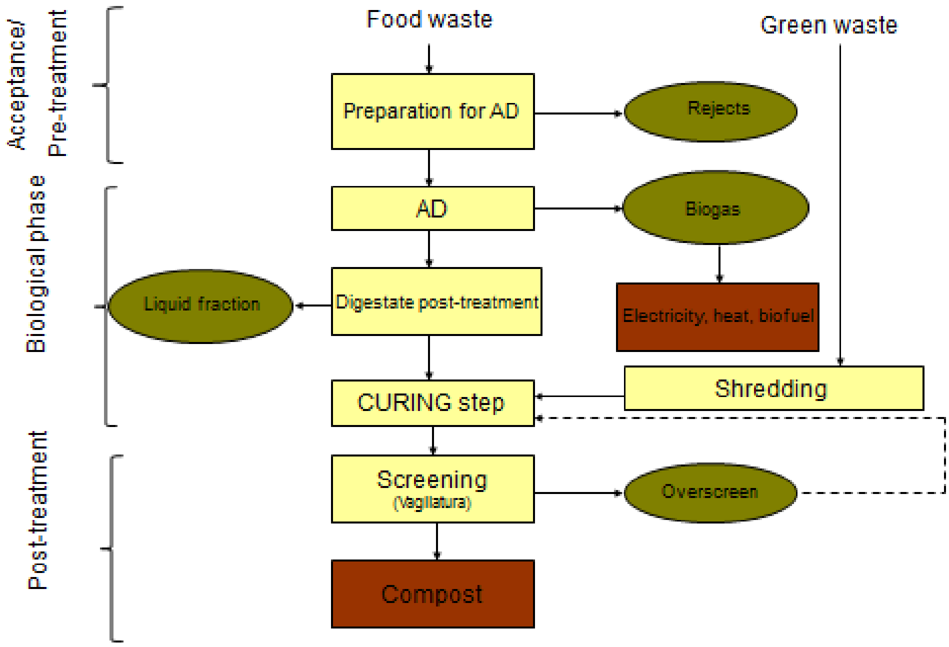
For these reasons, compost storage should be placed at least in a roofed area, large enough to stock the product for the time required to place it on the market (on average 2-months is recommended) in piles not higher than 2-3 m.

5.5 Anaerobic digestion: specific indications and requirements

This chapter deals with the case when the ACT step of composting is replaced by an AD step.

Figure 3 gives an example of the modification to the overall layout of the process.

Figure 3: Material flow of a combined AD and composting process



Due to the highly variable approaches of the AD process, the detailed explanation of which is not in the scope of this document, Annex I is provided in order to give information of the different types of AD technologies available on the market.

In the case of AD, depending on the technology the process can require a range of durations, or Hydraulic Retention Time (HRT), generally between 15 and 30 days. Possible variations depend on the thermal profile and the number of stages, as shown in Table 8 below.

Table 8: Typical duration of AD processes

Number of stages	HRT (days)	Thermal profile
Single stage	20-28	Mesophilic
	18-25	Thermophilic
Multi stage	18-23	Mesophilic
	15-20	Thermophilic

5.5.1 Input materials and additives

Acceptable organic waste has been listed in Chapter 5.1.

Additives to the fermentation may be applied in order to stabilise and optimise the anaerobic digestion process. The maximum quantity is 2 % of the fresh mass of the input material. Only those additives with proven effect should be used to improve the biogas production process. The following effective substances may be used:

- Flocculation agents and flocculation aids
- Trace elements

- Precipitants
- Enzymes
- Free and immobilized archaea, prokaryotic and eukaryotic biomass
- Emulgators (e.g. tensides)
- Anti-foam agents
- Complexing agents
- Anti-scalants
- Macromolecules (Na, Mg, Ca, Carbonate and Phosphate)

5.5.2 Pre-treatments

Mechanical pre-treatments include a number of operations which are strictly connected with the specific AD technology chosen including the following possible layouts:

A. Bags opening, screening, hydro-pulping/centrifuge/pressure, all aiming at removal of low density inert fractions

B. Shredding, screening, ferrous-metal removing, dens-metric separation, dilution with screw mixer

C. Shredding/bags opening, mixing with digestate (10 to 50% by weight)

The layout A is mainly used for wet digestion processes and the layout C for dry-batch processes performed in biocell-shaped reactors, while the layout B is mainly suitable for dry or semi-dry anaerobic digesters. Ingestate is subsequently fed to the digester according to organic loading rate (OLR) ranges (specific recommendations must be given by technology suppliers) that are summarised in Table 9 below.

Table 9: Ranges of organic loading rate (OLR) for different AD technologies

Technology	OLR (kg VS/m^3 digester * day)
Wet	2-4
Dry-continuous	3-8
Dry-batch	n.a.

5.5.3 Anaerobic biological phase

Depending on the technology adopted, digesters can be provided with equipment for:

- Mixing ingestate
- Maintaining the target process temperature
- Collecting heavy inert fractions at the bottom of the reactor (stones, sand)
- Collecting light inert fractions at the top of the reactors (e.g. plastics)
- Re-circulating digestate

Mixing equipment plays the role of increasing the rate of organic matter degradation, with the advantage of shortening the process duration and/or increasing biogas production. There are several different kinds of equipment, which can be summarised as in Table 10 below.

Table 10: Types of mixing equipment for AD

Type of mixing device	Advantages	Disadvantages
Gas injection – cover–mounted lances	• Lower maintenance and less hindrance to cleaning than bottom-mounted diffusers. • Effective against scum formation	• Corrosion of gas piping and equipment • High maintenance for compressor • Potential gas seal problem • Compressor problems if foam gets inside • Solids deposition • Plugging of gas lances
Gas injection – bottom mounted diffusers	• Better movement of bottom deposits than cover-mounted lances	• Corrosion of gas piping and equipment • High maintenance for compressor • Potential gas seal problem • Scum and foam problems • incomplete mixing • Plugging of diffusers. B • Bottom deposits alter mixing patterns • Breakage of bottom-mounted gas piping • Need of digester dewatering for maintenance
Mechanical stirring – low-speed turbines	• Good mixing efficiency	• Wear of impellers and shafts • Bearing failures • Long overhung loads • Interferences of impellers by rags • Requires oversized gear boxes • Gas leaks at shaft seal
Mechanical stirring – low-speed mixers	• Break up scum layers	• Not designed to mix entire tank contents • Bearing and gear box failures • Wear of impellers • Interference of impellers by rags
Mechanical pumping – internal or external draft tubes	• Good top-to-bottom mixing, minimal scum build-up	• Sensitive to liquid level • Corrosion and wear of impeller • Bearing and gear box failures • Requires oversized gear box • Plugging of draft tube by rags.
Biogas blowing from bottom	• Good even in high solid content system	• Higher energy costs for biogas compression

Temperature inside the digester must be kept at the temperature required by the specific technology chosen. Thermal adjustment can be made outside or inside the digester. In the first case, ingestate is preheated.

Inert fractions layering inside the digesters must be prevented by:

1) A strong removal activity during some of the mechanical pre-treatments (in particular, pulping systems provided with grit removal can be effective).
2) A continuous mixing inside the digester, an activity which helps residual floating inert to be taken out with digestate.
3) Proper design and slope of digester's floor facilitating the concentration of heavy inert in easy-to-remove positions, and light inert (above all plastics) to be periodically removed through superficial inspection and at removal points.

Several parameters have to be monitored along the process in order to assure optimal performance.

Table 11 summarises the key parameters. Some of the parameters have ranges of acceptability which allow the process to be performed under optimal conditions, while others are strictly dependent on the technology chosen, the kind of biomass treated and other local conditions. For this reason, it is important to define for each plant a database collecting the history and evolution of each parameter, monitoring in particular their consistency over time rather than their absolute values.

At the end of the process, a partial recirculation of digestate inside the digester is often required in order to:

- Help waste dilution and reduce the demand of fresh water
- Inoculate waste with anaerobic microflora in order to speed up the fermentation rate
- Pre-heat ingestate

Recirculation takes place by means of pipelines in wet and continuous dry technologies; on the other hand, dry batch technologies make use of simple wheel loaders to mix fresh waste with digestate removed from the fermentation reactors.

5.5.4 Curing phase of digestate

The shovellable digestate from dry AD or the de-watered solid digestate from wet AD consists of a relatively "dry" material (20-40% of dry matter content) which holds N and COD (Chemical Oxygen Demand) concentrations comparable with digestate. There may be still concerns on possible pathogens content, unless a pre-pasteurization unit has been installed prior to organic waste digestion. It is therefore necessary to consider a **post-composting step of the digestate solid fraction** which, owing to the strong reduction in putrescible organic compounds incurred during the anaerobic reactor, can be completed in merely 4-6 weeks.

The **aims of the post-composting** step are:

- The reduction of moisture content, due to the heat production from aerobic oxidation of organic matter and subsequent evaporation of water in excess

- The reduction of free mineral N concentration, by a combined action of ammonia evaporation and its turning into an organic form due to microbial actions

- Sanitization, due to the production of biogenic heat and the increase of temperature over 55-60°C for several days

- The obtainment of a solid product (i.e. compost) suitable for market than direct application on agricultural soil (horticulture, gardening, domestic applications, etc.).

With reference to the classification of composting technologies provided in Chapter 3, it is recommended to perform digestate composting in intensive forced-ventilated enclosed systems, in order to better control the foreseeable high ammonia load and residual CH_4 presence through the exhaust air cleaning system.

Table 11: Standard parameters and range for AD of organic waste

	Parameter	Optimum range	Typical monitoring frequency
MATERIAL IN FERMENTATION	Biogas composition	e.g. 55 – 65%	Daily
	pH	7-8	
	VFA	500-3.000 mg Acetic Acid eq/l	Weekly
	Alkalinity	3.000-5.000 mg$CaCO_3$/l	
	VOA/Alkalinity ratio	0,3-0,5	
	Redox potential	<-400 mV	
	Total Solids	<12% for wet digestion 10-20% for semi-dry dig. >20% for dry-digestion	
	Volatile Solids	>75% of D.M.	Monthly
	Nitrogen	Depending on the type of matrices fed	
	Ammonia	Always <3.000 mg/l (optimum 200-1.500 mg/l)	
	C/N ratio	<30	
	COD	100.000-140.000 mgO_2/l	
	BOD_5	50.000-90.000 mgO_2/l	
	Organic Carbon	Depending on the type of materials fed	
	Micro-elements	Co <1-5 ppm, Ni 5-20 ppm, Se < 0,05ppm, W<1 ppm, Fe 10-5000 ppm	Yearly
DIGESTATE	pH	7,5-8,5	Weekly
	Electrical conductivity		
	Total Solid	Depending on the type of material fed	Monthly
	Volatile Solids	Reduction about 60-70% of ingestate	
	COD	25.000-45.000 mgO_2/l	
	BOD_5	15.000-30.000 mgO_2/l	

	Total Nitrogen	Depending on the type of materials fed	
	Ammonium (NH_4)	Depending on the type of materials fed	

5.6 Quality of outputs, characterization and applications

Compost is a provider of humified (humus and clay-complex) organic matter and plant nutrients, and serves as organic soil improver, fertilizer and as a constituent in growing media and other blends. In this document **"<u>Compost</u>" shall mean** the final humus rich material containing at least 15% by weight of organic Carbon.

According to Brazilian national legislation, compost must comply with the standards provided by the following norms:

- *IN 23 of 31/08/2005 – Revisada e Substituída pela IN 25 de 27/07/2009 Aprova as definições e normas sobre as especificações e as garantias, as tolerâncias, o registro, a embalagem e a rotulagem dos fertilizantes orgânicos simples, mistos, compostos, organominerais e biofertilizantes destinados à agricultura.*

- *IN 27 of 05/06/2006 - Dispõe sobre fertilizantes, corretivos, inoculantes e biofertilizantes, para serem produzidos, importados ou comercializados, deverão atender aos limites estabelecidos no Anexos I, II, III, IV e V desta Instrução Normativa no que se refere às concentrações máximas admitidas para agentes fitotóxicos, patogênicos ao homem, animais e plantas, metais pesados tóxicos, pragas e ervas daninhas.*

- *Resolução Conama nº 375 of 29/08/2006 Define critérios e procedimentos para o uso agrícola de lodos de esgoto gerados em estações de tratamento de esgoto sanitário e seus produtos derivados, e dá outras providências.*

Compost in Brazil can be defined as "compost de lixo" according to Annex I, art. 1, paragraph III of the *IN 25/2009* and is described[6] as "the product obtained by separating the organic part of household solid waste and composting, resulting in safe use in agriculture product in view of the parameters set out in Annex III and the maximum limits for contaminants "

According to the above named legislation, organic fertilizers can be produced starting from a large set of organic residues (or waste types) and can be divided into four classes. For each compost class the technical norm IN 25/2009 issued by the MAPA[7] details the technical specification, limit values, registers, packaging and labelling. According to these definitions, the compost obtained by recycling organic waste of MSW origin can be an organic fertilizer in Class-A if only green waste is included as an input material or in Class-C if it includes any amount of organic waste from households, or in Class-D if the input feedstock also includes sludge from waste water treatment plants.

Organic fertilizers (I.e. Compost) obtained from organic waste according to Brazilian legislations	
Classe "A"	*organic fertilizer obtained from waste of vegetable origin, of animal origin or from agro-industries*
Classe "C"	*organic fertilizer obtained from (as feedstock for the composting process) any amount of domestic waste included in the input materials*

[6] The original wording is: *produto obtido pela separação da parte orgânica dos resíduos sólidos domiciliares e sua compostagem, resultando em produto de utilização segura na agricultura, atendendo aos pa râmetros estabelecidos no Anexo III e aos limites máximos estabelecidos para contaminantes*.

[7] Secretaria de Defesa Agropecuária (SDA/MAPA) nº. 25 de julho de 2009.

Classe "D"	*organic fertilizer obtained including (as feedstock for the composting process) also sludge from waste water treatment*

It must be stressed that current Brazilian legislations do not request organic waste from households to be separately collected but states that the organic fraction of MSW obtained from mechanical treatment (i.e. from MBT) might be a suitable input for the production of Class C compost.

According to Annex V of IN 27 of 05/06/2006, compost must comply with limits for heavy metals and pathogens. National limits for compost classes (those obtained from organic waste from MSW) are listed in Table 12 below. In the last column, "Further suggested parameters/limits" can help to increase the recognition of a higher quality product, aiming at being utilized for wider applications.

Table 12: Parameters for compost[8] obtained from organic waste

Parameter	m.u.	Clase A	Clase C	Clase D	Further suggested parameters/limits
Moisture content	%	≤50	≤50	≤70	≤50
pH		≥6,0	≥6,5	≥6,0	≤8,5
Organic C	% d.m.	≥15			≥20
Humic Acids +Fulvic Acids	% d.m.	no value provided			≥7
Total N	% d.m.	≥0,5			
Organic N	%Ntot (d.m.)	no value provided			≥80
C/N		≤20			
As	mg/kg d.m.	≤20			
Se	mg/kg d.m.	80			
Pb	mg/kg d.m.	≤150			
Cd	mg/kg d.m.	≤3			
Ni	mg/kg d.m.	≤70			
Hg	mg/kg d.m.	≤1			
Cr	mg/kg d.m.	≤200			
Plastic, glass, metals ≥ 2 mm	%d.m.	no value provided			≤0,5
Inert (Stones) ≥ 5 mm	%d.m.	no value provided			≤5
Salmonellae	MPN/10g d.m.	Absent			
Thermo-tolerant coliforms	MPN/g d.m.	≤1.000			
Viable eggs of helminths	n°/4g d.m.	1			
Germination index (30% dilution)	%	no value provided			≥ 60

Limitations in the application of "Clase D" compost are provided by Annex IV of IN 25/2009, where the following restrictions are reported:

- Application only by mechanized equipment
- For handling and application, individual protection devices must be worn

[8] It is advisable to monitor compost quality by means of samples analyses with the frequency calculated by the following formula: N° samples (n°/y) = throughput capacity (t/y) / 10.000 + 1, for a maximum of 12 samples/year

- Application is prohibited on pastures and horticultural crops, tubers and roots, flooded crops and other crops whose edible part are in contact with the ground

For compost produced from APBs, instead

- It is permitted to use on pastures and forages only through soil incorporation
- In the case of grassland, grazing is allowed only after 40 days after incorporation of the fertilizer to the soil.
- It is forbidden the utilization for animal feeding
- Compost must be stored in a way that prevents ruminants

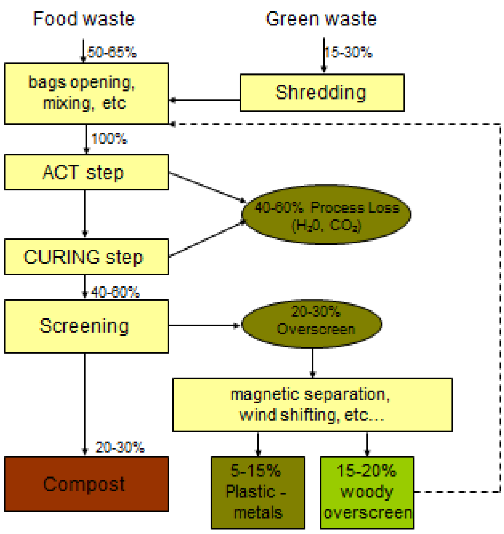
It has to be clarified by competent authorities whether food waste has to be considered among ABPs, in which case, according to this document, this product would fall under "Clase C" compost. In Europe for example, specific derogations apply in several European legislations.

Registration of the product, labelling and quality assessment instructions must comply with the law on fertilizers IN 25/09 and the Decree Nº 4.954/2004 (as modified by Decree Nº 8.059/2013).

5.7 Average mass balance

The average mass balance for a typical composting process is shown in Figure 4 below.

Figure 4: Example of mass-balance of a composting process



The average mass balance for AD in different operating conditions is shown in

Figure 5, Figure 6 and

Figure 7. In order to give an idea of the differences among the technological approaches for anaerobic digestion of organic waste, three illustrative mass balances are proposed, referred to:

- A wet fermentation approach
- A dry-continuous fermentation approach
- A dry-batch fermentation approach

In all cases, digestate is further treated aerobically for compost production.

Figure 5: Example of mass-balance of a combined AD (wet fermentation) and composting process

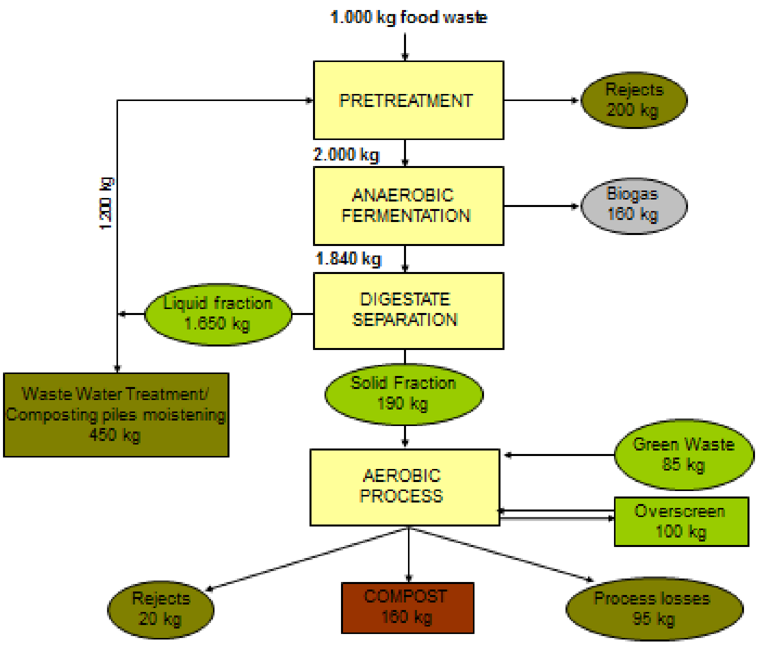


Figure 6: Example of mass-balance of a combined AD (dry continuous fermentation) and composting process

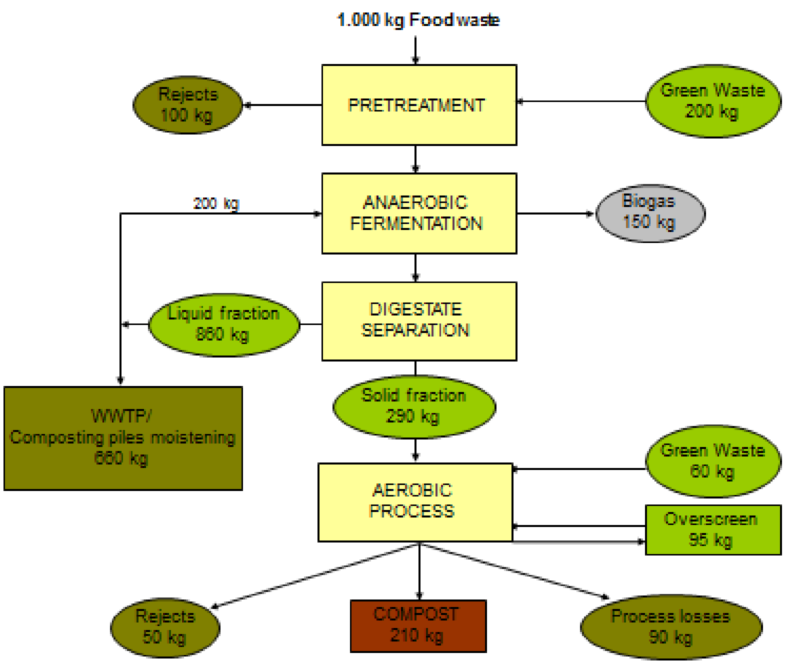
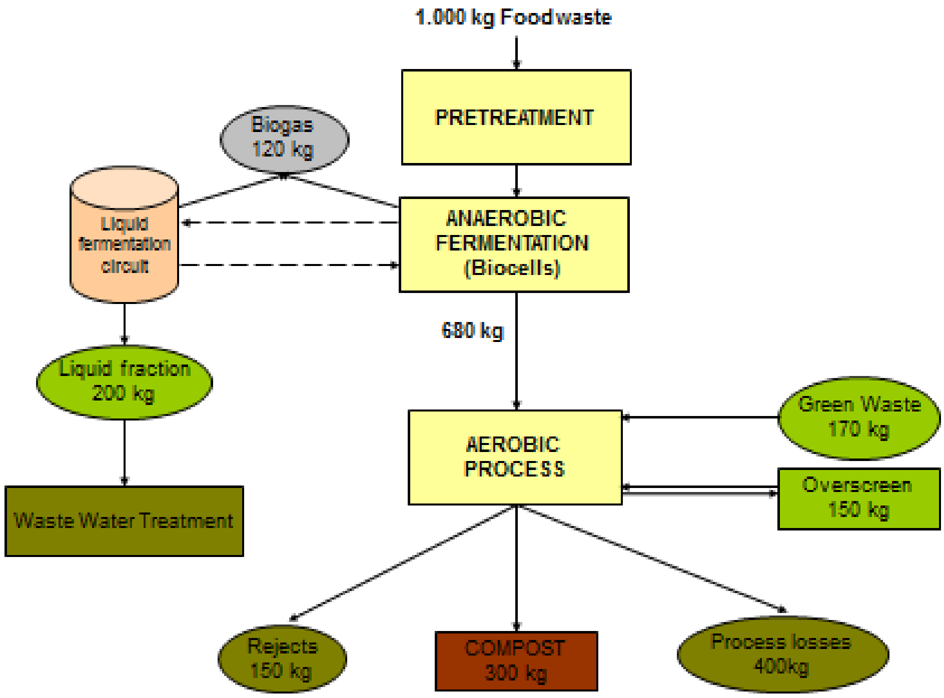


Figure 7: Example of mass-balance of a combined AD (dry batch fermentation) and composting process



5.8 Footprint of medium/high-tech facilities

The footprint of the evaluated composting facilities ranges, depending on the composting system, from 0,5 to 1,5 m²/t input feedstock. It reduces with increased windrow height, premature removal to storage for maturation in large volume trapezoidal windrows and with increased processing intensity. The first two factors reduce the compost quality. Table 13 provides the range of area required to operate open windrow systems according to the technical description for licensing compost plants.

Table 13: Range of footprint of open windrow composting plants depending on turning technology, pile size and process management

	Composting	AD
Area demand (m²) per tonnes of input material	0,67 - 1,67 m²/t	0,3 – 1 m²/t

The overall footprint accounts for all buildings and technical areas required for the process (in brackets, area required for integrated AD/composting processes):

- Reception/pre-treatment hall
- ACT step hall (anaerobic fermentation reactors)
- (digestate mechanical post-treatment)
- Curing step hall (digestate composting hall)
- (biogas cleaning, storage and utilization)

- Compost storage area
- Air cleaning/water cleaning equipment
- Offices/warehouses

5.9 Technical requirements on the design and operation

5.9.1 Plant general design

In order to prevent odour nuisance on sensitive receptors (hospitals, health resorts, residential dwellings, city centres, recreation and sport facilities, schools, public parks, playgrounds, camping sites, restaurants. etc.), a minimum distance of 250-500 m (depending on the overall throughput and, in particular, on the amount of putrescible organic waste) should be observed when planning composting/AD plants. If the given critical distances between potentially odour emitting sites of operation and nearest settlements are not met, a detailed odour modelling exercise must be performed by the applicant in order to assess the suitability of the location based on the probability of the occurrence of nuisance to the neighbourhood caused by odour problems.

- The plant shall be settled on a sealed paving in order to prevent leachate percolation through soil to groundwater.
- Waste acceptance, pre-treatment and ACT step areas must be kept in enclosed buildings provided with fast opening doors (a further improvement can be double sequential doors for receiving waste and tipping, high pressure air barriers activated when doors are open). The enclosure of curing phase and compost storage areas should be evaluated through odour dispersion modelling.
- Digestate storage tanks shall be covered in order to prevent fugitive methane emissions. Exhaust air can be fed to biogas cleaning systems and used for further exploitation.
- All enclosed buildings in which waste at any stage of the process is present must be provided with an air suction equipment able to guarantee at least the following air exchange performances:
    - 2 times the volume of the building (tipping areas, pre-treatment area, buildings hosting waste in-vessels such as bio-containers and bio-cells)
    - 3 times the volume of the building (buildings hosting waste under the ACT step not encapsulated in vessels, such as piles and windrows). In case of dynamic systems with the presence of workers inside the buildings, air exchange volume must be at least 4 times the volume of the buildings
    - 2 times the volume of the building (in the case of indoor curing step)
- Takeover / tipping and intermediate storage of raw feedstocks need to be carried out in a bunker with side walls, in order to facilitate the wheel loader activity.
- A weighbridge must be installed at the entrance of facilities in order to record waste accepted and reject disposed.
- Tipping area needs to be designed for complete emptying and cleaning.
- There needs to be sufficient tipping capacity, including a buffer equivalent to a 2-3 day tipping, in the case of an operational breakdown.
- In the tipping area different bunkers must be present for temporary storage of
    - Food waste,

- Green waste. divided in a “fresh green waste” and a pre-shredded green waste” zone
- Organic waste and other non-woody materials with a higher water and nitrogen content
- Over-screen materials deriving from final post-treatments to be re-circulated in the process

This is necessary in order to provide separate pre-processing and allow the specific mixing of the ingredients for the preparation of the starting mixture;

- ➢ Stationary indoor conveyors should be enclosed to minimize dust and aerosol emissions, and discharge points should be equipped with additional vacuum systems.
- ➢ An adequate area/container must be reserved for the storage of rejects (both from pre- and post-treatments) or batch failures (compost not complying to the product standards) prior to disposal or further treatment
- ➢ In order to prevent any possible cross-contamination of the sanitized compost, strictly separate clean and dirty areas shall be planned. This also applies to the use of technology, e.g. wheel loaders with exchangeable buckets.
- ➢ All equipment, instruments and installations must comply with all existing national regulations.

5.9.2 Prevention of odour emission

Keeping optimal conditions for the aerobic process is the first primary method to reduce the production of excessive odours. This is summarized by the following recommendations:

- ➢ Prepare a good initial mixture, in terms of density, moisture content, C/N ratio (see Chapter 5.4.1)
- ➢ Guarantee a proper oxygenation of the mixture along the biological phases (see Chapter 5.4.2)
- ➢ Monitor temperature profile and moisture content along the process, and put in place appropriate solutions in order to maintain these parameters within acceptable ranges (see Chapter 5.4.4);

At facilities that operate partly open systems located at sites with problematic dispersion conditions, site procedures could need to be modified in order to prevent problems arising. As a minimum, each site should:

- Install an on-site weather station
- Undertake modified operating procedures to accommodate certain weather conditions that are likely to give rise to odour problems
- Immediate and efficient processing of delivered waste materials
- Keep the facility clean - regular cleaning of surfaces, equipment and all traffic routes etc.

5.9.3 Management of exhaust air

The entire amount of air sucked from the enclosed buildings must be pre-treated before its release into the atmosphere in order to abate odorous compounds. Bio-filters are the recommended devices to be adopted. In order to guarantee optimal performances and they must be properly sized and managed, the main construction requirements are elaborated in the following sub-chapters.

5.9.3.1 *Biofilters*

Bio-filters management and maintenance shall consider the following aspects:

- A high NH_3 load in the exhaust gas (e.g. > 50mg/Nm^3). This is particularly true when composting digestate therefore necessitates a preceding treatment with an acid scrubber (NH3 stripping.
- The humidity of the filter material should be kept at the optimum operational level (as indicated by the supplier) by appropriate measures such as through an air humidifier, irrigation facility.
- The extractor fan needs to be configured and capable of operating at increased pressures caused by compaction of the filter medium.
- The relative humidity of the supply air should be kept at saturation, supplied through an air humidifier.
- The supply air temperature should be kept between + 10 and + 40 °C (optimum at 25 - 30 °C)
- The filter medium must be built in such a way that the waste air is distributed evenly through it and may not escape along the boundary between filter medium and container walls.
- Variability in the composition of the input gas load should be minimized.
- The filter medium must be replaced periodically before it reaches the end of its active life.

In order to evaluate bio-filtration efficiency, it is recommended to monitor the following parameters in the air before and after bio-filtration:

- NH_3 concentration - a limit of 5mg/Nm^3 after bio-filtration is recommended.
- Odour concentration (according to the dynamic olfactometry method, EN 13725)- a limit of 300 O.U./m^3 for clean air (average of several samplings) is recommended.
- Visual inspection of the filter surface (to look for the occurrence of channels of least resistance where the air is released, compaction zones), preferably early in the morning (when steam formation is likely to be at its greatest due to cooler ambient temperatures).
- Measure the inlet air temperature and the filtering material temperature (the filtering material should always be slightly warmer than the inlet air).
- Measure, at least monthly, the counter pressure of the filter in order to detect compaction zones in the filter medium.

Table 14: Parameters for exhaust air management

Parameter	Range/value
Retention time*	≥36 minutes
Specific load*	80-100 m^3/h * m^3 of filtering material
Modularity (bio-filters modular design in order to provide the required maintenance to each module without compromising the overall air treatment capacity of the plant)	at least 3 modules
Bio-filtration material height	100-200 cm
Bio-filtration material	5-15cm long lignin based chips are the most common filtering materials. In general, any material capable to support biofilm and with good bulking properties can be suitable.

*RT and SL are connected through the following formula: RT = 3600/SL (36-45 sec)

5.9.3.2 *Scrubbers*

The most important technical principles and scrubber systems include:

- Activated sludge process
- Spray scrubber
- Column scrubber
- Sprinkle bed scrubber
- Packed tower scrubber / solid state bedding
- Tricking filter
- Percolating filter.

Scrubber systems are similar to bio-filters in that they require a large contact area in order to achieve rapid and intensive exchange between vapour and liquid phases. In composting systems, exhaust air scrubbers have limited applications. Due to short contact time between exhaust air and washing medium, the elimination of odorous substances may not be satisfactory. Additionally, peak loads may only be buffered to a low extent. Therefore scrubbers in high capacity composting plants are only installed as a preceding device (e.g. to reduce the ammonia content) before a conventional bio-filter.

Table 15: Examples of chemical and oxidative scrubber systems (Jüstel, 1987 and Krill *et al*., 1994)

Washing agent solvent	Reaction of the absorbent	Absorbent	Stripped compounds
Water	Alkaline	Sodium hydroxide, Potassium hydroxide, Sodium bi-carbonate, among others	Hydrogen sulphide, Organic acids, Phenol, cresols Mercaptane
Water	Acid	Nitric acid	Ammonia
		Sulphuric acid	Ammonia, Amines, Pyridines
Water	Oxidising	Potassium permanganate, Hydrogen peroxide [1], Ozone [1], sodium hypo chlorite [2], Chloride [2], among others.	Hydrogen sulphide, Sulphur dioxide, all organic odour compounds

[1] additional UV-radiation increases the reactivity

[2] application is questionable, because toxic or explosive and/or hardly degradable oxidation products may be formed

5.9.3.3 *Troubleshooting*

Error! Reference source not found. shows the results of a survey on the frequently occurring malfunctions at a facility for waste air purification (Bio-filter), the effects of the emissions and possible solutions.

Table 16: Effects and adjustments of malfunctions of a bio-filter by a facility operator

Problem	Consequences	Possible solutions
High odour units in the inlet air	High filter charges. Despite high efficacy, increased exhaust air concentration	Optimize starting mixtures and composting process, inlet air preconditioning, e.g. by a scrubber
High variability in odour units and /or high temperatures in the inlet air	High variability in the nutrient content in the supply air for the micro-organisms	Mixing of different air flow sources, eventually conditioning of inlet air
Quick or uneven degradation of the filter medium, uneven air flow	Increase in the counter pressure in the filter, uneven efficacy, environmental gas breakthrough	Periodical turning or exchange of the filter medium, use filter media with a high operating life
Drying out of the filter medium	Decrease of the efficacy resulting in gas breakthrough	Moistening of the inlet air and/or of the filter surface
Filter medium is exhausted	Decrease of the efficacy resulting in gas breakthrough	Regular inspection, turning or exchange of the filter medium

5.9.3.4 *Odour assessments through dynamic olfactometry*

Odours are generally measured using a panel of test persons who are presented with the test gas diluted in an odour-free gas. They sniff the gasses through a 'sniffing port' and are asked to report the presence or absence of an odour.

The establishment of odour thresholds by using test persons is an objective analytical procedure that has been described in a European standard (EN 13725). The method is based on dilution of the sample to the odour threshold (the point at which the odour is only perceptible to 50 % of the test panel). The odour concentration is derived from the dilution required to reach the threshold, and is quoted in European Odour Units per volume of air (OU_E/m^3).

Response deviations of up to three dilution steps as a rule can be expected in individual measurements (12 series, 3 repetitions, 4 test persons). Variations at the 95%-confidence interval may reach a factor of 3 within repeated measurements in the same lab. That means that for a true mean value of 300 OU_E/m^3, single measurement results of 200 up to 450 OU_E/m^3 would be acceptable. A comparison between different labs[9] has suggested even greater variance (by a factor of four). Thus limit values for odour concentrations must be set carefully and measurements and value interpretations need to accommodate allowable deviations between individual measurements.

[9] VDI, 2002. Biological waste gas purification - Biofilters, VDI (Verein Deutscher Ingenieure) guideline 3477

It is now possible to predict odour emissions (frequency and intensity) and dispersion from planned composting facilities based on knowledge about potential feedstock characteristics, operating procedures, technologies employed, local climatic conditions and other relevant factors. This is an important tool in order to assess projects sited at critical locations. Experience also shows that if a minimum distance to settlements is observed, coupled with the application of basic management tools, odour problems can be avoided also by open windrow composting site. Therefore many countries have established minimum distance criteria between composting sites and 'sensitive receptors'. They are simple to handle but less flexible than individual site-specific assessments based on odour prognosis models. Where minimum distances have been specified, modelling would only be necessary if the distance to the next settlement falls short of a certain critical figure.

In order to keep such approval distance standards flexible, minimum distances criteria should be based on annual throughput and the type of material composted.

5.9.4 Workers health and safety

Composting plants' design and operations have to be in compliance with the relevant Brazilian health and safety regulations.

In order to prevent risks for workers, particularly biological risks associated with bio-aerosol and dust inhalation, all operations inside the facility must be performed inside conditioned vehicles; or if performed manually, workers must wear appropriate protective equipment including disposable suits, safety gloves and shoes, dust-filtering breathe masks, glasses and helmet.

A worker's behaviour manual must be produced and communicated in which needs to account for:

- Personal hygiene when entering and exiting the plant. The employer shall ensure that all work clothes are cleaned regularly. Lockers, showers, toilets must be equipped with separated clean and dirty areas.
- Adequate training in handling waste and the utilization of equipment.
- Periodical health check against the most probable risks: biological agents, dust, noise, vibrations (for those spending part of their activity on wheel loaders).
- Allowing smoking, eating and the consumption of food in specially designated areas only.
- Prohibiting any unprotected persons from staying in an enclosed composting area.

Recommended operational measures:

- When working inside the buildings, turning and discharging windrows, respiratory protection should be used. Furthermore, compost turners should be equipped with dust covers and moisture injection equipment in order to reduce the release of dust. Temporal coordination with prevalent winds and attention to land-use in the vicinity can help reduce exposure to neighbours.
- Immediate processing of input organic waste should be carried out in order to prevent attracting rodents, birds and insects.
- Regular cleaning and decontamination of the areas of the facility that are exposed to fresh feedstocks (i.e. that have not been sanitized) should be carried out in order to reduce unwanted microbial growth.
- The operational processes should be designed to avoid employees working permanently in ACT areas.

- The cleaning and servicing of equipment used in the intensive composting area should be undertaken in non-contaminated areas.

- Doors and windows should be kept closed during operation. The cleanliness of the control cabin should be maintained.

- With cleansing and servicing work, which generate considerable amounts of microbial aerosols (e.g. bio-filter exchange), respiratory protection should always be worn.

- The driveways and working areas should be moistened, kept dust-free and cleaned regularly preferably with a sweeper or industrial vacuum cleaner. When using of high pressure cleaner respiratory protection should be worn. Cleansing with a broom should be avoided.

- Avoid untreated process water from coming into contact with sanitized composting materials to prevent contamination.

5.9.5 Waste water management

Generally, leachate and run-off water may not be allowed to drain off into the soil without prior treatment, as it has the potential to pollute ground and surface waters therefore organic waste recycling must be carried out on a sealed pavement and waste water (leachate and run-off) must be captured.

The intermediate waste water tank needs to be sized taking into account the size of the site and rainfall in order to hold leachate and run-off from all paved areas where compost or raw materials are stored or treated.

In addition, a waste water management plan must ensure adequate treatment and reuse of the waste water.

5.9.5.1 *Origin and types of waste water*

Waste water at a composting facility arises from a number of different sources and stages during composting:

Leachate, which is liquid that percolates through composting material or resulting from the metabolic activity inside the composting pile

Condensate on equipment and in pipes

Waste water from cleaning activities

Precipitation water in open areas (run-off water from compost piles surface as well as from traffic routes)

Precipitation water from roofs

5.9.5.2 *Waste water prevention*

It is always best to prevent waste water arising in the first place. Good practice for prevention include:

- Covering open windrows with geo-textiles or composting under a roofed structure.
- Mixing feedstocks with additives that provide a good structure and water holding capacity. This increases the water holding capacity and absorbs leachate and process water.
- Frequently turning windrows to increase the rate of evaporation of water.
- Adjusting the initial moisture content of the feedstocks to the optimum values recommended.

5.9.5.3 *Waste water collection and use*

Waste water needs to be collected and treated according to the requirements of water protection principles - to prevent pollution of ground and surface wasters due to its high biological oxygen demand and nutrient content.

It is important to note that waste water arising in areas where the composting feedstocks have not been sanitised fully to destroy unwanted pathogens (e.g. tipping areas, storage of untreated feedstocks, the first active decomposition) should not be used to add moisture to sanitised compost piles (e.g. mature compost where no further thermal hygienization could be expected), in order to prevent re-contamination of the compost.

5.9.5.4 *Construction elements of a waste water drainage system*

All storage and treatment areas must allow for the controlled drainage of all types of waste water to avoid water-logging at the windrow-base. This is achieved by constructing the composting area on a slight slope to avoid water stagnating. The minimum slope of both pavement and drain/aeration pipes below the windrows should be of at least 1%, or 2% for open facilities or sections where annual precipitation exceeds 500mm and whenever ACT step is carried out without any forced aeration system in place. A minimum slope of 3% is required for the tipping area and intermediate storage of waste materials with high water content. The slope should not exceed 5% as shifting (undesired relocation) of the windrow may require additional handling.

It is important to ensure that leachate from a windrow cannot cross over and be absorbed by another windrow, as it may lead to cross-contamination.

Waste water collection and management must be differentiated on the basis of water's origin. Indications are also given on proper sizing for storage tanks. In the case of superficial groundwater table, a double tank (one inside the other) must be provided or, alternatively, off-the –ground storage tanks must be considered.

5.9.5.5 *Process waters (leachate and condensation water) in closed building or under roofed areas from waste tipping to ACT step*

Water that percolates through composting material- press or process water from the metabolic activity inside the composting pile, alongside with condensate on equipment and in pipes, must be re-circulated in the composting or AD process, with the provided recommendations about cross contamination avoidance (re-circulation prior to waste sanitization). In order to collect process waters, the capacity of the storage tank complies with the following formula:

$C = R \times Q \times T : 1000$

Where:

C = capacity of the tank (m3)

R = water release coefficient (L/t*day); R ranges between 2 and 5, where the minimum value is applied to forcibly ventilated systems by means of air blowing from the floor, and the maximum value to forcibly ventilated systems by means of air sucking from the floor. Waste tipping areas where wet and putrescible waste are received, R is considered to be equal to 5

Q = amount (t) of organic waste simultaneously present in the plant

T = maximum time (days) between two consecutive wetting operations

5.9.5.6 *Liquid digestate*

This fraction which is the main output from anaerobic digestion phase (typical range 40-100% of organic waste treated) can be either:

- Recycled in the post-composting step (exploiting the evaporation power of composting processes)
- Recycled in the anaerobic digester (possibly after a depuration step in order to reduce N content)
- Disposed to a WWTP, or treated inside the AD plant, above all in order to reduce $N\text{-}NH_3$, BOD, COD, Cl^- and Na^+

5.9.5.7 *Process waters (leachate) from outdoor curing area*

This water must be used for biomass wetting, irrespectively to the process step since it is considered sanitised. In order to collect these process waters, the capacity of the storage tank complies with the following formula:

$$C = S * (P:1000) / 30$$

Where:

C = capacity of the tank (m3)

S = curing area (m2)

P = yearly average rainfall (mm)

The excess of process waters must be treated as a liquid waste and treated in a WWTP before being released to a receiving water body.

5.9.5.8 *Rainwater*

Rainwater falling on areas unaffected by trucks or loaders' transit can be released to a receiving water body, but must be separated as "first rain water". Otherwise it has to be treated (oil and grit removal) before being recirculated in the process or released to a receiving water body. In order to collect these process waters, the capacity of the storage tank must be able to collect the first 5 mm or the first 15 minutes of a rain event.

5.9.5.9 *Cleaning waters*

To be treated or released to the sewer according the national regulation.

5.9.6 Noise Emissions

Noise can be defined as unwanted sound. Generally, mobile and/or stationary technical equipment is used on composting facilities such as screens, wheel loader, grinders, turners, blenders, ventilators, conveyor belts which are a sources of noise emission. Furthermore traffic movements to, from and within the site will add to the noise load.

For this reason consideration must be given to noise protection for workers and residents nearby, during both the construction as well as the operation of facilities. Requirements regarding worker-related noise protection include:

- At the workplace the noise load may not exceed 85 dB for more than 8 hours per day given a 40-hour working week.
- With noise loads exceeding this limit protective measures must be taken. In addition, appropriate personal protective equipment (e.g. ear protection) must be provided by the employer and worn by the workers.

6 Small-scale, low-tech facilities for recycling organic waste

This chapter will recall some information, indications and recommendations provided in Chapter 5, properly adapted to the context of small-scale, low-tech facilities.

According to the PGIRS, several types of small scale composting facilities are considered, with treatment capacities of a few tons/day up to 50 tons/day.

According to the directives from the IV "*Conferência Municipal de Meio Ambiente*", it is recommended to implement composting *in-situ* and to use compost near the production *sites* for urban agriculture purposes („*compostagem e biodigestão in situ e uso de composto nos locais de geração, em agricultura urbana*"). The PGIRS then suggests the implementation of community composting in low-income areas with difficult access to the separate collection service („*implantação de soluções locais de compostagem comunitária em comunidades de baixa renda e com dificuldades de acesso para coleta*"). Accordingly a strategy for *in-situ* composting is defined as follows:

- Implementing composting and digestion in homes and high-rise buildings, with adequate technical, public and private support for the borough ("*Implantar compostagem e biodigestão em domicílios e condomínios, com adequado apoio técnico público e privado, por subprefeitura*")
- Promoting composting solutions associated with urban gardens, supporting social empowerment, generating jobs and local income ("*Implantar soluções de compostagem comunitária associadas a hortas urbanas, fomentando o empoderamento social, gerando trabalho e renda local, combatendo vetores e melhorando a limpeza pública*")
- For composting in-situ in municipal public facilities:
    - Implementing composting of organic waste in municipal educational institutions, integrated with urban gardens ("*Implantar compostagem de resíduos orgânicos em estabelecimentos municipais de ensino, integrada às hortas urbanas, ...*")
    - Implementing composting of organic waste by markets, grocery stores, local health facilities, parks and squares, sports and other public facilities, integrated with urban gardens and urban farming ("*Implantar compostagem de resíduos orgânicos em mercados, sacolões, estabelecimentos municipais de saúde, parques e praças, equipamentos esportivos e o utros estabelecimentos públicos, integrada às hortas urbanas e agricultura familiar agroecológica*");
- Implementing "green waste" composting, in order to provide garden waste composting in 69 parks ("Estabelecer a compostagem de podas nos 69 parques implantados")
- Adapting public works codes to include spaces for composting, to facilitate composting *in-situ*

In this chapter, indications are provided for the implementation and operation of decentralized composting sites where small amounts of organic waste (from few hundreds to few thousand tons per year) can be recycled. Both green waste composting and mixed organic waste composting will be considered, even though it must be stressed that:

- From a strategic point of view, most of the "green waste" should be used also at large centralized composting facilities, serving as structuring material for the composting process.
- Small-scale food waste composting using simple technologies with low environmental protection devices should mix with green waste, in order to increase the mixture's porosity and minimize odour generation and dispersion.

6.1 Acceptable input waste and characterization

With reference to the categories of organic waste described in Chapter 5.1, the following organic waste can be accepted at small-scale, low-tech facilities:

Table 17: Acceptable organic input waste at small-scale low-tech composting facilities

Putrescible organic waste (high Nitrogen concentration, high moisture content, low permeability to air)	Lignin/cellulose based organic waste (high Carbon concentration, low moisture content, high permeability to air)
Food waste (OFMSW) Waste from markets (vegetable and fruit rejects)	Yard waste (e.g. grass, tree and shrub pruning, flowers etc.) Waste from private gardens or from public areas such as parks and playgrounds[1] Wood (solid or chippings) Saw dust/shavings (untreated wood only) Paper, cardboard and other compostable packaging (e.g. wood fibre, cotton fibre, jute)

[1] mowing from green strips of highly frequented roads should be excluded

In principle, the use of the acceptable input waste listed in the previous paragraph should allow the production of a high quality final product. As described in Chapter 5.2, attention must be paid to impurities and physical contaminants present in food waste and market waste. For small composting facilities there are fewer opportunities for the mechanical removal of these undesired materials. As an example, the CIC classification of food waste only accept "class A" food and market waste, since poorer quality waste would be translated in time-demanding manual sorting of compost after the biological step.

6.2 Composting: main techniques

The biological process develops through the same phases as described in Chapter 5.4 which are recalled accordingly in this Chapter.

6.2.1 Mechanical pre-treatments

Pre-treatments are mainly aimed at "conditioning" the physical nature of waste to be biologically processed by:

- Shredding/de-fibering lignin based woody organic waste
- Opening bags containing the putrescible organic waste fraction
- Mixing/homogenizing different types of organic waste
- Drying/moistening the starting mixture

6.2.1.1 *Requirements for pre-treatment*

Only bulky non-compostable materials shall be manually removed at this stage, leaving most of the sorting work after the biological phase.

Cheaper shredding solutions for green waste pre-treatment in small facilities can be outsourced to farmers or other providers. In this case, it is important to provide space enough for a long-term storage of green waste in order to optimize shredding activity, concentrating it in a few days per year.

According to the PGIRS, some of the small composting facilities shall be dedicated to green waste from parks and gardens. In this case, no further pre-treatments are required but mixing shredded green waste with recirculated overscreen from mechanical post-treatments. Otherwise, in the case of food waste treatment, input materials shall be a blended with shredded green waste in order to produce the right “starting mixture” which will undergo the biological process (see Chapter 5.4.1). Small or very small facilities can replace screw mixers by:

- **Mixing waste** by a wheel loader. In this case, a proper volume, generally a multiple of the volume of the bucket, of different types of organic waste (including the over-screen fraction recovered from mechanical post-treatments) shall be poured on the ground in a pile, and then repeatedly turned before being placed in the biological phase area.

- **Placing the different types of waste in thin layers** directly shaping the final windrows. This operation can be either done manually or by a wheel loader. It is important that each layer do not exceed a thickness of 20-30cm in order to allow a sufficient contact between the different types of materials, and thus a faster biological process.

According to the available technologies for the biological phase, the starting mixture should have a density not exceeding 0,65 t/m^3 for non-ventilated dynamic windrows and 0,55 t/ m^3 for non-ventilated static windrows. Incorporating higher amounts of green waste including the over-screen fraction from mechanical post-treatment will allow lower densities in the starting mixture. For this reason, the plant should be able to receive at least 1 ton of green waste for each ton of putrescible waste treated.

6.2.2 Biological phase

The biological phase of the composting process is split into the two main steps described in Chapter 5.4.2:

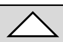
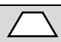
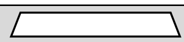
The distinction between these steps tends to lose meaning when green waste is the only type of organic waste treated in a composting facility, since the low amounts of putrescible compounds will rather turn the process into a long lasting curing step.

6.2.2.1 *ACT step*

Small composting facilities mostly rely on open non-ventilated systems where windrow oxygenation can be assured by a combination of passive air convection and periodical turnings.

Typical open systems (possibly under a roof) are aerated static piles and turned windrows. A variety of windrow-geometries, ranging from triangular to trapezoidal can be realized, as summarized in Table 18.

Table 18: Typical windrow-geometries for composting

Shape			
Height	1,2 – 2 m	2 – 2,5 m	1,5 – 4 m
Width	3 – 4 m	4 – 6 m	6 – 75 m
Length	30m – (depending on the throughput)	30m – (depending on the throughput)	10m - (depending on the throughput)

The triangular windrow shape has been proven in practice to be the most ideal form of windrow composting. The optimal windrow dimensions are 3 m base width and 1,4 m in height. Proper windrow turners can guarantee to produce the "ideal" shape, although simple wheel loaders operated by experienced operators can produce similar results. This kind of windrows can be aerated either passively or through forced ventilation, possibly coupled with periodical turnings.

Typical trapezoidal windrows are mostly found in enclosed facilities with forced aeration and automated turning systems.

Large trapezoidal windrows are generally found in green waste composting facilities with restricted space availability. At a windrow height up to 4 m there is a great need for structural materials. This shape is hardly compatible with static composting due to the likely formation of compaction zones.

6.2.2.2 *Curing step*

Same as for ACT, the curing step can be performed in triangular or trapezoidal windrows. Forced ventilation is no longer a need, since ventilation can be more easily ensured through passive aeration or periodical turnings.

Decomposition and transformation of organic substances are facilitated through:

- Regular turnings associated with passive aeration
- Maintenance of the necessary moisture content:
    - Through periodical watering
    - Covering triangular windrows (especially those with a height below 1,5 m) with a mulching layer (10-15 cm of straw, mature compost or other natural material) in warm and dry seasons. Trapezoidal or table windrows with a larger cross-section must not be covered.
    - Performing the curing step on a roofed ground, since yearly rain in Sao Paulo exceeds[10] 1.000 mm.

6.2.3 Main equipment used for the biological phase

- Machinery suitable for turning and material manipulation such as a wheel loader; a turning machine is recommended for dynamic windrows or for facilities with throughput higher than 5.000 t/y including significant amounts of food waste
- Devices for temperature measurements such as manual probes
- Devices for maintaining the optimum water content. Often, turning machines are equipped with water sprinkling function active during the turning operations; otherwise, manual irrigation with a simple irrigation hose can fit for purpose.

6.2.4 Requirements for the biological phase

6.2.4.1 *Air supply*

In principle, the same indications given in Chapter 5.4.2 shall be followed. The further option of passively ventilated windrows without turnings can be accepted provided that windrows have a triangular cross section with a height below 1,2m during ACT and 1,5m during the curing step. In this case, it is recommended

[10] Precipitation in Sao Paulo: Max 200mm/month and cumulative (annual) 1055mm. From: http://www.worldweatheronline.com/sao-paulo-weather-averages/sao-paulo/br.aspx

to monitor the O_2 content at least weekly in order to detect and take measures to avoid possible anaerobic situations.

6.2.4.2 *Process optimization and monitoring*

In principle, the same indications given in Chapter 5.4.2 shall be followed. In order to optimize process monitoring in small composting facilities, the following recommendations are available:

- O_2 concentration: to be monitored at least weekly in passively aerated windrows without turnings, until acceptable stable conditions are obtained. Measurement must be repeated in the case of significant changes in waste or climate conditions which could largely affect windrows.

- Temperature: it is important to verify that time-temperature profiles are such that sanitization conditions (see Table 19 below) are met. For this reason, a daily temperature measurement in ACT (for each windrow, 3 points at 2 distinct depth must be measured and registered) and a weekly measurement in the curing step are required.

Table 19: Time-temperature profiles for sanitization during low-tech composting processes

Temperature	Time	Additional requirements
≥55°C	5 days	After sanitization, appropriate measures must be taken in order to avoid any cross contamination between sanitized and fresh organic waste.
≥60°C	4 days	
≥65°C	3 days	
40°C*	5 days	at least 55°C for 4 consecutive hour

* Sanitization requirements for sewage sludge sanitization prior to utilization in agriculture according to the Brazilian CONAMA Res. N°375/2006

6.2.4.3 *Process duration*

Process duration is mainly determined by the effectiveness of technologies in place.

The duration of the ACT step depends on the specific technology adopted and on the chemical-physical features of the organic waste treated, generally varing between 6 and 8 weeks. In order to produce a mature compost, an additional curing step of at least 8-9 weeks (up to 14-15, in the case of green waste composting) is required. The overall duration of the process shall then be at least 100-120 days (150-160 in the case of green waste only composting).

6.2.5 Mechanical post- treatments

Post- treatments are aimed at:

- Removing non-compostable and sorting bulking woody fractions by:
  - Screening by size in order to recover large-sized woody materials to be re-circulated in the starting mixture
  - Manually sorting out from the over-screen fraction undesired materials such as plastics or metals

- Increasing the value of the final product:
  - Vermicomposting
  - Compost blending with other ingredients in order to produce growing media

6.2.5.1 *Main equipment used for post-treatment of organic waste*

The basic equipment required for post-treatment of organic waste is a drum screen with a mesh size generally between 8 and 15 mm (depending on the required particle size for compost and the cleanliness of food and market waste treated). When available, an additional drum with a mesh size of 60-90 mm can be useful for the automatic removal of most of the impurities.

In very small composting facilities (tens or few hundred t/y) manual screening of compost can be done through manually shovelling the compost materials through a simple sloping iron net.

6.2.6 Storage of compost

The same indications given in Chapter 5.4.6 can be followed. Compost storage can be made without periodical turnings if the product is placed in a roofed area, or covered by a semi-permeable geo-textile membrane, shaped in piles not exceeding a height of 1,5 m.

6.3 Minimum standards for plant equipment, process criteria and key issues

6.3.1 Plant design

Requirements for the composting site:

- The surface should be on a slight slope (ca. 3 - 5%).
- The plant shall be settled at a minimum distance > 75 m from surface waters and > 100 m from a spring or well.
- In order to prevent odour nuisance on sensitive receptors, a minimum distance of 100-200m (depending on the overall throughput and in particular, on the amount of putrescible organic waste) should be observed.
- Composting is not permitted on light sandy soils or gravel with a high percolation potential, on sites where there is the potential for landslides or floods, on sites where the groundwater level is less than 200 cm below the soil surface.
- Roofing is recommended if the following criteria concurrently apply:
  - Annual precipitation > 1.400 mm
  - annual throughput at the site exceeds 5.000 t
  - More than 30 % (w/w) of the materials are with a high level of moisture and nitrogen content (e.g. organic waste with a high proportion of food waste, fresh grass clippings, humid wastes stemming from food industry and sludge).
- Sealed paving: necessary for plants with a throughput >3.000 t/y and treating putrescible organic waste (see Table 17 for the types of putrescible organic waste) more than 30% w:w of total input waste.
- Waste acceptance, pre-treatment and the ACT step must be kept in enclosed buildings for plants with a throughput >5.000 t/y of putrescible organic waste.

➢ All enclosed buildings in which waste at any stage of the process is present must be provided with an air suction equipment able to guarantee at least the following air exchange performances:

- 2 times the volume of the building (tipping areas, pre-treatment area, buildings hosting waste in-vessels, such as bio-containers, bio-cells, etc.)
- 3 times the volume of the building for buildings hosting waste under the ACT step not encapsulated in vessels, such as piles and windrows. In dynamic systems with stable presence of workers inside the buildings, air exchange volume must be at least 4 times the volume of the building.

➢ Takeover / tipping and intermediate storage of raw feedstocks need to be carried out in an area with side walls, in order to facilitate the wheel loader activity.

➢ The amount of input waste and, if possible, output waste/products must be registered. Preferably, a weighing device or an alternative waste registration tool must be installed at the entrance of facilities.

➢ The sealed areas need to be designed for complete emptying and cleaning.

➢ Incoming putrescible waste must be pre-treated daily.

➢ It is strongly recommended to keep a stock of green/over-screen material in order to be able to mix it with the everyday putrescible waste accepted.

➢ In order to prevent any possible cross-contamination of the sanitized compost, strictly separate clean and dirty areas.

➢ All equipment, instruments and installations must comply with existing national regulations.

6.3.2 Odour emission prevention

Keeping the optimal conditions for the aerobic process is the main method to reduce the production of excess of odours. This is summarized by the following recommendations:

➢ Prepare a good initial mixture, in terms of density, moisture content, C/N ratio (see Chapter 6.2.1)

➢ Guarantee a proper oxygenation of the mixture along the biological phase (see Chapter 6.2.2)

➢ Monitor temperature profile and moisture content along the process, and put in place appropriate solutions in order to maintain these parameters within acceptable ranges (see Chapter 6.2.2);

➢ Undertake modified operating procedures to accommodate certain weather conditions likely to give rise to odour problems (e.g. do not turn windrows, especially those under ACT step, when wind flows towards sensitive receptors)

➢ Static windrows can be covered with a 10-15cm thick layer of mature compost or natural lignin-based material (e.g. straw) acting as a bio-filter

➢ Keep the facility clean (regular cleaning of surfaces, equipment and all traffic routes etc.); drain leachate puddles with mature compost, saw, straw or other spongy material, in order to prevent evaporation of smelly compounds

6.3.3 Exhaust air management

Whenever enclosed buildings must be built for performing part of the composting process, the entire amount of air sucked from the enclosed buildings must be pre-treated before its release into the atmosphere through a bio-filtration system installed and operated with the criteria illustrated in Chapter **Error! Reference source not found.**, in order to abate odorous compounds.

6.3.4 Workers health and safety

The same procedures and recommendations provided in Chapter 5.9.4 shall be followed. It will be up to the competent health authorities to allow a reasonable reduction of individual protection devices for small facilities.

6.3.5 Waste water management

The same procedures and recommendations provided in Chapter 5.9.5 shall be followed in all sections provided with a sealed pavement or an enclosed building.

6.4 Outputs quality, characterization and applications

The same criteria reported in Chapter 5.6, with particular reference to "Classe C" compost.

6.5 Average mass balance

Many factors can affect the mass balance of small composting facilities. In the following Table 20, an estimation on a simplified mass balance in the case of treatment of green waste only or a mixture of putrescible and green waste (50%:50% w:w) is provided below.

Table 20: Average mass balance for low-tech/scale composting

	Green Waste Composting	Mixed organic waste composting (50% green waste)
Starting mixture	100%	100%
End of ACT step	50-60%	60-70%
End of curing step		50-60%
Compost (under-screen)	30-40% (15mm screen)	20-30%
Over-screen (to be re-circulated)	10-30%	20-30%

6.6 Footprint of small sale, low-tech facilities

At optimised operational and process conditions the footprint can be reduced to 1,2 m^2/t.

6.7 Main process problems and proposed solutions

In order to properly manage the plant, a parameter-specific monitoring timetable is suggested in Table 21. Practical solutions to most common issues are:

- If piles are too dry:

The biological process causes a high water evaporation. If moisture content falls under a critic value, micro-organisms are no more able to carry on their degradation activities. When lacking the necessary instruments for moisture measurement, a visual inspection of the mixture can be performed, both on its surface and at a depth of 30-40cm. If the material gets too dusty, a moistening procedure must be put in place.

When moistening: it is better to moist the piles immediately before a turning operation, or between ACT and curing step. In this way, a uniform distribution of water will be guaranteed, and lower amounts of dust will be released when turning.

How much water to add: for each moistening operation, approximately 30-40 L/m^3 of material should be considered. This range can be affected by actual moisture conditions of the piles.

- If piles are too wet:

An excess of water in the mixture causes a significant reduction in permeability of O_2 through the piles, causing undesired anaerobic fermentation activities which affect the overall process kinetics and increase the arising of odours.

When lacking the necessary instruments for moisture measurement, an excess of water can be revealed by sampling small amounts of mixture and applying a light pressure - if a percolation of water from the mixture happens, the mxture must be considered too wet.

What to do: the problem can be challenged adding fresh green waste or dry compost to the mixture. In case none of them are available, piles must be reduced in height.

When and how to intervene: during mixture turning or shifting, adding 10-15% (w:w) green waste or 5-10% (w:w) compost with respect to the estimated amount of wet mixture.

If piles are placed outdoor, in rainy periods it can be useful to shape them in triangular section (instead of trapezoidal) in order to let most of the water slip through the sloping sides to the ground.

Table 21: Parameters to be monitored at a low-tech/scale composting facility

Phase	Parameter	Monitoring frequency
Waste acceptance and pre-treatment	Visual check of waste; hand removal of bulky impurities	At each delivery
Biological process	Temperature	Daily during ACT (3 points along each windrow at 2 distinct depths) Weekly during curing step
	O_2	In case of passively aerated windrows in absence of turnings, weekly monitoring (the same method used for temperature monitoring)
	Moisture (visual humidity control or by squeeze test)	When necessary to adjust moistening
Output	pH	Every month, on a sample at the end of the ACT step and on a sample at the end of the curing step
	Biological stability (Solvita Test or Self Heating Test)	Every month, on a sample at the end of the ACT step and on a sample at the end of the curing step
	Complete product analysis	In absence of any concerns, at least once every year a representative sample of compost must be taken and analysed according to the standard of “Clase C” compost (see Chapter 5.6)

7 MBT facilities for pre-treatment of mixed MSW

The PGIRS provides quite precise indications on treatment of mixed or residual solid waste (RW) before disposal. According to the strategy suggested, mechanical biological treatment (MBT) facilities, to be settled in "*Ecoparques*" (eco-parks), shall be in charge of reducing the hazardousness of this waste fraction prior to its final disposal. The PGIRS is even more precise in addressing RW to a specific type of biological process, a **dry-AD phase** with the aim to reduce the putrescible organic content and to recover biogas for further energy exploitation.

The PIGIRS also foresees that the digested organic fraction should be utilized as a bio-fertilizer, an aspect which deserves due attention. In fact, although the terms "MBT" and "composting" are often used together, as both processes are using very similar techniques, the two processes have to be distinguished in terms of input material and proper utilisation of the output. As MBT aims for efficient reduction of the organic material in residual waste, the input is mixed municipal waste, which is pre-treated by MBT prior to disposal.[11] An utilisation of the pre-treated waste may be possible such as using it as soil conditioner; however, it is subject to certain restrictions. If "compost like output" or "bio-stabilised output" is produced from mixed solid wastes by an MBT, the quality criteria and requirements for land application have to be met according to specific limitations.

7.1 Input waste and acceptance criteria

In principle, many types of waste materials can be accepted at an MBT plant. The "contaminated" materials needing to be broken down and digested in the biological stage include paper and board mixed with food-, kitchen- and green-organics disposed and collected together with RW (instead of being separately collected or home composted). It also includes organic content contained within nappies, packaging, textiles, etc. Generally, only unsorted RW of domestic origin or similar fractions coming from small shops, markets and offices enter the plant. Exclusions or restrictions are referred to some types of waste, such as:

- Hazardous waste, for which a special treatment is mandatory
- Waste for which a biological treatment is not appropriate (e.g. waste in which the organic fraction is below 10-15% w:w)
- Waste causing inhibition of the biological activity (e.g. waste contaminated by antibiotics)

Acceptance procedures include:

- Visual inspection of each batch delivery (large-size metals, ceramics or stones can damage mechanical treatment equipment)
- Radioactivity detection (related to contaminated nappies worn by children or old people after particular medical examinations). Radioactive batches must be isolated for time enough to allow radioactivity delay of common isotopes employed (generally, a few days), and then measure again. Competent authorities must be contacted in case of persistent radioactive contamination.

[11] This aspect has been analysed in the Strategy Paper prepared during this City Assistance Project offered to the Municipality of Sao Paulo (Brazil) under the framework of the Climate and Clean Air Coalition Municipal Solid Waste Initiative (CCAC MSWI).

7.2 Objectives of MBT

Mechanical biological treatment (MBT) is usually designed to recover materials for one or more purposes and to stabilise the organic fraction of the residual waste. The practical advantages of MBT plants are, above all, the **reduction of**:

- The volume and weight of waste treated

- The putrescible organic matter content of waste, in turn useful for:

  - Selecting and recovering dry materials to be sent for recycling (plastics, metals, paper/cardboard, etc.)
  - Recovering a "compost-like" fraction suitable for certain controlled application, such as environmental restoration, landfill capping and other non-food agronomic purposes
  - Increasing the LHV of waste to recover a refuse-derived fuel
  - Disposing into landfills a pre-treated and bio-stabilised waste characterized by lower environmental impacts[12] in the short-term (less attractive to rodents, birds, insects, etc.) and in the long-term (less GHG and leachate production in landfills)

According to qualified literature at the EU and international level the expected reductions in terms of oxygen demand, gas production potential and volume of waste are shown in Table 22:

Table 22: Effects of biological pre-treatment

Feature	Final Effect (source)	% reduction (compared to initial)
Respiration rate	AT4 = 5mg O2/g d.m. (96h) DRI = 1.000 mgO2/kg VS.h	[1] 80-90 [2]
Gas production potential	20L/kg d.m. 20L/kg d.m.	[1] 80-90 [2]
Volume	Final density (compacted): 1,2-1,4 t/m3 Mass loss (due to mineralization): 20-40%	[1] up to 60% [2]

[1] K. Leikam, R. Stegmann, "Landfill behavior of mechanical-biological pretreated waste". ISWA Times, 3/97, pp.23-27, 1997

[2] Adani F., 2001 Personal Communication (University of Milan) in Favoino E. "Drivers, trends, strategies and experiences for a proper management of organic waste and the role of MBT". Working Group on Composting and Integrated Waste Management, Scuola Agraria del Parco di Monza, Italy.

7.3 Minimum standards for plant equipment, process criteria and key issues

MBT plants contain a mechanical section focusing on the "dry" fractions (sorting, homogenizing, shredding, pressing, etc.) and a biological section focusing on the fraction richer in organic matter, aiming at reducing and stabilising the putrescible fraction.

[12] Souce: K. Leikam, R. Stegmann, "Landfill behaviour of mechanical-biological pretreated waste". ISWA Times, 3/97, pp.23-27, 1997
M. Kuehle-Weidemeier, "Landfilling of mechanically and biologically pre-treated Residual Municipal Solid Waste". By order of the University of Jyväskylä (Jyväskylän Yliopisto), Dept of Biological and Environmental Sciences, Kaatopro-project, Langenhagen (Germany) 2004

The common layout of an MBT provided with an anaerobic digestion and subsequent-aerobic phases involves the following steps (though **it must be stressed that the AD phase is optional** and many MBT plants rely on aerobic treatment only).

7.3.1 Mechanical treatments

Compared to composting, MBT requires higher requirements with regards to mechanical machineries, due to a broader range of and more heterogeneous feedstock. The mechanical treatment involves segregating and conditioning steps. The following processes may be involved:

- Opening of waste containing bags

- Diverting undesirable components that might damage the subsequent processing (e.g. bulky materials and metals)

- Manually sorting large valuable recyclables

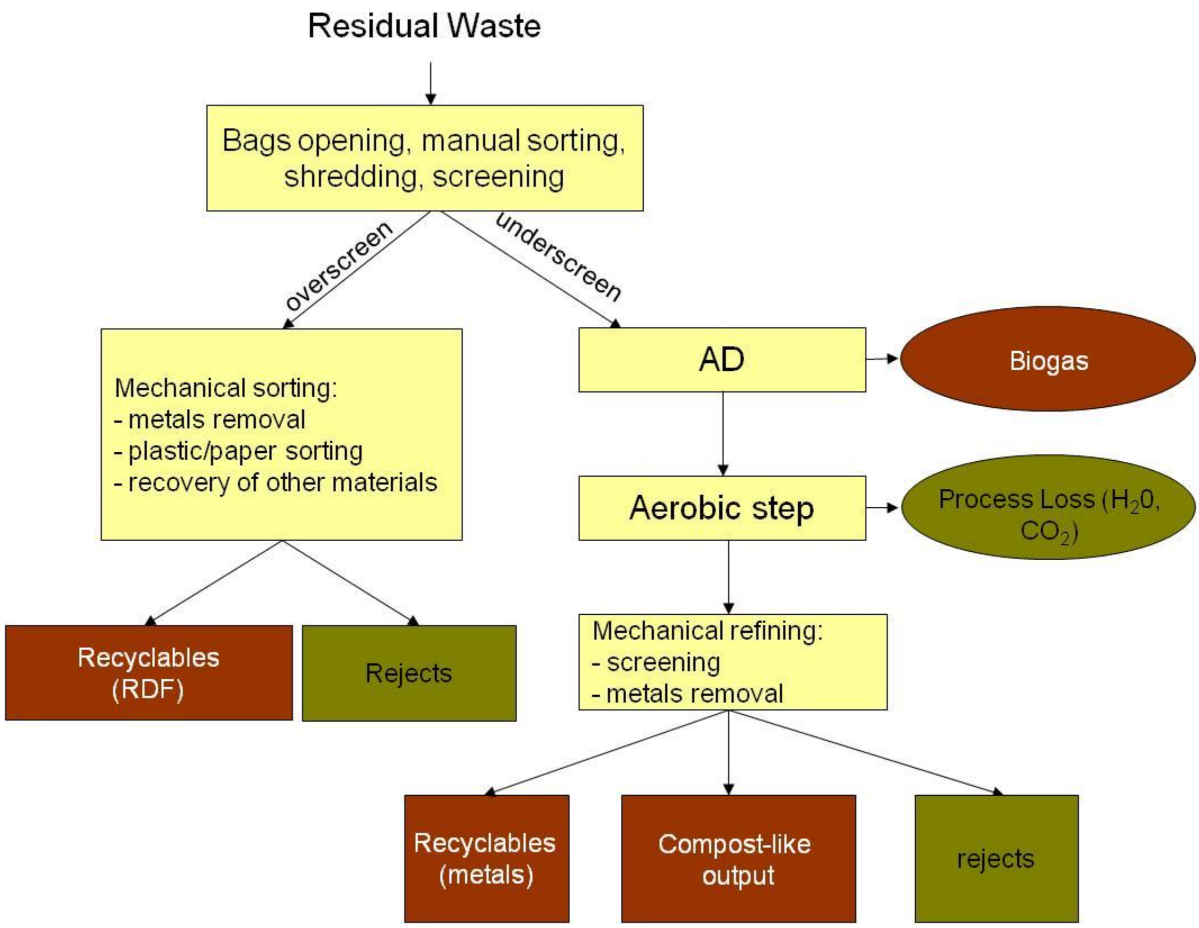
- Screening (80-120mm); then on the over-screen fraction:

    - Mechanical segregation of homogeneous groups of recyclable materials (single plastics, mixed plastics, paper/cardboard, glass, etc.)
    - Volume reduction and storage of recyclables
    - Storage or disposal of rejects

The number and sequence of mechanical operations are strictly related to the waste composition and the main objectives of each specific MBT facility – diversion of recyclables, production of refuse-derived fuels and landfilling after simple volume reduction, which corresponds to national environmental strategies and the market for recyclables or fuels.

Irrespective of the specific mechanical treatment layout, a common step among different MBT approaches is the **primary screening of RW after bags opening**, aimed at diverting an under-screen fraction (generally below 80-120 mm) which is considered to contain **the majority of the organic matter** present in the incoming waste.

Figure 8: Material flow of an MBT process including AD treatment



7.3.1.1 *Main equipment used for mechanical treatment*

The machineries involved in this phase can overlap with those described in Chapter 5.4.1 for composting, which will not be repeated in this chapter.

Generally the screening of the coarse fraction is carried out at 60 to 90 mm and can be performed at several stages during the process:

- Immediately after the tipping of input materials
- After handpicking of impurities or sorting in a sorting cabin from a conveyer
- After bags opening and or coarse shredding

The automatic sorting consists of different types of sensors for the detection of the recyclable materials:

- Near-infrared detection
- Cameras
- Laser
- X-ray

7.3.2 Biological phase

The biological steps of the MBT process are for the most part identical to those employed for the anaerobic digestion of separately collected organic waste. According to the proposal of the PGIRS, a dry-AD step shall characterize this phase.

Dry AD is further split into two distinct technological approaches as described in the following sub-chapters.

7.3.2.1 *Dry continuous AD systems*

In dry continuous AD systems, the ingestate (under-screen fraction of the MBT, possibly adjusted in moisture content through digestate re-circulation, according to the indication of the technology supplier) is fed at one end of the reactor, and moves through the reactor thanks to the combined action of the pressure from the input of new fresh ingestate and the digestate being emptied from the other end; the material inside the reactor is not mixed to a large extent.

For the dry continuous process the under-screen fraction can require additional mechanical preparation, consisting of a finer screening (approx. 50 mm) and a ballistic separation to reduce the content of inert materials which contribute to higher wearing in the process.

Typical HRT in the digester are approximately 3 weeks, depending on the actual throughput of waste in the MBT facility and in the efficiency of mechanical pre-sorting.

The Digestate has to be de-watered: solid digestate is then further matured by aerobic treatment. Liquid digestate is either re-circulated in the reactor or rejected as a liquid waste for waste water treatment. Any application on soil using liquid digestate has to be avoided due to possible contaminants (impurities, heavy metals, persistent organic pollutants, etc.).

7.3.2.2 *Dry batch AD systems*

Digesting units are designed as batch batteries of a certain number of independent containers (bio-cells), in order to guarantee an acceptably consistent gas production. For these systems the input material has to be sufficiently solid to allow it to be handled with a front-end loader.

Most of the batch systems claim that one of their advantages is that there is no mechanical preparation required at all, apart from mixing a given amount of digestate (up to 50% w:w, depending on the technology) with fresh ingestate. As the input-mixture must have a good structure to enable the percolation of the liquids a shredding of the organic waste might even be counterproductive. If the material is lacking a good structure, bulking agents may need to be added, e.g. drier waste, shredded bulky waste or shredded wood waste.

7.3.2.3 *Time-temperature requirements*

Temperature regime are the same as source-segregated organic waste AD. Systems operate in mesophilic (35°C to 40°C) or thermophilic (45°C to 60°C) temperatures. Under thermophilic conditions the process is faster, resulting in more biogas produced in the same time and hence the HRT can be reduced in comparison to mesophilic conditions. Moreover, high temperatures support sanitisation. A disadvantage of the thermophilic conditions is the higher energy demand for heating the material.

After the AD step, an aerobic curing step on digestate must be performed, with the objectives of:

- Further stabilising the digestate
- Drying the material for making it more easily to refine mechanically
- Allowing the sanitation, in case this has not been achieved during the AD step

The **aerobic curing step** is usually performed in intensive systems (e.g. bio-cells, bio-tunnels) or in static forcibly ventilated windrows. In order to increase the efficiency of this step, the heat produced when burning biogas in co-generators inside the plant can be exploited to pre-heat air blown through the digestate. The same temperature/time combinations can be required for assuring the sanitization of waste and are shown in Table 23

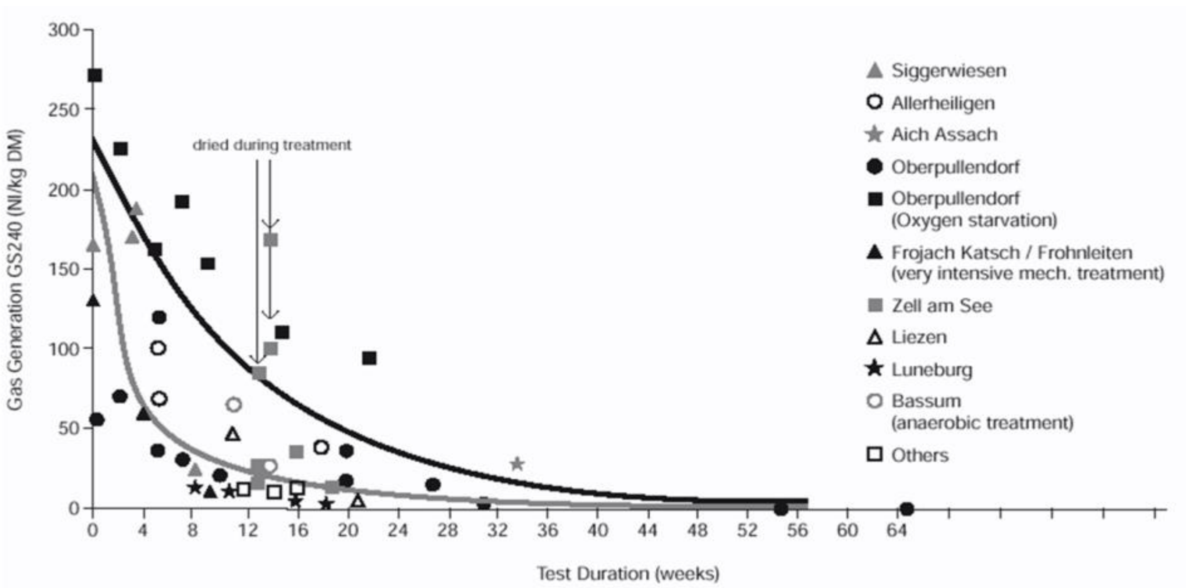
Mature bio-stabilised digestate can either be safely disposed in landfill (since odour generation[13] and methane generation potential have been largely reduced, as shown in Figure 9) or further mechanically refined in order to be utilized as a compost-like material in controlled and specific applications.

Table 23: Time-temperature profiles for sanitization during MBT aerobic processes

Temperature	Time	Additional requirements
≥55°C	5 days	After sanitization, appropriate measures must be taken in order to avoid any cross contamination between sanitized and fresh waste.
≥60°C	4 days	
≥65°C	3 days	
40°C*	5 days	at least 55°C for 4 consecutive hours

* Sanitization requirements for sewage sludge sanitization prior to utilization in agriculture according to the Brazilian CONAMA Res. N°375/2006

Figure 9: Reduction of gas production on landfills over time by materials from MBT in plants



Source: Binner E. "The Impact of Mechanical-Biological Pre-treatment on Landfill Behaviour", paper presented to the European Commission Organic waste Workshop, May 2002

[13] B. Scaglia, V. Orzia, A. Artola, X. Fontb, E. Davoli, A. Sanchez, F. Adani. "Odours and volatile organic compounds emitted from municipal solid waste at different stage of decomposition and relationship with biological stability" Bioresource Technology, Volume 102, Issue 7, April 2011, pp. 4638–4645

7.3.3 Mechanical refining of outputs

The following mechanical operations must be considered on the output from an MBT facility:

- Ferrous/non-ferrous fractions: storage in containers
- Other sorted fractions (paper, plastics, etc.):
  - Manual quality check to remove contaminants
  - Compaction
  - Storage in bales
- Refuse-derived fuel:
  - Fine shredding (depending on the end user requirements)
  - storage in containers or directly on trucks
- bio-stabilized output (for being turned into a compost-like output):
  - Removal of ferrous and non-ferrous metals for recycling
  - Fine screening for plastics/glass removal using a mesh size of 10-15mm
  - Storage in piles (with the same recommendations of compost storage, see Chapter 5.4.6)

7.4 Outputs quality, characterization and applications

The following outputs can be expected of an MBT facility treating MSW:

a. Recyclable fractions suitable for the market, possibly after further operation (i.e. washing, shredding, etc.) required by the final recycling industry:
   - Paper/cardboard
   - Single plastics (PET, HDPE, etc.) or mixed plastics (sent to densification/pelletization or similar material recovery options)
   - Metals (Ferrous and non-ferrous)
   - Glass
   - Others

b. Stabilised organic fraction, that may be considered a compost-like output

In some countries, the stabilised organic waste may be used as landfill cover if contamination is low enough, or it may be landfilled. At the end of the biological treatments, specific tests to assess the aerobic- (respiration) or anaerobic- (gas formation) decomposition have been applied in some countries and required in national regulations or guidelines[14]. These tests measure the oxygen demand of the treated organic waste

[14] A comparison of different test methodologies can be found in A. Godley et al., Biodegradability determination of municipal waste: an evaluation of methods, 2004

(respiration activity, AT4[15]; DR4[16]) or the gas formation (GB21[7]; BMP100[8]) on a laboratory scale. The lower the oxygen demand or gas formation rate the more stabilized is the waste.

The duration of an MBT process depends on the duration of the biological phase. Depending on the maturity required for the compost-like output, the duration can be summarised in Table 24:

Table 24: Examples of stabilisation of MSW during MBT treatment in terms of oxygen demand

Target of AT4 (mgO_2/g d.m.)	**< 10**	**< 5**
AD duration (weeks)	2-3	
Aerobic curing step duration (weeks)	2-5	4-10

The quality of the compost-like output is generally not acceptable for widespread use on soils[17] because of the contaminants associated with both the inert content (glass, plastic, etc.) and also the heavy metals content arising from other wastes entering the RM stream (batteries, etc.).

Table 25 lists additional recommended parameters to be monitored and limit values in a compost-like material for controlled applications in land reclamation or landscaping operations (as taken from the 2° Draft of EU organic waste Directive[18]).

Table 25: Possible limit values in a compost-like material for controlled applications in land reclamation

Parameter	**Limit value**
Cd	5 mg/kg d.m.
Cr (total)	600 mg/kg d.m.
Hg	5 mg/kg d.m.
Ni	150 mg/kg d.m.
Pb	500 mg/kg d.m.
Cu	600 mg/kg d.m.
Zn	1.500 mg/kg d.m.
Inserts (including plastics)	3% w:w
PCB	0,4 mg/kg d.m.
PAH	3 mg/kg d.m.

Possible applications of compost-like outputs, besides the use on landfills, are:

- Application in agriculture (under specific authorization which should include the assessment of chemical features of soil, a maximum application dose not exceeding a limit value (e.g. 30 t/ha) over three years, prohibitions for flooding areas, areas with superficial groundwater table, etc.)

[15] AT4 and GB21 is applied in Germany and Austria according to (DE) Ablagerungsverording 2001.
[16] DR4 and BM100 are applied in UK according to according to the "Guidance on monitoring MBT and other pretreatment processes for the landfill allowances schemes (England and Wales)", Environment Agency, August 2005.
[17] See also introduction of chapter 7 for further comments
[18] Source: 2° Draft of EU Organic waste Directive

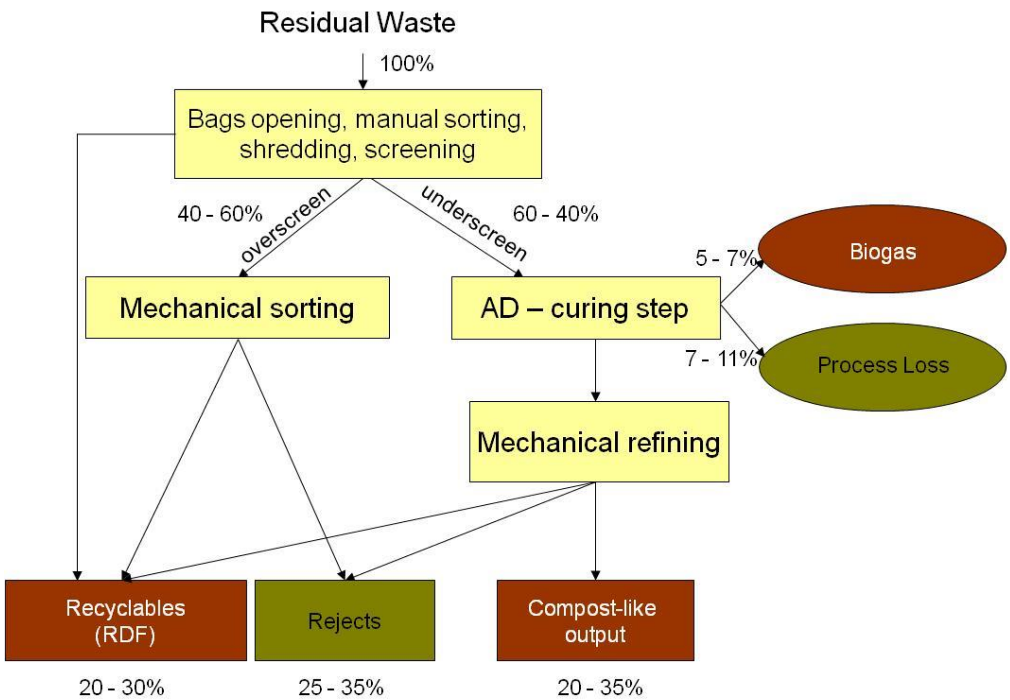
- Application in landscaping operations (degraded lands reclamation, old landfills final capping and vegetation, landscaping of mines, utilization as technical material for railways, motorways, public or private green areas, golf course, etc.).

Maximum acceptable load shouldn't exceed[19] 500 t/ha, always in mixture with natural ground. Besides, further limitations can be applied to the heavy metal content of the compost-like output in accordance with the acceptable heavy metals load of the area and kind of application (higher loads for industrial areas, lower for residential areas).

7.5 Average mass balance

Even assuming that the main goals of MBT facilities according to the PGIRS are the production of biogas and a compost-like material, the average mass balance of an MBT plant depends on a number of variables such as RW composition and specific layout chosen. For this reason, a wide range of output/rejects generation must be expected.

Figure 10: Example for mass balance of a MBT process and possible outputs



7.6 Footprint of MBT facilities

Based on a strongly intensive and enclosed system, the expected space demand of an MBT facility can range from 0,2 to 0,35 m^2 per ton of residual waste treated. This means that an MBT facility with a throughput capacity of 390.000 t/y (1.250 t/d) would demand an overall footprint ranging from 60.000 to 105.000 m^2.

[19] Italy, Region Veneto. Regional Decree n. 568/2005 "Norme tecniche ed indirizzi operativi per la realizzazione e la conduzione degli impianti di recupero e di trattamento delle frazioni organiche dei rifiuti urbani ed altre matrici organiche mediante compostaggio, biostabilizzazione e digestione anaerobica".

7.7 Technical requirements on the design and operation:

7.7.1 Plant general design

➢ In order to prevent odour nuisance on sensitive receptors (hospitals, health resorts, residential dwellings, city canters, recreation and sport facilities, schools, public parks, playgrounds, camping sites, restaurants. etc.), a minimum distance of 500-1000 m (depending on the overall throughput) should be observed. If the given critical distances between potentially odour emitting sites of operation and nearest settlements are not met, a detailed odour modelling exercise must be performed by the applicant, in order to assess the suitability of the location based on the probability of the occurrence of nuisance to the neighbourhood caused by odour problems.

➢ The plant shall be settled on a sealed paving, in order to prevent leachate percolation through soil to groundwater.

➢ All process phases shall be kept in enclosed buildings provided with fast opening doors (a further improvement can be double sequential doors for waste receiving and tipping and high pressure air barriers activated when doors are open).

➢ All enclosed buildings in which waste at any stage of the process is present must be provided with an air suction equipment able to guarantee at least the following air exchange performances:

- 2 times per hour the volume of the building (tipping areas, pre-treatment area, buildings hosting waste in-vessels, such as bio-containers, bio-cells, etc.)
- 3 times per hour the volume of the building (buildings hosting waste under the ACT step not encapsulated in vessels, such as piles and windrows). For dynamic systems with stable the presence of workers inside the buildings, air exchange volume must be at least 4 times the volume of the buildings.
- 2 times the volume of the building hosting the curing step.

➢ Takeover/tipping and intermediate storage of raw feedstock need to be carried out in a bunker with side walls, in order to facilitate the wheel loader activity or in a receiving pit whenever the plant is equipped with a travel bridge crane for automatic RW loading to the processing unit.

➢ A weighbridge must be installed at the entrance of facilities in order to record waste accepted and reject disposed.

➢ The tipping area needs to be designed for complete emptying and cleaning.

➢ There needs to be sufficient tipping capacity, including a buffer equivalent to a 5 day tipping, in case of an operational breakdown.

➢ All equipment, instruments and installations must comply with existing national regulations.

7.7.2 Odour and dust emission prevention

The emission of odour and dust can be prevented by:

➢ Immediate and efficient process of delivered waste material

➢ Keeping the facility clean by regular cleaning of surfaces, equipment and all traffic routes

➢ Enclosing stationary indoor conveyors, shredders and screens

- Equipping discharge points with additional vacuum systems

To minimize dust from traffic, all roads must be regularly cleaned. To avoid the transfer of waste from the plant to the environment outside of the plant, a wheel washing installation should be in place.

7.7.3 Exhaust air management

- Dust filter has to be installed with mechanical treatment units (shredders, screens, conveyors). A limit of 10 mg/m³ dust is recommended for cleaned air.

- The entire amount of air sucked from the enclosed buildings must be pre-treated before its release into the atmosphere, in order to abate odorous compounds. Bio-filters preceded by scrubbers are the recommended devices to be adopted, with the same indications recommended in Chapter **Error! Reference source not found.**.

7.7.4 Workers health and safety

The design and operations of an MBT plant have to be done in compliance with the relevant Brazilian health and safety regulations.

In order to prevent risks for workers, in particular biological risks associated with bio-aerosol and dust inhalation, all operations inside the facility must be performed inside conditioned vehicles, or if done manually, workers need to wear appropriate personal protective equipment such as disposable suits, safety gloves and shoes to protect against cuts, dust-filtering breathe masks, glasses and helmet.

The manual separation of impurities shall be done in enclosed cabins using sorting conveyers safeguarding workers' health. Permanent working places for manual sorting should only be placed in sorting cabins with air conditioning and effective air change systems. Doors of sorting cabins need to close automatically. The air above the conveyer should be sucked off along the entire sorting line. The capacity of the aeration device should guarantee that the air inside the sorting cabin comply with health regulations. The ventilation facility has to be cleaned and maintained according to the producer's manual, but at least once a year. Any other automatic sorting or screening processes need to be installed outside of the sorting cabin.

Minimum requirements for a manual sorting cabin are:

- Maximum working width: 0,6 m

- Maximum conveyer width: 1 m

- Preferably two opposite working places

- Conveyer speed:

  - One working place: 0,1 – 0,2 m/sec (ideal: 4 - 10 m/min) independent of the particle size, throughput and density
  - Two working places: in practice frequently reported: 0,5-0,8 m/sec
  - Only one layer of material

- Illumination: minimum 500 Lux

A worker's behaviour manual must be produced and communicated which must account for:

➢ Personal hygiene when entering and exiting the plant. The employer shall ensure that all work clothes are cleaned regularly; lockers, showers and toilets must be equipped with separate clean and dirty areas.

➢ Adequate training in the utilization of equipment and handling of waste

➢ Periodical health check against the most probable risks: biological agents, dust, noise, vibrations (for those spending part of their activity on wheel loaders)

➢ Allowing smoking, eating and the consumption of food in specially designated areas only

➢ Prohibiting any unprotected persons from staying in an enclosed area

7.7.5 Recommended operational measures

➢ When working inside the buildings, respiratory protection should be used.

➢ Regular cleaning and decontamination of the areas of the facility that are exposed to fresh feedstock (i.e. that have not been sanitized) should be carried out to reduce unwanted microbial growth.

➢ The operational processes should be designed to avoid employees working permanently inside the buildings, except for manual sorters who shall work in appropriate cabins.

➢ Doors and windows should be kept closed during operation. The cleanliness of the control cabin should be maintained.

➢ With cleansing and servicing work such as bio-filter exchange, which generate considerable amounts of microbial aerosols, respiratory protection should always be worn.

➢ The driveways and working areas should be moistened and kept dust-free and should be cleaned regularly, preferably with a sweeper or industrial vacuum cleaner. When using high pressure cleaner respiratory protection should be worn. Cleansing with a broom should be avoided.

7.7.6 Waste water management

Generally, leachate and run-off water may not be allowed to drain off into the soil without prior treatment, as it has the potential to pollute ground and surface waters.

All phases of an MBT must be carried out on a sealed pavement and waste water must be captured in order to prevent any uncontrolled release of waste water to ground or surface water.

The size of the intermediate waste water tank needs to take into account the size of the facility and the amount of rainfall in order to hold leachate and run-off from all paved areas where compost or raw material is stored or treated.

In addition, a waste water management plan must ensure adequate treatment and reuse of the waste water.

7.7.6.1 *Origin and types of waste water*

Waste water at an MBT facility arises from a number of different sources and stages:

➢ Press and process water (also called leachate, which is water that percolates through RW or resulting from the metabolic activity)

- Condensate on equipment and in pipes
- Waste water from cleaning activities
- Precipitation water in open areas (run-off water from compost piles surface as well as from traffic routes)
- Precipitation water from roofs

7.7.6.2 *Waste water collection and use*

Waste water needs to be collected and treated according to the requirements of water protection principles- to prevent pollution of ground and surface wasters due to its high biological oxygen demand and nutrient content.

Prior to its final disposal, waste water can be added to leachate re-circulation system of the AD step in order to increase the overall biogas production.

7.7.6.3 *Construction elements of a wastewater drainage system*

All storage and treatment areas must allow for the controlled drainage of all liquids including those originated from the feedstocks, storage, active composting and precipitation, to avoid water-logging at the windrow-base. This is achieved by constructing the composting pad on a slight slope to avoid water stagnation. The minimum slope of both pavement and drain/aeration pipes below the windrows should be of at least 1%.

7.7.6.4 *Process waters (leachate and condensation water) in closed building*

Water that percolates through waste can be re-circulated in the AD process. In order to collect process waters, the capacity of the storage tank complies with the following formula:

$$C = R \times Q \times T : 1000$$

Where:

C = capacity of the tank (m^3);

R = water release coefficient (L/t*day); R ranges between 2 and 5, where the minimum value is applied to forcibly ventilated systems by air blowing from the floor, and the maximum value to forcibly ventilated systems by air sucking from the floor. Waste tipping areas where wet and putrescible waste are received, R is considered to be equal to 5;

Q = amount (t) of RW simultaneously present in the plant;

T = maximum time (days) between two consecutive wetting operations

7.7.6.5 *Liquid digestate*

This fraction can be either:

- Recycled in the anaerobic digester
- Disposed to a WWTP, considering that besides $N\text{-}NH_3$, BOD, COD, Cl^- and Na^+, heavy metals contamination can be significant.

7.7.6.6 *Rainwater*

Rainwater falling on areas unaffected by trucks or loaders' transit can be released to a receiving water body, but must be separated as "first rain water". Otherwise it has to be treated (oil and grit removal) before being recirculated in the process or released to a receiving water body. In order to collect these process waters, the capacity of the storage tank should be able to collect the first 5 mm or the first 15 minutes of a rain event.

7.7.6.7 *Cleaning waters*

Cleaning waters should be treated or released to the sewer according the national regulation.

7.7.7 Noise Emissions

Noise can be defined as unwanted sound. Generally, mobile and/or stationary technical equipment is used by MBT facilities (e.g. wheel loader, grinders, screens, turners, ventilators and conveyor belts) which are a source of noise emission. Furthermore traffic movements to, from and within the site will add to the noise load.

For this reason consideration must be given to noise protection for workers and residents, during both the construction and operation of facilities. Requirements regarding worker-related noise protection include:

- At the workplace the noise load may not exceed 85 dB for more than 8 hours per day given a 40-hour working week.
- With noise loads exceeding this limit, protective measures must be taken and appropriate personal protective equipment (e.g. ear protection) must be provided by the employer and worn by the workers.

7.7.8 Fire and explosion protection

MBT has to be designed and operated in compliance with the relevant fire and explosion prevention regulations.

8 Possible Timing

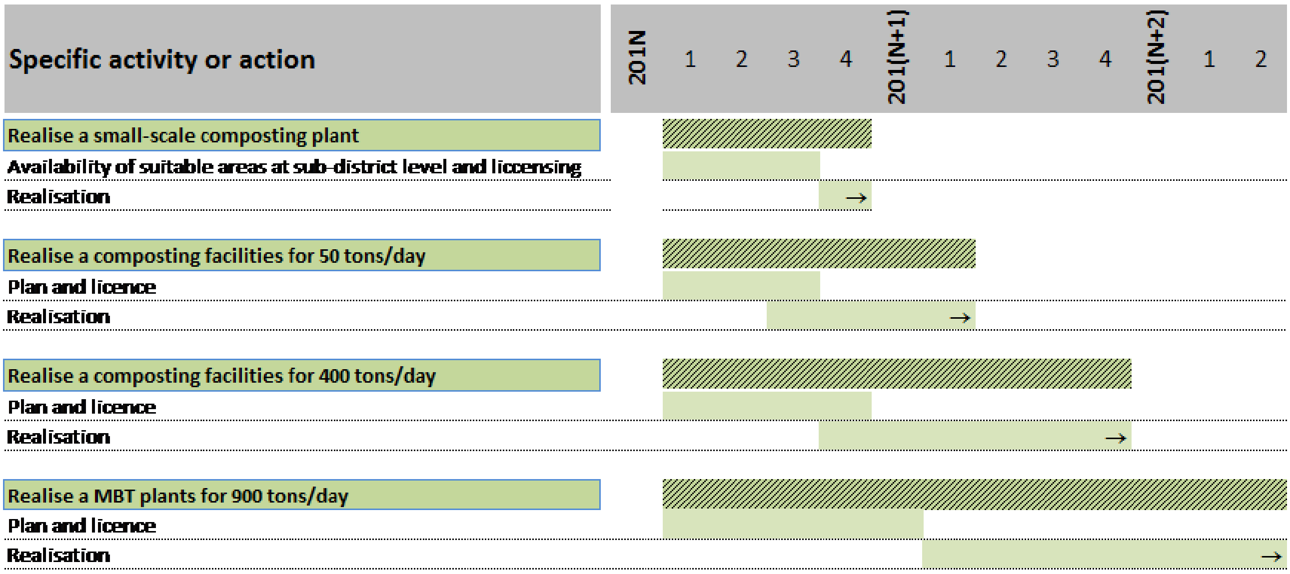
The time required for the implementation of a composting, AD or an MBT facility depends on the time necessary for obtaining the necessary permits, the features of the site (e.g. the need of particular works for ground retaining) and the technical complexity of the plant, in turn indirectly related to the overall throughput.

In general, once the permit or licences for realising and operating the facilities is obtained, one can expect that the time needed for the construction of a composting plant (as described in chapter 5 and 6) or an MBT plant (see Chapter 7) can range from 10 to 15 months.

Smaller and low-tech composting sites, where a significant part of the process is performed outdoor and/or on unsealed ground, the construction time can be significantly reduced (from a few weeks to a few months).

A visual timeline assuming ideal conditions for realising different types of facilities are show in Figure 11. The timeline is expressed in quarters (3 months).

Figure 11. Average timeline for realising different types of facilities assuming ideal conditions



Annex I - Principles for anaerobic digestion

Over the years, investigations and practice experience on Anaerobic Digestion (AD) of a broad range of organic feedstock have brought to a differentiation of several technologies.

The main distinctions among different technologies and process types are in:

- Dry matter content of the substrate
- Temperature profile of the fermentation process
- Loading system for the substrate (continuous v.s. batch system)
- Number of subsequent reactors
- Type of reactors (vertical v.s. horizontal; mixing technology)

Dry matter content

The main distinction is based on the dry matter of the substrate fed to the digester. Anaerobic digestion technologies can be divided in the following groups:

- *Wet* digestion, where the substrate shall have a dry matter content lower than 10%
- *Dry* digestion, where the substrate shall have a dry matter content higher than 20%
- Processes which are run with dry matter content between the above-mentioned two types are less common and are generally referred to as *semi-dry*.

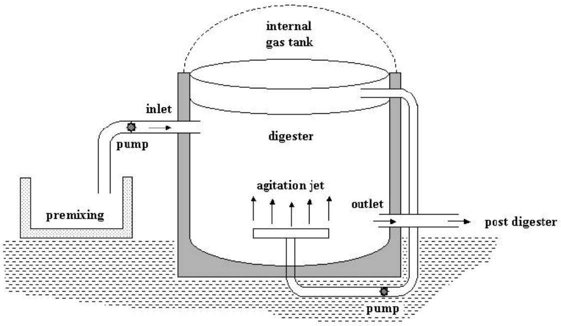
The wet digestion has its roots in the first applications of anaerobic digestion to sewage sludge in waste water treatment plants where liquid waste and organic waste characterised by a high moisture content and a relatively low contamination by non-organics. Dry anaerobic digestion was specifically developed for treating unsorted waste (MSW) or organic waste rich in dry or hardly dilutable fractions such as wood and plastics, with the aim to avoid hard pre-treatments, maintenance and consequent costs.

Temperature profile

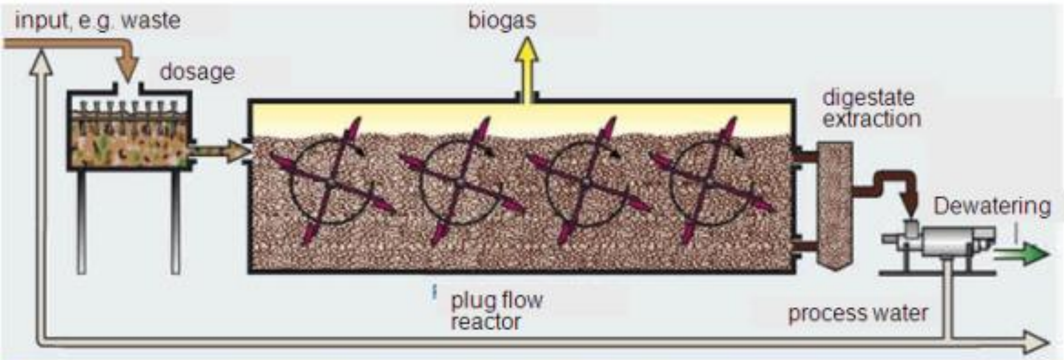
A second classification is based on the temperature at which the anaerobic process is performed. The following types of process are then identified:

- *Psychrophilic* processes (average temperature 20°C)
- *Mesophilic* processes (average temperature 38°C)
- *Thermophilic* processes (average temperature 55°C)

Mesophilic and thermophilic processes are the most commonly used at industrial scale, while the psychrophilic processes are generally characterised by lower capital and management costs and by “robust” biological processes. Thermophilic reactors can achieve higher biogas productions, although maintaining a proper process balance can be harder and more expensive.



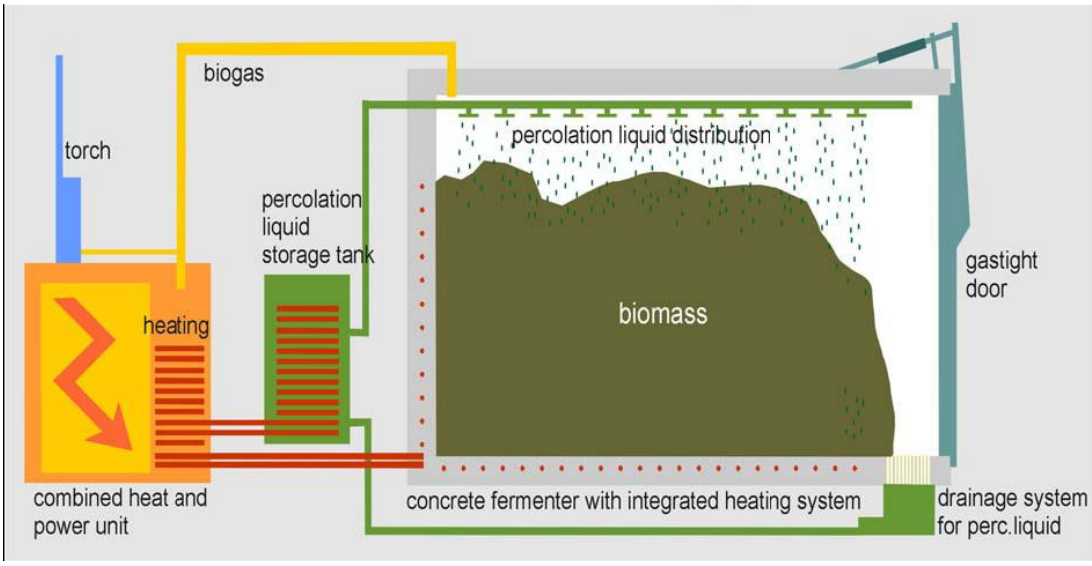
Annex I - Fig. 1: Wet digestion system in a vertically-shaped reactor (Source: left scheme, M. Plöchl, M. Heiermann, 2006; right figure, ETRA SpA wet anaerobic reactor)



Annex I - Fig. 2: Horizontal, dry digestion system (Source: Kompogas)

Loading system

Reactors' loading systems are either *batch* processes or *continuous* processes. In the latter case, the digesters are periodically (daily or every few hours) fed with a given amount of waste, and an equal amount of digestate is withdrawn. While batch technologies are considered easier to be managed, a higher biogas production is generally granted by continuous processes where microbial kinetics are constantly kept at their best.



Annex I - Fig. 3: Batch type digestion (Source: Bekon)

Number of reactors in series

A last technological distinction is related to the number of bio-reactors employed in the anaerobic process. In fact, the chain of reactions which leads to the production of methane from the complex organic matter produces intermediate metabolites which can negatively interfere with other steps of the process. More specifically, the first hydrolytic step produces high amounts of Volatile Fatty Acids (VFA) which slow down the formation of methane by methanogenic bacteria. On this presumption, the physical separation of ingestate at different stages can enhance the overall process performances. This is realised by those technologies, known as *multi-stage* technologies, which provide two or more series of digesters. It is conceptually distinct from the *one-stage* technologies where the complete process is performed in a single bio-reactor.

Obviously single-stage technologies are generally less expensive and less space demanding than multi-stage ones.

Type of reactors (vertical – horizontal; mixing technology)

The continuous systems can be either fully mixed vertical systems which are usually equivalent to wet AD systems, or they are designed as upright or horizontal plug flow reactors.

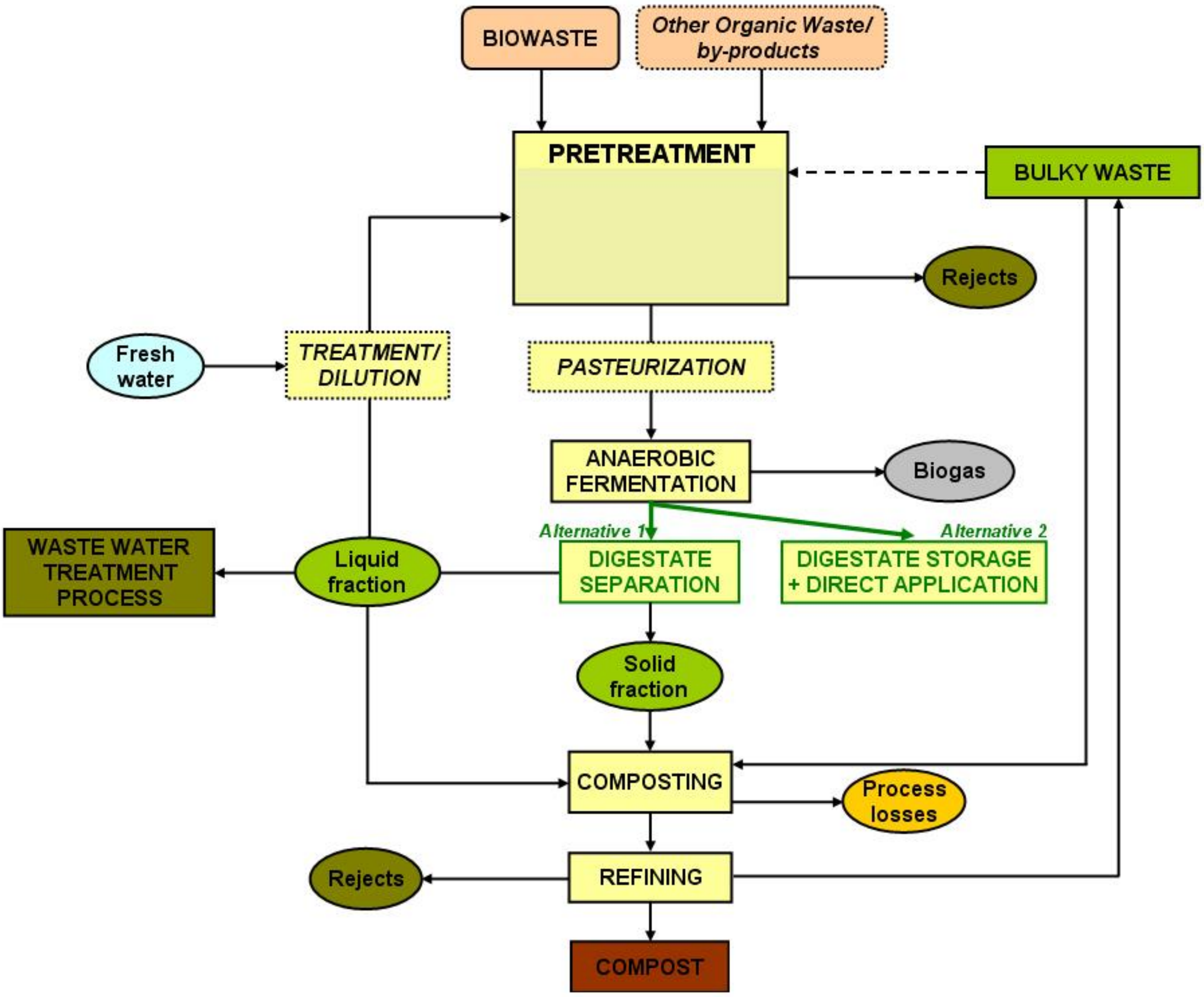
The fully mixed vertical reactors are regarded as the “classical wet digestion” and are still the most commonly used (see Annex I - Fig. 1:). The digestate is paste-like but feedstuff can be added in a solid or liquid state. The reactor is mixed by agitators or hydraulically. To be capable of being mixed thoroughly the material has to be fairly wet.

In the dry, continuous AD systems, the material moves through the reactor without being mixed with fresher or older material to a large extent. The digestate is either in a shovellable or pumpable state. Digesters can be either vertically shaped or horizontal, such as in the example of Annex I – Fig. 2.

The discontinuous systems are mainly batch processes. Usually the fermentation units are designed as batch batteries of a certain number of containers (bio- cells) in order to reach a quasi-continuous process with almost consistent gas production. For the batch systems the material has to be shovellable, namely sufficiently solid to allow it to be handled with a front-end loader (see Annex I – Fig. 3). Dry batch systems are not provided with any mixing devices.

Process flow sheet and description

Depending on the technology, organic waste anaerobic digestion is performed according to a number of different operational steps which can be summarised by the following flow chart.



Notes: dotted arrows mean optional applications, and dotted boxes mean optional operations. A main remark has to be made regarding the fate of digestate produced at the end of the anaerobic fermentation step, which can either be stored and directly applied onto soils, or more likely, be further processed in order to become a compost.

Annex I - Fig. 4: General flow chart of an anaerobic digestion process

Biogas - quality and use

The production of biogas and its composition depends on several aspects, ranging from organic waste composition to the technology features and performances. It is then useful to give a figure of the potential biogas production for some of the main biomasses.

Prior to its utilisation, the biogas produced is stored in gasholders which act as a buffer maintaining the best working conditions for its further application. Gasholders are usually sized for holding the biogas produced in at least 4-5 hours. They can either be rigid or flexible, generally using a “double” membrane technology. Rigid gasholders are usually settled alongside the digester, while flexible ones are placed on the roof of the reactors.

The biogas produced can be utilized as a renewable energy source in combined heat and power plants, a vehicle fuel or as a substitute of natural gas.

Organic Waste	**Nm^3/tVS**	**$\%CH_4$**
Organic fraction of MSW*	650-750	52
Market waste	450-550	54
Fruit scraps	450-550	56
Fat	950-1.100	56
Whey	400-550	57
Slaughter waste	700-900	53
Sewage sludge	200-300	70

* Separately collected from garden waste

Annex I - Tab. 1: Examples of biogas potential production of the main substrates (various sources)

Biogas exploitation in combined heat and power plants:

In this case, a biogas pre-treatment is necessary in order to:

- De-watering (by means of condensation in pipes or in a chiller)
- H_2S removal (either biologically with sulphur oxidising micro-aerophilic bacteria, or chemically by flowing biogas through an oxidising means)

Pre-treated biogas is then fed into a combined heat and power engine that is able to recover:

- Electricity (efficiency 38-40% of biogas LHV)
- Heat (around 45% of biogas LHV)

Alternatively, biogas can be used for district heating; in this case, heat recovery from biogas burning can reach 78-86% efficiency.

Biogas upgrading

The process of upgrading entails enriching biogas into methane by removing CO_2 and trace elements, in order to obtain a final methane content between 96 and 99% purity, suitable to be used as biofuel for vehicles of grid injection. Apart from methane and carbon dioxide, biogas can also contain water, hydrogen sulphide, nitrogen, oxygen, ammonia, siloxanes and particles.

The main upgrading processes, all based on chemical and/or physical operations, and upgrading performances are:

	Pressure swing adsorption	**Water scrubbing**	**Organic physical scrubbing**	**Chemical scrubbing**
Methane content in upgraded gas	> 96%	> 97%	> 96%	> 99%

Annex I - Tab. 2: Expected methane content according to the upgrading technologies